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Abstract

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Keywords

consequential learning, productive disciplinary engagement, asset-based, engineering, engineering design, renewable energy

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Real Work with Real Consequences: Enlisting Community Energy Engineering as an Approach to Envisioning Engineering in Context

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Abstract

This study describes an illustrative case study from a year-round program that positions middle and high school youth to explore the social value of energy systems in their homes, schools, and neighborhoods. Designed to center existing youth assets, interests and values, Community Energy Engineering (CEE) frames engineering as a tool that students can enlist in order to understand and interrogate their local socio-energy system while also acting to transform it. CEE partners with Title 1 schools in Latino/a neighborhoods in the U.S. southwest. CEE situates youth community-based solar energy innovation projects as consequential, evolving in and with historically contingent engineering practices, and shaping and shaped by interactions across multiple contexts. We present our analysis of an asset-based approach to pre-college energy engineering education by following an exemplary project team across 15 months of programming. We used critical design ethnography to address the research question: How do community-centered energy engineering projects organize opportunities for productive disciplinary engagement and consequential learning? Findings are presented through the endogenous, first-person accounts of five youth as they participated in their project, and as they reflected on their participation during interviews. We consider connections to a wider array of cases reported using a sociocultural theoretical perspective on asset-based approaches to pre-college engineering education. We discuss these connections in relation to reciprocity as an asset-based approach to ingenuity and care, as well as two overarching design principles that emerged: (a) real work with real consequences and (b) everyone a learner, everyone a contributor.

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Introduction

Engineering can illuminate how energy systems entangle social and technological aspects of local settings. However, these entanglements remain invisible to many communities, thereby limiting their options for agentive action and maintaining inequitable and unjust energy burdens (Drehobl & Ross, 2016; Hernández & Siegel, 2019). Increasing youth awareness of the potential for engineers to shape social and technological opportunities and burdens in our energy systems positions engineering not only as a repertoire of disciplinary practices but also as a mechanism for community transformation. Through real engineering work with the potential to achieve real consequences in local energy systems, youth can also contribute to the ongoing evolution of local energyscapes. Our choice of the phrase "real work with real consequences" goes beyond introducing youth to engineering examples rooted in everyday life (Lammi et al., 2018;

Strobel et al., 2013). Further, real work challenges youth to productively engage with engineering in relation to consequential learning about local energy systems. We report on programming in which youth are defining problems in their own communities, generating engineering solutions, and working with community members to initiate and implement engineering projects.

This research presents a case study situated in an after-school education program that frames engineering not only as a technical profession but also as one entangled with the wider social backdrop against which technical insights emerge and evolve (Conlon, 2008; Miller et al., 2013; Mitchell, 2011). In this view, engineering and, by extension, engineering education can and must work to improve human and environmental conditions by addressing issues of sustainability, health, vulnerability, and joy, among others (National Academy of Engineering, 2020). The idea of community-centered solar energy engineering featured in this education program reflects this socio-technical orientation towards the grand challenges of engineering.

But why focus community-centered engineering education on energy systems? Foremost, energy systems are literally and figuratively wired into the everyday life of most communities. They are hidden in plain sight but readily accessible. And yet, despite being ubiquitous, they remain largely invisible to youth. At the same time, energy systems as a whole are dynamic and evolving yet seemingly unchangeable in local communities. Focusing on energy systems can therefore position youth to understand these systems and, through engineering, directly shape an energy system they will inherit as adults. Focusing on the energy sector is also timely because it is a socio-technical system in transition, driven by the need for a cleaner, more equitable, and sustainable socio-ecological future (Biswas, 2020). Citizens obviously care about whether or not the power is on, and other direct services; many also advocate for carbon-neutral fuels. However, it remains difficult for local communities to monitor and understand energy innovations or to evaluate their social, environmental, or economic risks, let alone contribute to energy decisions and policy (Miller et al., 2013). This is particularly true for minoritized racial and ethnic groups who are disproportionately affected by energy poverty and insecurity (Hernández & Siegel, 2019). Renewable energy sources like solar and wind now outpace coal and other carbon-based sources in electricity generating capacity (Feaster, 2020; Taylor, 2021; U.S. Energy Information Administration, 2021). This tipping point punctuates a social and educational imperative for the sustainable development of all local communities and ultimately a global one.

Community-centered science, technology, engineering, and mathematics (STEM) education is an imperative because school-based opportunities for learning often remain unresponsive to the interests and values of youth, particularly among members of disenfranchised communities underrepresented in college and career STEM pipelines (Calabrese Barton & Tan, 2018; Wilson-Lopez et al., 2016). In turn, infusing STEM disciplines with diverse perspectives and experience obviously is a process that begins by broadening participation before college. By involving youth with their local energy system, a community-centered approach to engineering education positions each learner to explore and advance sustainable and energy-just alternatives that can benefit their families and communities. Ongoing efforts to engineer socio-technical systems for a global socio-ecological future run the risk of achieving carbon neutrality at the expense of disenfranchised communities. These engineering agendas cannot ignore challenges that maintain enduring inequities; they also cannot ignore youth, who are not invited to contribute, let alone lead, but who arguably have the most at stake.

Research Purpose

This study aims to describe and understand an asset-based youth learning program, Community Energy Engineering (CEE). CEE seeks to consequentially engage youth simultaneously as learners and as contributors. By designing community-centered task structures, CEE enables learners to develop innovations for energy systems in, for, and with their own communities. To analyze youth participation, we draw on the *productive disciplinary engagement* framework to understand whether and how youth engage with disciplinary problems, use disciplinary practices to address these problems, and ultimately use these practices productively over time (e.g., Engle & Conant, 2002). Further, because asset-based approaches to engineering education emphasize epistemic diversity, our analysis equally considers the enactment of our design in relation to extra-disciplinary ideas and practices (cf. Agarwal & Sengupta-Irving, 2019). Thus, we utilize the construct of *consequential learning* to examine meaningful changes in youth's participation, including how they connected community knowledge, practices, and commitments to disciplinary knowledge, and youth's impact and position in the multiple communities involved with their engineering work (Birmingham et al., 2017; Hall & Jurow, 2015). Specifically, we conducted a critical design ethnography focused on a group of youth across 15 months as they participated in CEE. Employing energy engineering as a disciplinary lens for pursuing a more just and equitable socio-ecological future, this study explores the following question:

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> How do community-centered solar energy engineering projects organize opportunities for productive disciplinary engagement and consequential learning?

We further explain our use of the *productive disciplinary engagement* and *consequential learning* frameworks in the sections below.

Theoretical Perspective

Our work is grounded in sociocultural theories of learning and teaching that assume a productive tension between learning and use, between content and context, and between knowing what and knowing how (e.g., Greeno et al., 1996; Vygotsky, 1978). Through the lens of situated cognition, these interdependencies underscore that what counts as knowledge cannot be separated from the activities and situations through which knowledge is produced (Brown et al., 1989). Said differently, there are not universal representations of engineering knowledge that all learners acquire but rather contingent ones, each relating to and reflecting the unique activities and situations through which the representation emerged.

Consistent with asset-based approaches to teaching and learning (López, 2017), we enlist socio-cultural theory to better understand and judiciously explain how the wealth of assets (e.g., knowledge, practices, interests, and identities) generated through experience provides a powerful foundation for pre-college engineering education. This experiential foundation, however, expands the enumerated assumptions above to include interdependence between what is in the head and what the head is in (Cole & Wertsch, 1996). For example, through the lens of social practice theory (Holland & Lave, 2009), an adequate epistemology (Brown et al., 1989) also entails a social ontology (e.g., Packer & Goicoechea, 2000). Social practice theory considers social life in terms of all that is simultaneously situated in the present moment. Moreover, it considers social life in terms of what is sequentially, or historically, woven into the present moment. This interdependency between cognition and culture, and between simultaneity and sequentiality, therefore implicates both psychology and anthropology in the development of an adequate epistemology and ontology. Advancing asset-based approaches to engineering education in pre-college programs therefore entails

> regarding the community as the shop in which thoughts are constructed and deconstructed, history the terrain they seize and surrender, and to attend therefore to such muscular matters as the representation of authority, the marking of boundaries, the rhetoric of persuasion, the expression of commitment, and the registering of dissent. (Geertz, 1983, p. 153)

In this view, engineering disciplines are not stores of normalized or ready-made knowledge catalogued in textbooks and awaiting rediscovery. Instead, engineering processes, like scientific methods, are a complex of social and technical practices inextricably bound up in learning and use; content and context; as well as knowing what and how. In this way, STEM content cannot be divorced from the practices and processes through which it emerges (Medin & Bang, 2014).

These interdependencies extend engineering education and aspects of every learner's unique lived experience into one another. This mutual expansion integrates youth's prior experiences to advance a local and conditional approach to learning where each student is not merely a *welcomed guest* in engineering activities but a recognized and legitimized consequential contributor (Calabrese Barton & Tan, 2020). Further, prior experiences can be more than an individual resource because they are shared experiences and, as such, a community resource. Moreover, individual experiences remain bound up in social relations and the dynamics of power and ideology (Agarwal & Sengupta-Irving, 2019). Sociocultural theory can therefore contribute a serious appraisal of what counts as knowledge in pre-college engineering by examining ways in which community-oriented engineering programming and projects foster knowledge-in-use and how it is learned. Within the context of the current study, we sought to design CEE pedagogies and tasks that (a) recognize and recruit personal and cultural assets youth bring from their home communities; (b) infrastructure a program that fosters relational assets youth can draw on to support ingenuity as they interact with diverse collaborators to make progress on real work; and (c) invite consequential participation in engineering that creates value for youth's communities.

Productive Disciplinary Engagement

To understand engineering learning, productive disciplinary engagement (PDE; Engle, 2012) characterizes how youth throw themselves into disciplinary problems (i.e., engagement), appropriate engineering disciplinary ideas and practices to understand these problems (i.e., disciplinary engagement), and ultimately make progress using disciplinary practices to solve disciplinary problems (i.e., productive disciplinary engagement). Synthesizing across studies primarily focused on argumentation in science and mathematics contexts, Engle (2012) defined PDE in terms of making "intellectual progress" on a problem by using the content, discourses, and practices of a discipline. In engineering contexts, scholars investigating

PDE emphasize the interplay between progress in producing a product to meet a need and constructing new understandings in service to that production (Koretsky et al., 2015, 2019). Further, we argue that if the responsibilities of engineers are to create products and insights alike, then the roles that engineers assume are both learner and contributor. In community-centered engineering, these roles are not only intertwined in relation to engineering but also to mentors and peers in the program, and to members of youth's home communities.

To support PDE, Engle and Conant (2002) propose four complementary design principles. PDE is likely to be stronger if learners actively problematize a discipline, use the discipline to author ideas, use it to hold others' ideas accountable to the discipline, and finally utilize disciplinary resources in relation to the preceding three principles. CEE programming and projects that are the contextual grounding for the case study we present sought to problematize the discipline of engineering by encouraging youth to take up risks and uncertainties engendered by genuine engineering problems and processes. These include uncertainties about what to do, what to conclude, and how to justify what they were doing or concluding (Engle, 2012).

Importantly, analysis of community-centered programming can illuminate PDE in two complementary ways. First, research employing PDE predominantly focuses on science and mathematics; few PDE studies enlist engineering as a disciplinary context (but see Dasgupta, 2019; Koretsky et al., 2015, 2019). Second, studies employing PDE typically consider students in general rather than examining how the principles are differentially embodied in particular groups (Nasir et al., 2008), thus integrating issues of identity, culture, and power into analysis of disciplinary learning (e.g., Agarwal & Sengupta-Irving, 2019).

Consequential Learning

In our design enactment of CEE, our intention was to attend to, build on, and build up youth assets. Assuming that energy engineering is irreducibly social and technological, and that its value is defined by the services it provides to communities, we draw on community energy systems as a focus for organizing a pedagogy of community ethnography (Calabrese Barton & Tan, 2018, 2019) in engineering education. In turn, youth are able to enlist engineering as a tool for taking action in their communities based on the insights of their own ethnographic inquiry. In this way, youth simultaneously explore and identify with various community assets in order to do real engineering work on energy systems in their own community.

Accordingly, we characterize *consequential learning* in communities as learning that is valued by the community, related to students' participation in their community, and developed through interactions with people and resources over time (Hall & Jurow, 2015). Consequential learning assumes that youth are not isolated individuals but rather social participants embedded in and connected to a wider world. It is in relation to this wider world that conceptions of engineering must be interrogated and, as necessary, reimagined. Consequential learning assumes youth do not need remediation but rather that systems of teaching and learning must be transformed to include a wider range of tools and assistance (Gutiérrez & Jurow, 2016).

Consequential learning is centered in issues of power (Jurow & Shay, 2015), the ways in which students are granted rightful presence, or legitimate membership, in STEM (Calabrese Barton & Tan, 2019). *Rightful presence* goes beyond an expanded view of who has a right to be a participant in a community or requiring that newcomers adopt the practices of a community within the existing power structures. Rather, when youth are granted rightful presence within an energy engineering community, they are "recognized as competent and valued participants" in social change making (Calabrese Barton & Tan, 2019, p. 41). In relation to our study, the CEE program designed for rightful presence by disrupting relational dynamics of power that commonly exist among youth and adults in both neighborhood and professional communities by redesigning relations and routines to foster youth ingenuity (Greenberg et al., 2020).

Literature Review

In relation to our theoretical perspective, this study builds on scholarship examining how pre-college engineering education programs and projects overlap systematically with youth knowledge, priorities, and commitments. This focus is expressed in the aims of current STEM education policy. For example, United States science education standards aim to

> provide all students with the background to systematically investigate issues related to their personal and community priorities…frame scientific questions pertinent to their interests, conduct investigations and seek out relevant scientific arguments and data, review, and apply those arguments to the situation at hand, and communicate their scientific understanding. (National Research Council, 2012, p. 278)

This aim is both an emerging opportunity and an ongoing challenge because educators and researchers alike must shift from an isolated focus on disciplines to an integrative focus on local activities in relation to disciplinary activities, and vice

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versa (Lee & Roth, 2003; McDermott & Webber, 1998). In this study, we examine how youth navigate local and disciplinary activities in order to forge integrative community-centered agendas. This section establishes the intellectual merit of focusing an asset-based approach to engineering education through community-centered solar energy programming and projects, and then characterizes prior research in this area.

Focusing on Solar Energy Engineering Education

Engineering design in K-12 education involves navigating uncertainty (Jordan & McDaniel, 2014) and surfaces tensions between competing project goals and stakeholder values (Tatar, 2007). These inescapable tensions reflect the theoretical interdependencies above and resolve a tension central to this study. Solar energy intersects with STEM education in many ways, but can asset-based approaches to engineering education programs and projects foster connections to the priorities of individual students or their local communities?

While energy is obviously a longstanding aspect of STEM education (e.g., U.S. Department of Energy, 2017), solar energy engineering remains an emerging and uncommon pre-college programmatic focus (Mälkki & Paatero, 2015; Sen, 2011; e.g., Antink-Meyer & Aldeman, 2020; Ayala & Jordan, 2018). Similarly, although individuals and communities increasingly engage with commercial products that feature solar technologies, solar energy engineering and innovation are rarely visible, accessible, or personally relevant. Geography and space prove limiting. For example, few communities reside near solar generation stations and fewer still near photovoltaic manufacturing facilities, which might make aesthetics and pollution key local priorities, respectively; at the same time, the reach of solar energy continues to extend further across the energy sector (Plumer, 2020), suggesting greater influence and relevance.

The increased adoption of solar energy also signals greater demand for solar energy engineers and innovators as key to the future of the energy sector. Industry organizations have called for energy engineering workforce development (Reder et al., 2010) and researchers echo this need (Kandpal & Broman, 2014). However, calls that do not address the underrepresentation of communities of color and other groups minoritized in STEM fields run the risk of also underrepresenting these communities in decision-making processes (Sakellariou, 2013). Despite complex entanglements between energy systems and the social and technological aspects of local communities, the overlap often remains invisible and unactionable. Making these complex relationships visible can be challenging but increasingly urgent as technical demands are now being met by social demands for renewable energy (Craig & Petrun Sayers, 2019)—including demands from youth (e.g., Lawson, 2011). These are coupled with calls for transformational notions of engineering practice that urge creation of socially just and ecologically sensitive solutions in response to climate change (Karwat et al., 2015). An asset-based approach to energy engineering education is one possible way to begin to address such issues (Svhila et al., 2016).

Asset-Based Approaches to Energy Engineering Education

Asset-based approaches to education focus on students' cultural differences as strengths (Gay, 2010; López, 2017). In STEM learning contexts, such approaches help youth leverage their everyday experiences as a resource to address issues they identify as important to themselves or their communities, and connect those resources to STEM disciplinary knowledge and practices (Penuel et al., 2016). Yet, youth's existing knowledge, practices, and identities are seldom recognized or utilized as strengths well suited to inform engineering design work (Wilson-Lopez et al., 2018). *Asset pedagogies* that "actively value, solicit, and incorporate students' cultural practices" (Wilson-Lopez et al., 2016, p. 280) can help students develop disciplinary knowledge and skills while avoiding defining these—and the field itself—in ways that alienate youth from groups historically marginalized in engineering (Rodriguez, 2015). Community engineering projects that connect youth's cultural knowledge, experiences, and values with legitimized engineering knowledge and practice can help grow additional assets (Wilson-Lopez et al., 2018). For instance, many Latino/a communities, including the one featured in this study, value familism and collectivism, often prioritizing family and community outcomes over individual ones (Berkel et al., 2010). As ways to know and be, these assets resonate with "helping" aspects of engineering and connections between engineering and community. They also align well with the National Academy of Engineering's (2008) recommendation that K-12 educators emphasize engineering's "real-world applications" and its "positive effect on people's everyday lives" (p. 5) over traditional definitions of engineering as applied mathematics and science. Focusing on technical aspects of engineering without the accompanying social components can dissuade those from minoritized populations from pursuing careers in engineering (Rodriguez, 2015).

A longstanding line of asset-based inquiry in green energy engineering is the work of Calabrese Barton and colleagues. Their ongoing work develops and examines after-school green energy STEM programming with middle school students (Calabrese Barton & Tan, 2018). The program is guided by interrelated design principles, including: ensuring community relevance, valuing youth expertise, distributed expertise and decision making involving local experts, and empowering youth to take action (Calabrese Barton et al., 2013).

Consistent with asset-based approaches, research into this green energy programming has also "built upon [youth] social worlds" (Calabrese Barton & Tan, 2010, p. 226). A foundation in the social worlds of participating youth illuminates how youth exercise agency in their own local communities with STEM. An analysis of youth investigations into the urban heat island effect from earlier in this line of inquiry illustrates ways in which youth identify as community science experts over time. Rather than modeling the effect, youth insisted on authoring their own local investigations, centering their concerns for how urban heat islands impact people in their neighborhood using talk that was accessible and relevant for community members. Moreover, by enacting science expertise in this way, youth interactions depart from exclusive or formal scientific stance-taking and, instead, realize locally meaningful re-creations of otherwise formal or even isolated STEM practices. By locating phenomena like urban heat islands in their communities and putting related STEM ideas to work in their neighborhoods, "youth show the complexity inherent in enacting critical science agency and the disservice that is done to them by restricting the range of their expression of and engagement with ideas" (p. 226).

In another example from this line of inquiry, the complexity of exercising agency beyond yet about science and engineering is further illuminated through the first-person accounts of participants (Birmingham et al., 2017). Four female youth from non-dominant communities characterize science in connection to their own commitments and communities. Together, their cases underscore that empowering youth to take action entails accounting not only for disciplinary demands but also for social, political, and institutional ones. Importantly, these multilayered demands also entangle communities in issues of power and privilege, underscoring the importance of not only involvement but rightful presence (Calabrese Barton & Tan, 2020). Relationality surfaces in retrospective analysis of this line of inquiry; asset-based approaches to engineering education remain inextricably bound not only to the mix of people, resources, and ideas but to the movement and remixing of them across time and space (Calabrese Barton & Tan, 2018; Calabrese Barton et al., 2020; Greenberg et al., 2020). By doing so, they assert youth's right to instrumentalize STEM tools and enlist ingenuity for community-centered purposes.

In relation to these efforts, our own work has explored how various aspects of solar energy engineering have afforded or constrained participating youth's learning and engagement in and through community-centered projects. Foremost, Wakefield and colleagues (2018) describe how a guiding intuition at the outset of our work quickly evolved into a formal programmatic principle. By positioning youth participants as both learners and contributors during events involving a diverse cadre of participants (e.g., youth, teachers, university students, faculty), we found that youth viewed themselves as authentic members of an engineering community and engaged in consequential work to achieve meaningful goals within their home community. These findings illuminate a need to infrastructure long-term relational agency that encourages and promotes youth ingenuity in pursuit of solutions to personally meaningful projects. Subsequently, Jordan and colleagues (2019) found that a focus on building participants' socio-technical engineering knowledge positively influenced students' work on community solar energy engineering projects. This focus facilitated students' more sophisticated understanding of the importance of social value to solar energy engineering generally and their project specifically. Participants were better able to articulate social value such projects could bring to their families and neighbors and to design their project around community needs and desires. In relation to these preliminary studies, the current study examines program-wide participation over 15 months and across wide-ranging sites involving varied local and government stakeholders.

The emerging scholarship related specifically to asset-based engineering education shows that engaging youth in consequential youth-led community-based design has promise as a way to increase their participation in STEM and promote equitable societal outcomes (Calabrese Barton & Tan, 2019; Wilson-Lopez et al., 2018). However, research to date has rarely moved to make youth innovation consequential beyond the classroom community, or designed with the intention that youth pursue implementation of their innovations beyond the design pitch. Penuel (2016) argues that science and engineering education should help people put these disciplines to work in communities; using them as a tool to do real work with real consequences in our everyday lives. Engineering more than science is well positioned to realize this aim precisely because of its socio-technical nature. Interestingly, this is underspecified in epistemic practices (Kelly & Cunningham, 2019) as well as standards like the Next Generation Science Standards (NGSS). A study of community-centered engineering can make progress on these ill-defined but much needed intersections. Finally, little research focuses on an asset-based approach to energy engineering, and specifically to solar energy engineering. The time is ripe for such scholarly work because of the growing demand for equitable access to renewable energy sources and the increasing interest of youth in sustainable solutions to pressing social and technical issues.

Method

As an example of critical design ethnography (Barab et al., 2004), CEE researchers, educators, and often youth participants collaboratively worked to co-design a solar energy engineering education program with two goals: (a) developing critical socio-technical understanding of community energy needs and (b) enlisting solar energy engineering to take action in light of these needs. Critical design ethnography starts with the assertion that education, educational research, and designed curricula and tools are necessarily entangled with issues of power and transformation. Thus, researchers committed to this perspective take up issues that go beyond academic content, overtly advocating for a social consequence to applied research, acknowledging the ways they hope their designs will disrupt existing inequities and offer empowering alternatives and possibilities. Critical design ethnography also forwards in-depth methodological processes that explicitly incorporate critique and advocacy into designed innovations and ethnographic observation of learners engaged with a design implementation.

By turning a critical design ethnography lens on this case study, we acknowledge our conjecture that asset-based and consequential approaches to engineering education are needed to broaden participation in engineering and to advocate for students and communities historically minoritized in engineering (National Center for Science and Engineering Statistics, 2017) and unjustly burdened by existing energy systems (Drehobl & Ross, 2016). Our intention is to create new possibilities for pursuing a more just and equitable socio-ecological future, using energy engineering as a disciplinary lens for engaging youth in developing innovations with and for their community. Thus, we generated rich contextual data to understand how CEE projects organize opportunities for productive disciplinary engagement and consequential learning.

Our roles as both ethnographers and designers attended to the emic perspectives of youth participants (Erickson, 1984) while purposefully evolving an etic perspective on design features that facilitate approaches to learning that might extend to other sites and new, future contexts. In co-developing an etic perspective, three authors established themselves as CEE program insiders. All three contributed to co-designing the program. Respectively, they worked as a school based youth facilitator, as a university-based program director, and as a program assistant. One author self-identified as a community insider: she had been a teacher within youths' school district for 16 years, and regularly utilized public transportation and frequented stores in their neighborhood. Moreover, her sociocultural background through ethnicity, upbringing, and socioeconomic history positioned her as a cultural insider. The other two CEE program insiders identified as *community outsiders* in that they were not members of the neighborhood in which the youth lived and for whom the youth were contributing their engineering efforts. Moreover, they were not of the race/ethnicity or socioeconomic class of the youth or of the predominant community members being served by the youth's real work. Finally, one author participated in some program activities and as a project consultant, but remained both a CEE and community outsider.

Program Overview

The CEE program organizes year-round programming in partnership with a university engineering research center and two public schools serving the same Latino/a-majority neighborhood. Programming involves an interplay between university- and community-based activities. Each annual cycle begins with university-based summer programming that involves youth in multi-day workshops and follow-up events at a solar energy engineering research laboratory. Many of the activities also involve additional participants, including K-12 teachers, and university faculty and students. During the academic year, community-based programming revolves around weekly after-school activities and monthly weekend events. Together, they provide opportunities to explore interests, individual and community assets, and solar energy systems and, in turn, to translate these opportunities into youth-led projects pursued within their community. Table 1 summarizes annual programming at each site across the program's three years of operation to date and provides a general description of activities and examples of enactment by youth in the focal case, five of whom participated across all three years.

CEE projects challenge small groups to develop and champion community-centered engineering innovations as the central task in the CEE program. Each project specifically focuses on socio-technical solutions to local solar energy needs. Thus, the focus of participants' real work in the program remains situated in the lifeworlds of the participants. Importantly, CEE youth were purposefully recruited from the same neighborhood. This targeting of a youth cohort cohesive in physical/cultural space sought to foster relational agency that would support belonging, engagement, interest, and identity. It enabled the youth to come together around common experiences and shared understandings that coalesced into collective commitments to their project work. Further, each CEE team scopes and frames their own engineering problem space rather than being handed a predetermined challenge. In this way, programming sets the stage to do work that is real to the students themselves, and responsive to learners' own interests (Engle, 2012). Examples of CEE projects include solar water filters to combat unsafe drinking water, a portfolio of STEAM activities and a community network to implement them in a local middle school, and, as presented in the case study below, a project that began as a community solar cooperative and iterated to become a school solar pavilion.

Participants

CEE recruited youth from STEM after-school programs at two middle schools in a same large, urban school district. The district predominantly serves students of color (94%; 75% Latino/a) and students from households categorized as low-income (92%). These demographics well reflect the larger neighborhood served by the district.

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Table 1
Description of yearly cycles of CEE programming.

Year	Site	Description of activities	Participants Total (case)
1	University	Six-day energy engineering experience (across three weeks + culminating event)	12
		Simulate solar cell fabrication with undergraduate leaders	(12)
		Create video "pitch" for community solar co-op design	
		Present project and video to scholars and industry at poster session	
	Community	Biweekly after-school and monthly weekend activities	8
		Create first 3D scaled model of their project	(5)
		Present community solar co-op to public at university event	
		Participate at international conference on eradicating poverty	
2	University	Five-week intensive program on socio-technical energy engineering research	17
		Attend and present at an energy engineering research conference	(5)
		Integrate new technical knowledge on utility grid into pitches	
		Mentor next-generation CEE youth in developing community projects	
	Community	Biweekly after-school and monthly weekend activities	12
		Interview a PV student from MIT about graduate school	(5)
		Volunteer at a community STEM Saturday event	
		Pitch solar pavilion project at a district board meeting	
3	University	Five-week full-day energy engineering research experiences	17
		Participate in fabricating solar cells in a clean room laboratory	(5)
		Collaborate with district leader to promote solar pavilion	
		Present research to scholars and industry at end-of-summer session	
	Community	Biweekly after-school and monthly weekend activities	13
		Collaborate with graduate student to develop 3D printed model	(5)
		Lead a study session for the district school board	
		Volunteer mentors at science museum STEM events	

Teachers at both schools recruited students based on (a) sustained participation in STEM after-school programs and demonstrated interest in STEM and (b) residence in the same neighborhood. Recruiting from a single neighborhood focuses projects on the same community and facilitates transportation to and from university-based programming. Across three years, 35 youth participated in the program with a majority identifying as Latino/a (80%) and others as Black (11%), White (6%), and Asian (3%). Table 1 includes the total number of participants across all three years, including summer university-based participation and the number of youths who continued on with community-based programming into the fall and spring. At each year of implementation, a subset of the previous summer's cohort continued with their team's project, and helped to design and implement mentorship of the incoming CEE group.

The case study analysis reported here focuses on the project activity that emerged from the first iteration of CEE summer programming and the youth who came to comprise the Solar Co-op Team. We selected this project team, first, because of its strong community engineering focus that went beyond school-based agendas. Additionally, a subset of the team demonstrated a long-lasting commitment to their community-centered project by persisting despite challenges and by iterating their design in relation to these challenges. Simultaneously, they mentored the next generations of CEE participants, and thus influenced multiple iterations of programming.

This initial group of youth included 12 participants in Summer 1 university-based programming, and are highlighted in the first set of case study episodes described in the findings. All of these youth attended Title 1 middle schools in our partner district and matriculated into neighborhood high schools.

Half the participants (6) identified as female. Five participants identified as Latino/a, two as White, and one as Black. Eight of the youth continued with the program into Year 1. We focus particularly on five youth who persisted into and beyond Summer 2 programming. All five focal youth were first-generation college-bound students; three had parents whose education terminated at a middle school level. All were first- or second-generation immigrants; three faced challenges associated with self and/or family members' undocumented status. All spoke a primary home language other than English (four Spanish; one Russian). All qualified for free or reduced lunch.

Although the focal youth all entered the CEE program with interests in STEM, they described different disciplinary and extra-disciplinary goals for their program participation. For example, Dora identified her goals thus, "I'm hoping to learn how hard college is and how much confidence it takes since I'm not the most confident person… My goal is to learn more about solar energy and how it works." Ashley's goals were science focused: "I would like to learn how particles work with solar energy." Ruben alone identified engineering as central to his goals.

Each participant hoped their program participation would shape their future, though they entered with various envisioned trajectories. Overall, across time, the youth scholars all moved toward STEM-central or STEM-informed careers; all were concerned with helping others. Although attracted to engineering because of "how it, like, affects the world and how you could help the community," Dora's career interests at the beginning of the CEE program were unfocused: "I'm not sure what kind of job I want to get yet… I thought about teaching but I'm not a very social person." After three years of taking a central role in CEE, she planned to pursue a career in sustainability. Although interested in engineering, Manny entered the program thinking, "I'll probably stick to modern day things like computers or something like that." By the program's end, Manny was planning to apply to universities to pursue sustainability and engineering programs. Asked what career she might pursue after high school, Ashley's initial response was, "Maybe work at a restaurant." Three years later, she was investigating pre-law programs as a path to "help my community" around issues of energy and environmental justice. Jason's and Ruben's career interests stayed the most stable. Jason first identified his goals as "bio, something related," and finally, "biomedical engineering"; Ruben initially identified, "maybe engineering" and fully committed to an engineering pathway by program's end.

Data Generation

Members of the research team engaged in three data generation processes across the 15 months of programming and projects considered here. We observed and audio-video recorded program activities (50+ hours of audio-video recordings), often writing individual or collective ethnographic field notes based on observational records. We collected student-generated design artifacts (seven design sketches, one 3D model, two conference posters, and five drafts of project video pitches), 294 multimodal online discussion posts between team members and facilitators, and individual youth's responses to pre-post surveys and daily reflection questions. Daily reflections were at first crafted *in situ* by facilitators during Summer 1 in response to emerging events and youth concerns (e.g., "How have today's experiences made you rethink your project? What could you do to move forward? Who do you need to talk to?"). In Summer 2, the youth began determining many of their own reflection prompts. We conducted pre-post semi-structured interviews (Bogdan & Biklen, 2007) with the 12 participants in Summer 1 and the 5 focal youth in Summer 2. Example questions include, "What do you want to learn this summer and what do you hope to contribute?", "What kept you coming back?"

In addition to gathering these traditional forms of ethnographic data, the research team engaged in informal conversations with youth in order to better organize programming and support team projects. During these discussions, youth offered ideas and suggestions for program organization and helped co-design mentoring activities for incoming youth and adult participants based on their own program experience and expertise. Research team members met frequently following CEE events and activities to debrief and to write individual and collective reflective memos. Data transformation occurred as we catalogued all CEE activity pertaining to our illustrative case, creating a timeline in a spreadsheet where we described each programming event, and linked associated recordings, transcripts, artifacts, surveys, and field notes. Video logs were created to help identify rich episodes for further examination.

Data Analysis

To guide analytic interpretation of data generated from our exemplary youth-led project team, we employ two complementary analytical frameworks—PDE (e.g., Engle, 2012) and consequential learning (e.g., Hall & Jurow, 2015). Together, these frameworks develop the descriptive depth of our core research question, serving to characterize group interaction in relation to how the community-based solar engineering project that was the centerpiece of the CEE programming emerged and evolved. Findings are presented through the endogenous, first-person accounts of the group members as they worked on their project and as they reflected on their program participation.

First, in preparation for analysis of enactment of PDE in our focal case, we culled definitions of engagement, disciplinary engagement, and productive disciplinary engagement and the four design principles of PDE: problematizing, authority, accountability, and relevant resources from the literature (Engle, 2012; Engle & Conant, 2002) and operationalized their enactment for our engineering context. Because PDE is defined in terms of learners' making use of and progress with disciplinary discourse, practices, and content, it was necessary to also define the discipline of engineering. We drew on recent K-12 engineering research that seeks to identify the disciplinary features of engineering, i.e., "the kinds of work with which engineers engage, how engineers utilize and produce knowledge, the relationships between engineering and science, and the social environment that underlies all of these issues" (Pleasants & Olson, 2019, p. 159), and to characterize epistemic practices and tools of engineering (Kelly & Cunningham, 2019). We also drew on our own work on supporting youths' deployment of socio-technical energy innovation knowledge (Jordan et al., 2019).

Having established joint intersubjectivity around our definitions of PDE concepts, three researchers traced the evidence of its enactment in our illustrative case as it unfolded across time. Focusing on the collective work of the Solar Co-op

Team and relying primarily on audio-video recordings and transcripts of interactional activity (Jordan & Henderson, 1995), we tracked youth's engagement (active involvement), disciplinary engagement (use of disciplinary ideas and practices), and productive disciplinary engagement (making substantive progress with ideas and/or the project) against how engineering was embodied and enacted in CEE programming across time. During this step of analysis, we also drew on youth-generated artifacts, and our own field notes and collective memory of events to create thick memos related to the youths' use of engineering epistemic practices related to technical, socio-technical, and communicative processes. Working at a higher level of abstraction and adapting analytic processes from Engle (2012), we then identified strong and weak forms of evidence that each PDE principle was available to youth across time. Two authors first independently rated their perceptions of each principle's enactment on a scale from 1 (weak) to 3 (strong) before meeting to negotiate ratings.

We next sought to investigate the consequentiality of learning by attending to what became consequential for youth, their changing practices and positions in relation to the communities in which they participated during CEE programming (Hall & Jurow, 2015). We operationalized consequentiality in terms of (a) learning valued by youth in the present moment, (b) learning they valued for their future, and (c) how they saw their work as consequential to others. Throughout analysis, we focused on interpreting the experience of the five focal participants. Thus, analytic activity began with examination and memoing of youth's first-person perspectives as shared in interviews, surveys, and reflections. We sought to identify and categorize what they valued from their CEE experience, the difficulties they encountered, and how they navigated those difficulties. We interrogated youth's conceptions of engineering, how those conceptions were connected to their home community, and how they were or were not resonant with programming goals. We worked to understand what purposes were being pursued by youth across time and what they deemed important in their program experience.

Because consequentiality deals with issues of power and privilege, we next sought to characterize ways students were granted rightful presence in CEE and engineering—and explored potential failures to grant rightful presence (Calabrese Barton & Tan, 2019). Returning to our timeline from data transformation, we mapped the networks of interaction across the 15 months of the study: With whom did youth interact? What was the nature and consequences of the interaction? We noted shifts in power and youth agency across time. We looked for evidence of whether, to what extent, and how youth's legitimate membership was recognized within the CEE community that included adults in their summer cadre, program guests, and community leaders with whom they interacted. We examined how program structures encouraged or inhibited facilitators, guests, and other participants to recognize CEE youth as competent and valued participants engaged in social change making (Calabrese Barton & Tan, 2019).

We considered the enactment of CEE programming in relation to extra-disciplinary ideas and practices in order to illuminate invisible identities and additional generative resources (Agarwal & Sengupta-Irving, 2019). Returning to audio-video recordings and transcripts of interaction, we examined the range of tools and assistance to which youth had access (Gutierrez & Jurow, 2016), making memos related to task activity, participation structures, and interactional patterns. We especially attended to how personal and cultural knowledge, practices, and commitments were used as assets in project work (Wilson-Lopez et al., 2018). We noted how these assets were connected to disciplinary concepts and practices, as well as how they were differentially recognized by program interactants, and developed through project activity.

During weekly meetings with the entire research team, we reviewed and tested our thus-far negotiated interpretations, collectively viewing rich episodes from recordings, and re-reading transcripts and memos, and comparing analytical sketches and models in order to interrogate tentative assertions and themes. One author played devil's advocate during these team debriefings by interrogating the analyses conducted by the other three authors. Two CEE participants provided member checks on our initial interpretations early in our analytic process.

Findings

Context of the Case

The *Solar Co-op Team* is a group of high school youth who framed a community-based problem for which solar energy innovations might contribute towards lasting solutions. Informed by community ethnography conducted in their local neighborhood and with energy engineering, the team explored intersections between community and engineering over 15 months. During this time span, the team envisioned, designed, and pitched their namesake solar energy innovation: a public solar energy co-op. The proposed co-op would generate energy through photovoltaic structures located in a public park in order to provide affordable, renewable power to local residents and businesses through a membership plan. Using their own words, the team's rationale for the proposal captures a central focus of the case study.

> We have noticed that in our community…people are spending money on electricity more than their basic needs, which has caused us to create this plan…[W]ith the energy that is created from the solar shade [in parks], we can then

> redistribute it out into the community, in a membership style…In the course of ten years, the Silver [membership] will save over a thousand dollars…which in our community would be an extraordinary amount of money that could have people living better and healthier lives…[People in our community] can't afford to renovate their roofs so with our project we provide an option to join our co-op.

Their rationale resolves the economic value of the team's energy innovation using a three-tiered "membership style" resembling a "co-op."

As our case will further resolve, the youth's rationale also reflects an asset-based approach to considering problems in context, which is an epistemic practice of engineering (Kelly & Cunningham, 2019). Specifically, the passage above frames the proposal as a means of creating and redistributing energy and suggests that redistributing energy is, in turn, a means to "better and healthier lives." We argue that the rationale, the innovation, and the case below therefore focus on an ethic of reciprocity as a means to collective success. This focus illuminates an extra-disciplinary way to know and be operating productively within the team that reflects wider interest among Latino/a youth to give back to their communities and, thereby, develop community-based STEM identities (Lozano et al., 2018). In the first three months of the case, this ethic is an asset because it serves as a source of ingenuity when the team envisions energy innovation to meet community challenges. Importantly, the youth's rationale focuses not only on the economic value of ideas underlying their proposal but also the use value of putting those ideas to work locally (Lave, 1988). That is, another rationale for the team's proposal is to serve and care for their community, one in which some members are "spending money on electricity more than their basic needs." This focus frames the energy innovation not only as a proposal to pitch but also a purpose to pursue, resolving the team's intention to both think and act.

One consequence of the team's sustained engagement and commitment to action in service to their home community was a formal presentation of the solar co-op proposal to a city planner at his city government office. The city planner carefully listened then raised constructive and critical concerns before ultimately rejecting the proposal based on state policy violations. This meeting and evaluation punctuated the final three months of the case. The team recruited the same ethic, to serve their CEE community, as an asset again as the team reconciled its failed proposal. This reconciliation resonated with another epistemic practice of engineering: persisting and learning from failure (Kelly & Cunningham, 2019). In this latter instance, the idea that reciprocity is a means to collective success becomes a source of care within the team and the program. Against this backdrop of asset-based approach to ingenuity and care, inspired by the youth, supported by and emerging in CEE community infrastructures, we present a case study of the evolution of the Solar Co-op Team's CEE project. The goal of this case is to illuminate productive disciplinary engagement and consequential learning in relation to the program.

Illuminating PDE in CEE Programming

The first consideration in our analysis is whether the CEE program organized opportunities for PDE. To this end, we traced team engagement over time, including the enlistment of disciplinary understandings and the development of new ideas in order to make a general claim about the relative strength of PDE. Engle's (2012) PDE evaluation framework served to characterize the embodiment of PDE principles in program design and enactment. Foremost, we claim that program activities strongly embodied PDE principles during university-based programming but only variably embodied them during community-based programming. Similarly, observations of youth enacting program activities variably demonstrated PDE principles. Table 2 specifically delineates the separate characterizations of each PDE principle across university- and community-based program activities.

In sum, over the 15-month time period considered in this study, we claim that youth consistently enacted each principle moderately or strongly during program activities at the university as well as at their schools and in their communities. While the case study interrogates the relationship between the embodiment and enactment of PDE, we elaborate on this general claim first by mapping how the Solar Co-op Team enacted PDE over time.

The Solar Co-op Team increasingly demonstrated PDE principles as they progressed through the engineering design process. Each box in Figure 1 represents high-level actions taken by the team to frame, prototype, and implement the co-op.

Table 2
Strength of PDE as enacted and observed in program activities.

PDE principle	Summer 1 university	Year 1 community	Summer 2 university
Problematizing	3	1.5	2.5
Authority	2.5	2	2.5
Accountability	2.5	2	2.5
Resources	2	1.5	2.5

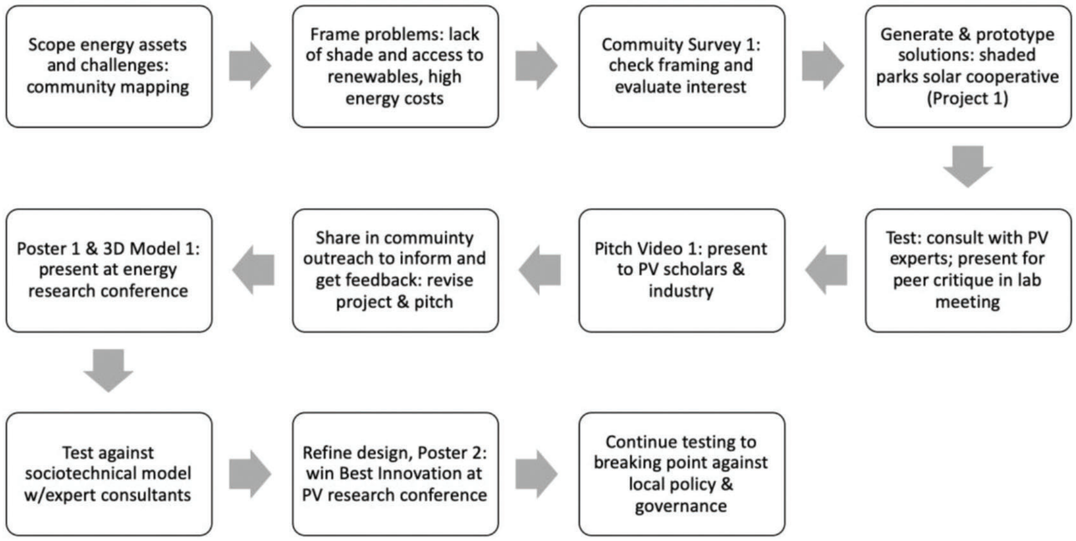

Figure 1. Timeline of Solar Co-op Team's project progress.

This timeline organized an interplay among social and technical aspects of energy systems. Most notably, a series of community ethnography activities (i.e., mapping and observing community sites as well as surveying community members) positioned the team to evaluate local energy assets, needs, and values. In turn, it enabled the youth to relate their local evaluations to the wider metropolitan energy system in order to frame a socio-technical problem and generate community solar engineering solutions. These actions reflect the epistemic practices of developing processes to solve problems and considering problems in context (Kelly & Cunningham, 2019). Next, the team envisioned, prototyped, and presented their solution at a public outreach event, and to experts in academia and industry at a disciplinary conference, reflecting the epistemic practices of envisioning multiple solutions and constructing models. Finally, they tested the solution through technical, socio-technical, as well as local policy and governance consultations, reflecting the epistemic practices of assessing implications of solutions and communicating effectively. Six episodes presented in the case below zoom-in on these high-level actions in order to resolve relationships between the embodiment and enactment of PDE in program activities and, ultimately, the relationship between disciplinary learning and consequential learning in community-centered engineering education.

Case Analysis

In this section, we consider how the CEE program organized opportunities for the Solar Co-op Team to envision and enact a community-centered solar energy engineering project. Building from the project rationale discussed above, we examine how an asset-based approach to engineering education unfolded, beginning with considering problems in context. More specifically, we examine how organizing CEE in terms of an interdependence between engineering problems and community problems can inform socio-technical solutions that leverage youth assets (and also depend on underlying technical, communicative, and iterative processes). To these ends, the case draws on two separate series of episodes from program activities during university-based programming in Summers 1 and 2.

Emerging PDE in Year 1 Program Activities

CEE programming emphasized community knowledge, commitment to community improvement, and energy engineering for sustainability as assets for disciplinary engagement. On the first day of university-based programming, youth engaged in community ethnography related to energy systems in order to support youth in defining their own engineering problem space, grounded in community needs, assets, and values. Community ethnography was intentionally designed into initial CEE activities to legitimize youth's community concerns. Participants gathered around large, color aerial photos (exemplifying the resources principle) that included their neighborhood in order to explore its features and to characterize physical assets and community concerns. Comparing where they lived with surrounding communities, they noticed fewer solar panels in their own neighborhood. While leaning over the photos during this session, Monica problematizes differences in solar panel prevalence in socio-economic terms.

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It's because we don't live in [a nearby city]. We live in, like, a more lower-class neighborhood. We're not all rich and stuff. So obviously not everyone is gonna…be able to…pay for [solar energy based] electricity because of the private ownership [of solar panels]. I don't think many people will be able to get it, like over in [a nearby city]. If we were in [that] region then maybe it would work.

This excerpt illustrates the problematizing principle. Monica hypothesizes that "private ownership" of solar panels relates to being "all rich and stuff." In contrast, renters like many of the residents in the team's neighborhood cannot afford solar panels or the land on which to install them, which preclude the private solar energy solutions prevalent in the nearby city. Monica's problematizing contributes to deeper engagement and resolves purpose around solar energy solutions for the needs of their community, which directly shapes the team's rationale for a solar co-op as their work continues.

As the team wrestles with how to increase solar energy use in their neighborhood, program activities position them with authority as community experts with social, cultural, and geographical knowledge. Emphasizing the community-centered nature of CEE projects, activities underscore that the team is both expected and entitled to frame problems that interest them and that reflect cultural and community needs and values. Having identified an energy inequity—the lack of solar in their neighborhood relative to a nearby wealthier neighborhood—the team interrogated potential reasons for this unequal distribution of a clean, low-cost energy source, as well as outcomes for community members. Drawing on their knowledge of community housing conditions, ratios of rentals to home ownership, and navigation of household energy costs, the group rejected private-roof-solar-solutions as an individual-based practice that would leave part of their community behind (i.e., renters and homeowners with weak rooftops). Prioritizing communal goals over individual goals, they generated community-owned solutions in order to benefit the whole community (e.g., traffic lights, street lights). Evaluating their ideas against community needs, they began to weigh community-services-solar-solutions benefits against the private benefit of saving people money (e.g., taxes, energy costs). In this vein, the transcript below illustrates the authoring principle of PDE during a preliminary solutions brainstorming activity on the afternoon of the first day of university-based programming.

Ramone: [We could save community members money] by having them not [put solar panels] on their own house.
Facilitator: What if we were to prove that if we were to do your idea with [solar] on the traffic lights and street lights, what if that lowered taxes? Would they care about that?
Lydia: Yeah. That's a big portion of their paycheck.
Monica: Or, we could get them to pitch in, to a community [solar station]. You know, like Lucia said, like in a park next to the whole neighborhood. It could be like they pay less to power their house. They have to pay something but it's not free.
Brenda: Like Costco.

In this excerpt, two team members enlist knowledge of and commitment to their home community in order to author an energy solution that approximates the project proposal presented as context for the case above. Through their turns at talk, the group engages in the epistemic practice of envisioning multiple solutions (Kelly & Cunningham, 2019), including "traffic light," "house," and "park" proposals. Importantly, authoring is not only an individual achievement but a collaborative one too. Ramone builds on Monica's problematizing contribution in the episode above from earlier in the day in order to affirm that private ownership is not a viable solution for saving community members money, given housing challenges many residents face. Similarly, Monica acknowledges and recruits a park idea "like Lucia said" to pivot from the "traffic light" solution; then Brenda relates the "park" idea to a successful and familiar business model. In this manner, the first iteration of the solar cooperative emerged as the team deeply engaged with a complex solar energy engineering challenge.

This trajectory continued on the second day of programming when the team engaged a second community ethnography activity. This activity framed the local physical neighborhood landscape as a critical resource (i.e., the resource principle) much like the aerial photos in day 1; moreover, it challenged the team to inhabit engineering roles and responsibilities in their everyday surroundings. Specifically, the team toured their neighborhood together in order to consider the role solar energy innovations might play for local residents and businesses. Through this activity, the team was expected and entitled to couple community and engineering knowledge as they literally re-searched familiar settings in a novel way. Reflecting an asset-based approach to engineering, the team viewed their everyday worlds through a solar energy engineering lens. A key insight related to the solar co-op proposal emerged as they toured local parks. Instead of seeing only what was present, namely the intense heat and sunlight that permeates a desert summer, they noticed also what was absent: shade. In turn, they identified the shade that panels provide as a secondary public benefit of a solar co-op located in a neighborhood park. The community values gathering families for birthdays, teams for sporting events, and children to play, but extreme heat precludes these activities for many months every year. With the added source of shade from solar panels, community members could spend more quality time in neighborhood parks, in addition to accessing low-cost clean energy as solar co-op members. This engagement illustrates how the team further resolved a communal community purpose; at the same time it further resolved an engineering proposal, assuming engineering roles and responsibilities to create public and community value and a solar energy project.

All five focal youth affirmed (a) commitment to community improvement and (b) prioritizing communal goals over individual goals many times across the summer, values that surfaced again and again across the project. For instance, in a retrospective interview much later in the program, Manny considers his own personal history and professional agendas in terms of this ongoing interplay between community and engineering in CEE project work.

> Before I joined the program, I mostly thought of myself like not getting involved into anything of science or engineering 'cause I thought that was way past me…Being in this program…helps me think of myself being an engineer when I'm older and also how, if our project works [in our community], then our world can be so much different…in a good way that can benefit people and help them a lot.

Through his experiences on the Solar Co-op Team and in the CEE program, Manny imagines himself in relation to both "being an engineer when I'm older" and a different world that "can benefit people and help them out." Against the backdrop of PDE, this reflection communicates more than PDE at work. Organizing community-centered projects entails engagement with a discipline but also a wider range of ways to know and be—what Agarwal and Sengupta-Irving (2019) label *connective and productive disciplinary engagement* (CPDE). CPDE provides a lens for understanding and leveraging histories-in-person (Holland & Lave, 2001). In this instance, Manny explicitly connects an imagined trajectory of disciplinary engagement through professional engineering to the prospective benefits of his group's current community-based project—to which he has contributed—and to the project's meaning in relation to global possibilities. In this way, the assets that he enlists through ways to know and be operating in his community shaped how he appropriated engineering practices and tools in relation to the project, informing and affirming one possible vision of his future.

These initial program activities demonstrate increasing engagement with and interplay between a solar energy engineering challenge and an emerging community-centered project. Importantly, community ethnography activities ground social interactions in the team's physical and cultural communities but they do not ground interactions in particular disciplinary practices that would constitute disciplinary engagement. As an asset-based approach, situating the challenge in the community enabled the team to begin from their own community-based experiences and cultural understandings. It also creates an occasion for and a need to learn about disciplinary practices that will advance their nascent solar co-op model.

To organize disciplinary engagement, program facilitators arranged opportunities for the team to consult with different energy experts, including members of the university's engineering research center, throughout the remainder of university-based programming in Year 1. Because of the role he continues to play in Year 2, we highlight an engineering expert and university graduate student named Tom. Tom met the team on the third day of programming during Summer 1. He shared research on base materials used to make solar cells and the differences between types of solar panels (e.g., silicon, cadmium telluride, thin film), which aligns with the epistemic practice of investigating properties and uses of materials (Kelly & Cunningham, 2019). Expert consultations reflected the program's principle: everyone a learner, everyone a contributor. In framing the activity, the CEE team facilitator positioned all participants, including Tom, as learners and contributors by describing the consultation as "more of a give and take" or a reciprocal consultation; "his work is very similar to what you have proposed. So his hope is that you can give him some feedback and also that he can influence your [project]". Disciplinary engagement here is much like community engagement for the team because it is driven by reciprocity between the group and their consultant. This social dynamic marks the emergence of a social infrastructure of care (Greenberg et al., 2020) within the program that the team enlisted later the same day and, indeed, later in the year, which we discuss later.

In relation to what Tom shared, the youth refined the solar co-op model in anticipation of presentations to engineering and community experts, which is another important element of disciplinary engagement (Darling & Dannels, 2010) and an epistemic practice of engineering as well (Kelly & Cunningham, 2019). In the transcript below, the team demonstrates disciplinary engagement through an interplay of the authoring and accountability principles. The episode is driven by two questions: first, Josie poses a question to the program director who, second, replies with a question of her own.

Josie: Could we use thin solar panels instead, because they're less expensive?
Director: The thin films? What are some of the cons of doing that?
Dora: They're less efficient.
Josie: But we could buy more.
Jason: They might break because they are so thin.

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Monica: And they won't last as long because they aren't as…
Josie: Durable. Yeah. (nodding)
Monica: But we could use both of them, depending on where you put them.
Director: You might keep thinking about that; I have a website I can send you that compares the different types of solar cells.

In this quick chat with the program director, four team members contribute to authoring ideas with technical understanding developed through their consultation with Tom as well as considering the socio-technical and socio-ecological implications (e.g., cost of the panels) of this project for their community. In particular, they built on one another's ideas to identify tradeoffs as well as different solar cell materials and some of their properties in order to optimize their design of a community solar cooperative. In response, the program director legitimized their activity, offering to supply additional disciplinary resources.

In addition to fostering disciplinary engagement, the consultation with Tom also included discussion of his own entrepreneurial community solar project that resembled the team's solar co-op model. The same facilitator explained that Tom would provide feedback on the team's initial presentation but expected the team to reciprocally provide feedback on his project too. Thus, a give and take similar to that with the program director above occurred as Tom and the Solar Co-op Team co-generated and compared multiple ideas. The transcript below follows after Tom described his plan to locate solar panels on private residential sites and thereby create a solar farm. He suggested that the team consider doing the same, then inquired as to where else could panels be put for their cooperative, if not a public park.

Lydia: If we asked, like Walmart or some big company with big parking lots, we could use solar panels for shade for parking lots, parks for kids…community areas where it will impact people's opinions on solar panels and how it provides double usage.
Tom: Yeah, for sure. I'll play devil's advocate a little bit on that one. Like Walmart, they'd probably want to use the solar panels in the parking lot for themselves.
Lydia: But maybe we could use that to our advantage where like, they could fund us for the solar co-op and they could use the solar panels. They would get some of the income and we could work as partners almost?
Tom: So that could, yea, split the usage. Like, use some of the energy generated for the community solar subscription.

Lydia offers a counter-proposal to locate the co-op at a commercial site but Tom holds that idea accountable to the profit motives of private companies. Lydia then counters again, envisioning a co-op supported by "partners almost" akin to a public–private partnership. In this way, CEE fostered interactions that organized opportunities for consequential learning by positioning youth as legitimate colleagues to this older and more experienced mentor (Hall & Jurow, 2015). In this and similar interactions, Tom and the team draw on disciplinary knowledge and practices to jointly negotiate the meaning of engineering problems and possible solutions related to their shared interest in community solar innovation for people living in low-income neighborhoods.

This account of emerging PDE spanning the first three days of university-based programming in Summer 1 are illustrative of wider conversations about socio-technical issues in solar energy engineering that occurred over the final three days of the summer too. In an interview at the end of summer program, Dora discussed how the team's project was consequential to her, a person whose strong commitment to her family and her community would eventually impact her decision to apply only to the local university.

I feel like if we work hard enough we could actually make this project into the community…It's important because one of my goals in life is to make a difference [in my community] so if I can make that small difference at this time it would help me feel accomplished…I never thought we could influence the community in that way.

Deepening engagement and increasing disciplinary engagement inspired and enabled the team to continue their work during community-based programming during the nine-month academic calendar. In a retrospective interview, Jason expressed a sense of agency and influence underlying his experience in the team. He reflected, "age and zip code should not determine who gets to contribute to energy futures."

Deepening PDE in Year 2 Program Activities

Five members of the Solar Co-op Team advanced the project further during community-based programming in fall and spring of Year 1. They also participated in extended university-based programming in Year 2 for which they received a

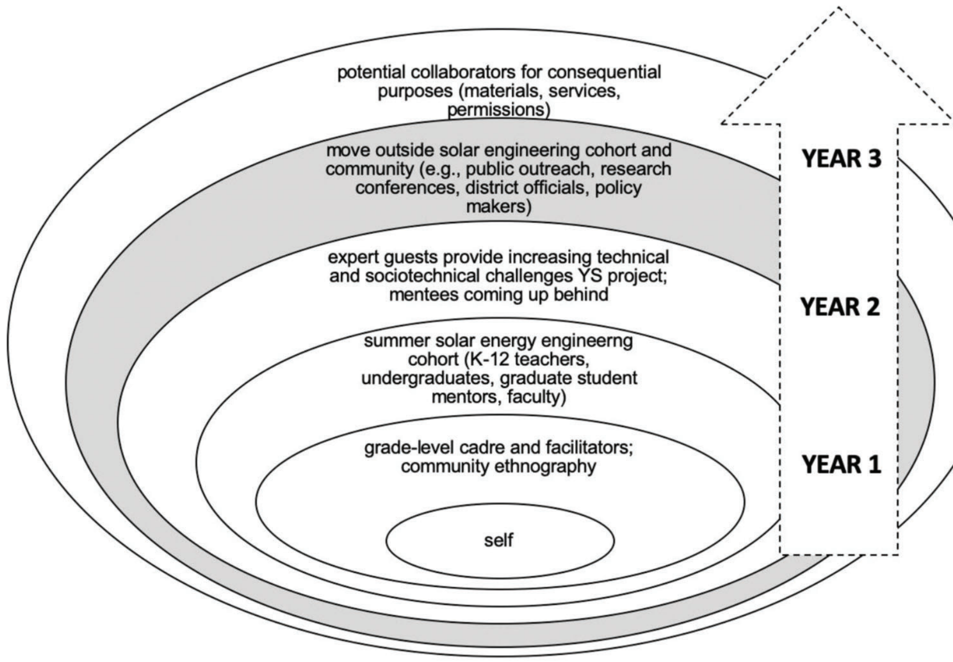

Figure 2. Increasing accountability: expanding networks of project collaborators. Figure adapted from Engle (2012).

modest stipend to recognize and support longer-term involvement. Year 2 programming accelerated a shift away from facilitated, scaffolded activities towards project work organized around disciplinary accountability.

This disciplinary shift situated the youth more centrally in the engineering research community and amplified the design principle, *everyone a learner, everyone a contributor*. Most relevant to their project, the group maintained a direct, summer-long collaboration with a faculty member whose research focused on implementation models for community energy innovation (e.g., Miller et al., 2013, 2018). While aspects of these community models informed the solar co-op design, engaging in ongoing collaboration with the faculty member illustrates increasing accountability to a disciplinary expert whose feedback ensured that the designed community-centered intervention actually aligns with the models.

In addition to a faculty collaborator, the team also met with other experts whose understanding of the model's layers provided additional insight. These consultations helped to refine the youth's community solar co-op design (see Jordan et al., 2019). Taken together, consultations represent a core feature of programming in Year 2 that embody the authoring and accountability principles with greater strength than in Year 1. They foster the progressive enactment of disciplinary engagement through an expanded network of supporters and collaborators, moving from more private and internal audiences to more public audiences (Engle, 2012). In turn, it expanded a social infrastructure of ingenuity coupling community and disciplinary ingenuity. Figure 2 maps this trajectory across the program.

Figure 2 maps an inside-out trajectory (Engle, 2012) whereby individuals first hold themselves accountable before inviting or expecting insiders like peers and teachers to hold one another accountable then increasingly outsiders like conference audiences, public officials, and external collaborators. Importantly, as this social infrastructure expands to support ingenuity, so too does risk and vulnerability and, thereby, the value of a commensurate social infrastructure of care, which is key to the next episode.

In order to demonstrate deeper disciplinary engagement, we concentrate on a Year 2 consultation and high-stakes accountability event that moved outside of the program community and into the offices of city hall, which falls within the shaded ring in Figure 2. The sustainability officer consultation further illuminates the interplay between the embodiment and enactment of PDE through experiences and voices of team members Dora, Jason, and Ashley.

To begin, the team eagerly anticipated and prepared extensively to present and discuss the solar co-op proposal with a city official. Garnering the official's feedback, and ideally support, would help bring the project to fruition. The sustainability officer meeting therefore reflected more than 12 months of program activities and project work in which the youth intellectually engaged and assumed significant responsibilities. It imbued the project with external significance and conferred recognition; the team were local authorities on their own project work. Moreover, engaging a city official also positioned them with greater authority: they were research contributors, co-testing the implementation model developed by their primary faculty consultant.

The sustainability officer meeting underscores that the team is accustomed to being held accountable to others. It builds on multiple pitches to professionals and researchers associated with the PV engineering discipline and various audiences within and beyond the program (see Figure 2). Nonetheless, the trip to city hall was one of the first times the team had moved outside their solar engineering cohort community, and, perhaps, one of the first times they recognized an interactant as a formal official. As Dora reflected, "We were all very nervous because it was one of our first experiences with an official person. When you hear, 'city official'…it's a little intimidating." Most of the previous CEE consultants had met the youth at the program site, which had become a familiar and comfortable setting. City hall represented a move to a new, unfamiliar environment.

Despite being nervous, the team prepared and presented their solar co-op pitch. However, they were not prepared for the city sustainability officer's response. Below, Dora provides a retrospective account.

> We just gave a quick summary of the idea rather than a presentation because it was more of a formal meeting rather than a presentational setting…I remember him talking about different solar technologies that were being created—kind of in a way to inspire us….I think that he was giving us those ideas because he was preparing to tell us that our project was not legal…it was a strategy for him to get us prepared for that. As we were talking about our [solar co-op], he told us since we weren't a utility and we didn't have the money to be a utility…we weren't able to have our project completed…[A]t the end, we all got on the elevator and we were very discouraged. It was kind of like a "What now?" situation.

Here, Dora exhibits the consequentiality of this pivotal moment. She is expressing the emotional weight of the encounter on both the city official, as he explained that their state currently makes no provisions for community solar, and on the team, as they encountered their toughest setback to date. In sum, the meeting pitted the ingenuity of a local socio-technical solution against the inertia of local socio-political systems: government policies that create well-intentioned constraints and monolithic utilities that wield power in their state's energy system.

In a single meeting, real work with real consequences had evolved to become both a powerful principle for the program and a powerful pain point for these five students. Consequential work around community-centered disciplinary engagement is not only real but risky and therefore can be rough; at the same time, its very consequentiality is one of the things that makes disciplinary engagement productive. Here in this problematic but instructive meeting, the youth met with genuine opportunities for problematizing, as the systems of power confronted them squarely with disciplinary uncertainties, including what to do next and how to go about it. The team was legitimately grappling with the uncertainties of the field (Engle, 2012) and with how to persist and learn from failure.

Considering what can foster youth resilience in the face of policy-influenced engineering failures is critical to youth's personal success, superseding project or program success. In such situations, protecting youth's sense of their rightful presence may be critical to their resilience. In relation to the program's social infrastructure, two sets of program activities provided caring and support that fostered youth success and youth resilience in the aftermath of this meeting.

Foremost, the program facilitator immediately scaffolded a debriefing session. During this session, the facilitator helped the team work through the emotional struggle of a project that could not be implemented. Team members named and compared their post-meeting emotional connection to the project (e.g., confused, stressed, despairing, conflicted) with their pre-meeting connection (e.g., revolutionary, proud, confident, innovative, inspiring) then envisioned an emotional future if they persisted in their community work (e.g., victorious, hopeful, proud, exhilarated, connected). By so doing, the facilitator helped the youth distinguish between the outcome of the meeting and their own worth. As Jason reported retrospectively, "You helped us see that this setback is not definitive of our progress or determinative of our progress or our self-value." More specifically, Dora further distinguished between testing their solar co-op and her own communicative performance at the meeting:

> I was discouraged [after that meeting] but also proud, because it was one of the meetings I asked a lot of questions, made sure I was on top of things, and felt like I made a good impression—even if the project wasn't what we planned it to be.

The reflections that both Jason and Dora shared each illustrate productive engagement with an ill-defined setback, one that, for the entire team, initially seemed definitive and final. By initially elevating the significance of the meeting, their impressions echoed a mainstream image of learning that conflates consequentiality with commodities like test scores or, in this case, project approvals. However, learning and project work alike are themselves means to something more. As the team's rationale suggested, the solar co-op was a means to "better and healthier lives."

In this view, learning is the progress that these student-engineers make with challenges over time. Engineering education cannot be abstracted or reduced by the lens that a test or city sustainability officer imposes. This particular setback underscores that the relationships between the processes and products of learning and what it means (i.e., significance) through one or another lens remain an enduring tension. For example, asset-based approaches to engineering education presume that a lens like learning standards is a connected package. That is, it connects explicit content to seemingly implicit contexts. Context remains implicit because it is more than codifying immediate surroundings and providing access to resources. Context is fundamentally a social reality; it entails the ways learners weave surroundings into significance (Cole, 1996) or ways to know and be. In this way, the same commitment to improvement in their local community had emerged as an asset in their program. Youth assets—the ways to know and be that youth literally embody—were subsequently reflected in the program's own social infrastructure of ingenuity and care (Greenberg et al., 2020). We draw on these dual assets of community infrastructure—ingenuity and care—to characterize a key aspect of program activities that demonstrated deeper, productive disciplinary engagement in Year 2.

In the days following the team meeting with a city sustainability officer, the CEE community infrastructuring proved to be key assets. Interactions with long-standing mentors and partners fostered resilience and ingenuity that ultimately helped the youth team pivot their project to a school solar pavilion. Three collaborators expressed support, offered encouragement, and provided resources to guide next steps. Tom, the graduate student consultant from Year 1, intentionally sought out the team. During the Year 1 meeting described in the section above, Tom had interacted with the youth as a consultant organized by the program facilitators; here he reached out in a more informal moment as a supportive more-experienced colleague. Tom listened to the youth's storying of their city hall experience, then, through discussion, proceeded to weigh out the issues, reinterpret state regulations, and generate alternative solutions. By doing so, he modeled engineering design practices and presented an intellectual model of disciplinary accountability. Moreover, he positioned the youth as entitled to—and expected to—iterate their project goals into an implementable solution for their community. The meeting with Tom became a safe place for the team to explore possible and fanciful acts of resistance and ingenuity such as "We can protest to fix the law" and "What if we make our own [electrical] grid?" These restorative and resistive acts rebuilt solidarity and worked to uphold youths' rightful presence, ultimately helping them maintain faith in their own ingenuity and in themselves as legitimate contributors to community-based engineering projects.

Asked one week later about how their conversation with Tom influenced their orientation towards their solar co-op, Jason reflected on how their new school solar pavilion idea could act as a gateway to the team's first design: "I think [the co-op idea] has potential, but we would have to work around that law and it's easier to work around the law when they see that something that's similar to it has been implemented and actually works." During the week subsequent to the city hall meeting, the same CEE community infrastructure that fostered ingenuity among the team now expressed concern and provided care and support, which Greenberg and colleagues (2020) argue is, itself, a necessary and transformative form of ingenuity. Building on their interactions with Tom and others, the team repositioned their solar cooperative plan not as a failure, but as a project in waiting. As Ashley later reinterpreted the city hall meeting outcome, "our project wasn't so good *at this specific time*." She and her teammates came to see the school solar pavilion design to which they had pivoted as a "starting project" that "could become a reality" and "make a change" in local policy regarding community-based solar energy that could eventually lead to a future where the community cooperative could also become a reality.

The sustainability officer meeting remained a significant event and ultimately a productive one too. CEE community infrastructures inspired and enabled the team to "get somewhere" (Engle, 2012) by pivoting towards a new iteration of their community-centered engineering project: a school solar pavilion. As Ashely observed of the meeting,

> [It] made me think…these types of projects are very difficult to accomplish. So, that kinda changed my mind and made me think about [how] not everything is technically…[It made me] want to research…how electrical companies are kind of like monopolies in a sense…That was like my eye opener in how the world was turned upside down for me.

Ashley's reflection expanded the project from a socio-technical innovation into a political challenge as well. The event opened her eyes to power structures and informed her efforts to realize a more just and equitable socio-ecological future for her community.

In this meeting, youth not only represented their community but participated in decision-making related to energy systems. The Solar Co-op Team did not achieve its goal, but they authentically worked to counter the historic underrepresentation of Latino/a communities in such decision-making processes (Sakellariou, 2013). This is yet another way asset-based CEE projects engage youth in real work with real consequences by remixing people, resources, and ideas in the activity of promoting justice-oriented futures (Calabrese Barton et al., 2020). Also in relation to this high-stakes meeting, we further submit that our study highlights only one form of care and that infrastructuring is an ongoing process. Other aspects of the same meeting provide a case in point. For first- or second-generation Latino/a immigrants to the USA, including the majority of the Solar Co-op Team, engaging with public officials can be unfamiliar and, as Dora noted above, "intimidating" because it resonates with a critical social history of laws and legalities between Latino/a communities and government officials in this particular state, if not also the personal and family histories of some team members. Similarly, identity- and justice-laden historicities explicitly surfaced when one team member and her parents became nervous about driving close to the international airport, with its visible presence of government officials. Thus, "enabling the development of [engineering] identities that integrate with, rather than challenge, students' sociocultural identities" (Lozano et al., 2018, p. 6) necessitates the facing and forbearance of youth and facilitators when navigating real work. While care is inherent to this work, only once students navigated risky situations did we recognize how structuring reciprocity can give rise to both ingenuity and care within a CEE program.

Discussion

In this illustrative case study, we enlisted a socio-technical approach to solar energy engineering (Miller et al., 2013) in order to involve youth in developing a more just and equitable socio-ecological future for their local community. Interrogating the CEE context using the frameworks of PDE and consequential learning, we found that the CEE design supported youth's appropriation of disciplinary ideas and practices and provided opportunities to enlist youth assets in pursuing engineering endeavors of importance to youth and their communities. Analysis pointed to ways youth demonstrated PDE. First, they were actively and meaningfully involved in determining a problem to address in their local community (i.e., lack of shade area in parks, need for alternatives to rooftop solar), and, in turn, generating and testing a viable solution (i.e., a community solar energy cooperative), establishing engagement as a foundation for PDE; second, in engaging this dilemma, they enlisted engineering content, discourses, and epistemic practices, constituting disciplinary engagement; and finally, they did so in service to making substantive progress with their project, realizing PDE (cf. Koretsky et al., 2015, 2019).

The CEE programming design fostered consequential learning, recognizing and legitimizing youth assets as powerful tools for community-based engineering. From day 1, youth were encouraged to draw on knowledge of their community: understanding of neighborhood parks as important gathering places for families and friends, dangers to residents presented by the local climate, and the varied challenges neighbors face in integrating solar in residential areas. Another asset that youth drew on to create a responsive community-based design was their commitment to their families, neighbors, and community, which has been described elsewhere as c*ommunity cultural wealth* and shown to foster persistence in engineering (Samuelson & Litzler, 2016). In turn, the project activity cultivated new assets by connecting personal and community assets to disciplinary ideas and practices (Wilson-Lopez et al., 2016). Moreover, the linkage between assets youth brought and assets youth built during program activity was forged through a core asset of reciprocity that ran through program activity.

Reciprocity as an Asset-Based Approach to Ingenuity and Care

As in previous research (e.g., Calabrese Barton & Tan, 2018), relationality surfaced as a core value and primary tool in this asset-based approach to engineering. Looking across our study findings as represented in the Year 1 and Year 2 episodes from the case analysis, we argue that the dynamic mix of people, resources, and ideas across time and space infrastructured an expanded ethic of reciprocity. CEE sought to infrastructure a relational pedagogy that fostered reciprocity through (a) a youth cohort intentionally recruited from the same neighborhood, (b) long-term relationships with adult CEE participants, and (c) collegial interactions with adult disciplinary experts who supported youth leadership. This reciprocity was an asset that reflected and built on existing assets youth brought to and enacted throughout the program, namely (a) prioritizing communal goals over individual goals; (b) commitment to community improvement; and (c) social, cultural, and geographical knowledge of their community. Thus, through our analysis, we came to see ways in which reciprocity shaped a CEE community of ingenuity and how the same community shaped reciprocity around care over time (Greenberg et al., 2020).

Reciprocity was intentionally designed for as a means to collective success that motivated ingenuity among the team of Latino/a and first-generation youth, exhibited, for instance, in the importance of community purpose that emerged from youth personal experiences and cultural commitments. An ethic of reciprocity keeps with previous scholarship that suggests communal goals of collaboration and helping others can benefit first-generation college and students from minoritized communities, many of whom hold communal orientations to engineering (Barajas-López & Bang, 2018; Boucher et al., 2017). Thus, infrastructuring for a community of ingenuity in CEE required recognizing and resonating with familism and collectivism that are common among many Latino/a communities (Berkel et al., 2010), thereby connecting engineering goals and solutions with family, local, and neighborhood values. Community-centered activities and a community-based project leveraged youth desires to give back to their community, thereby inspiring ingenuity responsive to community needs.

As our analysis of the case illuminated, reciprocity reflected in the CEE community subsequently afforded acts of care and support that came to be part of the CEE infrastructure, emerging in part from youths' commitment to pursuing consequential work for their community. Members of the team and the program responded to moments of inevitable risk, and sometimes failure, that accompany real engineering work. The case study illustrates how adults rallied around the team in the aftermath of the meeting with the city planner to provide care and concern that helped the youth reorient their project work. The Solar Co-op Team not only contributed to a consequential project but they were also subject to it; the very ingenuity that opened the door to a city official's office became the source of deep disappointment. Acts of caring by facilitators and adult collaborators and colleagues became an asset that youth could draw on to persist in the face of setbacks, a source of resilience that sustained them through to a revised community vision (i.e., a school solar pavilion) that was eventually ratified by the community.

Community-centered engineering projects are real and thus require infrastructuring for a community of ingenuity. Real engineering work entails a capacity to find, frame, and generate solutions to contextualized problems. Asset-based approaches are thus needed through which youth enlist and expand innovative solutions by coupling engineering and community ways to know and be. At the same time, infrastructuring a community of care is necessary when work is consequential because consequential is real and real is risky and rough. Real engineering work demands a capacity to navigate uncertainty and risk as one prototypes and tests solutions (Jordan & McDaniel, 2014; Wright et al., 2018). Asset-based pedagogical approaches are thus needed to ensure that care and concern accompany youth during rough moments.

From a sociocultural perspective, the care that counterbalances ingenuity in CEE activity renders a serious appraisal of what counts as knowledge in pre-college engineering by recognizing ontology (i.e., care) as much as epistemology (i.e., ingenuity). Packer and Goicoechea (2000) observe that learning entails changes in being that "rest on ontological assumptions, but these often go unnoticed" (p. 227) as they did for us in intentionally designing for ingenuity but not care. As these authors note, "people shape the social world, and in doing so are themselves transformed. This mutual constitution is accomplished in the social practices of human relationship and community" (p. 234). In the section below, we step back from the illustrative case above in order to consider its connections to wider sociocultural theoretical perspectives on asset-based approaches to pre-college engineering education. More specifically, we discuss how reciprocity can infrastructure communities of ingenuity and care through two overarching design principles that emerged, evolved, and ultimately became antifragile/stable in our work with CEE youth: (a) everyone a learner, everyone a contributor and (b) real work with real consequences.

Everyone a Learner, Everyone a Contributor

Our sociocultural approach reflects a social and systemic orientation; as such, we centered CEE programming on relationships rather than individuals. This relationship-centered focus evolved over time into a more stable design principle, namely "everyone a learner, everyone a contributor." The nature of engineering is such that engineers at all experience levels engage in continuous learning as they engage in cycles of design. Thus, people who might identify as engineers (those who do and those who could) are different only in level, not in kind (Wakefield et al., 2018). In this way, in engineering, everyone is a learner, and everyone is a contributor simultaneously. This does not mean that disciplinary expertise does not matter; only that different types of expertise contribute different things to the complex activity of engineering. Thus, we suggest that CEE and similar programming can only organize opportunities for PDE and consequential learning by working to remediate systems that position youth as learners who may someday contribute to engineering. We advocate for situating youth simultaneously as learners and contributors who are similar in kind to everyone who engineers anywhere, for anyone. Such opportunities are particularly important for youth from populations historically underrepresented in and underserved by engineering, as their rightful presence in STEM is at question (Calabrese Barton & Tan, 2019).

The principle of "everyone a learner, everyone a contributor" does not illuminate a situational mechanism but rather reflects a longer-term investment in remediating extra-classroom systems towards rightful presence and youth's personal, familial, and community assets through positive narratives. More specifically, reciprocity is regenerated by expanding social arrangements between youth and both university- and community-based stakeholders, giving rise to a more diverse array of weak and strong ties in the social networks of participating youth. Moreover, relationships entail reciprocity, such as when youth engineering teams and their supporters exchange perspectives on issues of mutual interest. Organizing CEE and other programming for consequential learning requires a cadre of adult supporters to come around youth to support youth energy innovation leadership. Further, adult supporters need to recognize their own shared positionality as perpetual learners and contributors to engineering in order to organize systems in which youth can be recognized legitimately as learners and contributors. When this fails to happen, it overly constrains youth options for PDE and consequential learning.

Real Work with Real Consequences

Based on study findings, we argue that legitimating youth social inquiry into everyday socio-energy systems in their families and communities organizes interactions and events that constitute community energy engineering. Simultaneously, this legitimization fosters systematic intersections between everyday activities and formal energy engineering through pedagogical and task structures that support youth in leading real work with real consequences for themselves and their communities. CEE programming was developed around the conjecture that youth have assets, capabilities, and commitments suitable for contributing to engineering endeavors at the outset. The impulse to engineer is linked with the desire to positively impact people through the design of novel technological and/or social innovation, and that anyone who takes action through problem framing and ideation, and/or prototype building and testing, can be thought of as engaging in engineering. To thwart the agentive impulse to engineer may also thwart the agentive impulse to make a positive impact on socio-technical worlds, both locally and globally.

As argued above, engineering is by definition consequential. Thus, we conjecture that youths' real work with real consequences in energy engineering requires not only productivity in understanding the discipline, but also the production of an effect through engineering activity that PDE does not fully capture (e.g., Penuel, 2016). PDE alone is not adequate for describing the work youth accomplished in the CEE program or for explaining how program facilitators promoted conditions for such work. We came to see that engaging youth in community-based innovation projects requires not only organizing opportunities for PDE, but also organizing those opportunities to couple with opportunities for consequential learning, for *connective and productive disciplinary engagement* (Agarwal & Sengupta-Irving, 2019).

To create affordances that make pathways for youth to engage in real energy engineering work requires programming based on design principles that value consequentiality as well as disciplinarity. Consequentiality assumes that youth do not need remediation but rather that systems of teaching and learning must be transformed to include a wider range of tools and assistance. Consequentiality is not solely technical or even socio-technical, it is also political and personal, dependent on "social relations and dynamics of power and ideology" (Agarwal & Sengupta-Irving, 2019, p. 351). Thus, engineering disciplines cannot be divorced from the consequence of its innovations as its value is defined by the services it provides to communities. Intention matters. CEE orients youth not only to thinking, but to purposefully acting in their community. Based on analysis of the case episodes illustrated in the findings above, we assert that members of the Solar Co-op Team saw the culmination of their project not only as a pitch to present but also a purpose to pursue.

We posit a reciprocity between PDE and consequential learning, linked through the two CEE design principles: *everyone a learner, everyone a contributor* and *real work with real consequences*. The former emphasizes the need to recognize youth's legitimacy as members of an engineering community, while the latter situates youth as rightful producers of knowledge and design solutions for and with their community. These relationships are represented in Figure 3.

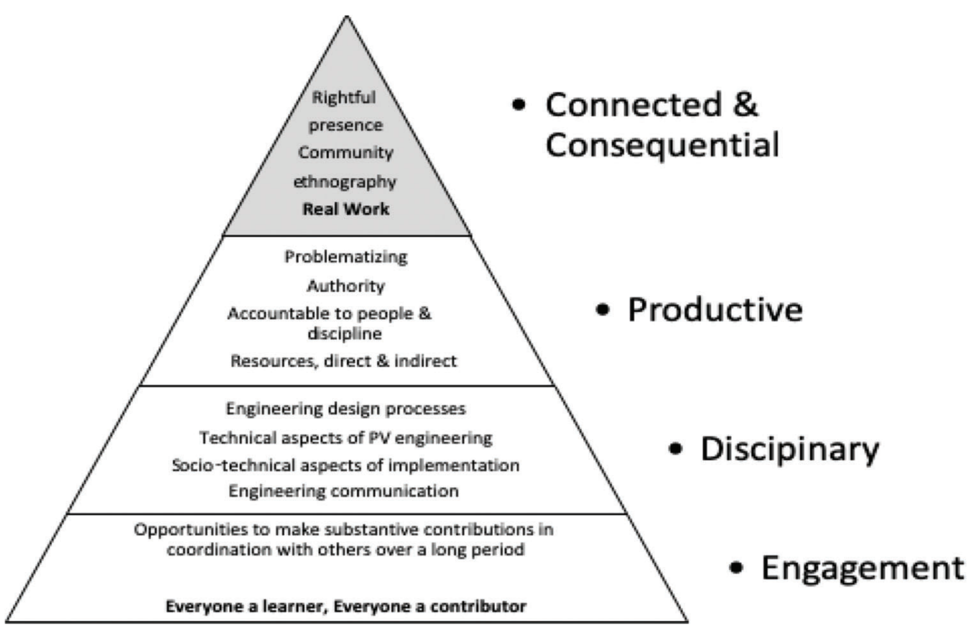

Figure 3. Elements that embody the two CEE design principles.

Without connected and consequential learning enacted through real work, even the strongest forms of authority and accountability will differentially benefit students whose education is already accompanied by similar opportunities for consequential learning, while realizing only E or DE among the students who need to identify with and experience with P the most. Moreover, problematizing is unlikely to induce grappling with deep disciplinary uncertainties; the emotional demands of risky design work may not be sustainable without the commitment and identity inherent to real work with real consequences. Thus, PDE can be a byproduct of project work that purposefully fosters consequential learning and rightful presence. Reciprocally, without opportunities for PDE, claims of youths' rightful presence may ring hollow, as competence with disciplinary concepts and practices undergirds responsible engineering practice engendered in the notion that everyone who engineers simultaneously learns and contributes.

Redefining Engineering

Conclusions from this study consider the generative interplay between questions of what energy engineering is through the endogenous experiences of Latino/a youth and when exactly energy engineering occurs. To position youth to accomplish energy engineering with and for their communities at near and far temporal scales, we need to abandon idealized versions of engineering in favor of noticing how youth gain access to both the wonder and the rigor of the discipline, and how they orient to the local impact and the imagined field.

Engineering in K-12 settings has been defined often in terms of depictions of engineering design processes, and it is through enactment of these processes that PDE is thought to take place. Dasgupta (2019), for instance, defined PDE by middle school learners in terms of five engineering practices: "decomposing the design challenge into individual design parameters, considering the relationship between design parameters, reasoning through multiple design parameters and making tradeoffs, weighing multiple solutions, and using design heuristics for ideation and design optimization" (p. 396). This definition is in keeping with engineering tasks commonly assigned in classroom contexts. Often, the problem to be engineered is predetermined and the set of material constraints preselected. Moreover, most K-12 engineering design tasks involve generalized challenges (e.g., Sadler et al., 2000) or fictionalized problem scenarios (e.g., Cunningham, 2009; McCormick & Hynes, 2012), rather than being situated in real contexts with real others (but see Calabrese Barton & Tan, 2019; Coyle et al., 2006). Although we find value in such activity (e.g., Jordan & McDaniel, 2014), we see limitations in this work for promoting PDE that is consequential, particularly for youth from communities that have been historically marginalized and continue to be marginalized in engineering.

Specifically, we find characterizations of engineering as design process insufficiently broad in scope to capture how engineering is practiced in the CEE program. Nor do such characterizations give adequate attention to conceptions of engineering arising in the discipline. For instance, engineering scholars and practitioners are reimagining the societal, environmental, and ethical purposes for engineering (National Academy of Engineering, 2020), repositioning the role of engineering communication (ABET, 2020; Hynes & Swenson, 2013), and recognizing the dangers of describing engineered innovations solely in technical terms (Karwat et al., 2015; Miller et al., 2018) and the unintended outcomes and emergent effects of technological innovations that can give rise to social and ecological inequities (Fisher & Mahajan, 2010; U.S. Congress, 2003). Yet, many renewable energy engineers remove themselves from issues of social justice and value creation (Sakellariou, 2013). This divorce between technological approaches and justice-oriented approaches does damage to both the practice of engineering and to marginalized youth. Thus, we wish to help generate a new legacy for academic experiences in the field through a more holistic approach to engineering education.

We join with practitioners, scholars, university and K-12 educators, and policy makers who are broadening the scope of engineering and, therefore, what might be considered PDE in pre-college engineering. The CEE program design included technical, socio-technical, communication, and engineering design processes as fundamentally entwined elements of the discipline. These engineering strands are also represented in the NGSS (2013) disciplinary core ideas, cross-cutting concepts; disciplinary practices, among other curriculum documents and engineering education literature. However, we argue that sociocultural and socio-technical aspects of engineering are still underspecified in NGSS and pre-college scholarship that, for instance, identify disciplinary features (Pleasants & Olson, 2019), and characterize epistemic practices of engineering (Kelly & Cunningham, 2019). We thus urge pre-college scholars to delve further into issues of purpose and power as the field considers ways to enlist community-based engineering as an approach to envisioning engineering in context.

Even holistic approaches to engineering from a disciplinary perspective can easily miss the influence of social interactions, power dynamics, and relational agency of engaging youth in real community engineering endeavors. Consequential learning assumes that youth are not isolated individuals but rather social participants embedded in and connected to a wider world (Hall & Jurow, 2015). It is in relation to this wider world that conceptions of engineering must be interrogated and, as necessary, reimagined. Definitions of engineering that situate youth actions as consequential for themselves and their communities need to account for how youth actions, like all engineering activity, evolve in and with historically contingent engineering practices, and how they shape and are shaped by interactions across multiple contexts (see Calabrese-Barton & Tan, 2019; Hall & Jurow, 2015). Most specifically, they should attend to how networks of relational agency can support community infrastructuring (Greenberg et al., 2020; Penuel et al., 2016). They should also address the varied ways youth discover, adapt, and generalize engineering practices over the long term, fitting them to use in community-based projects and in the broader scope of how they practice engineering within the spaces they inhabit (Hall & Jurow, 2015). Perhaps most importantly, efforts to redefine engineering should highlight assets youth bring to—and draw from—the transdisciplinary, technical, socio-technical, socio-ecological, socio-political, power-laden, humanistic, and communicative discipline of engineering.

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References

ABET. (2020). Criteria for Accrediting Engineering Programs, 2019–2020. Available at https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/

Agarwal, P., & Sengupta-Irving, T. (2019). Integrating power to advance the study of connective and productive disciplinary engagement in mathematics and science. *Cognition and Instruction*, *37*(3), 349–366. https://doi.org/10.1080/07370008.2019.1624544.

Antink-Meyer, A., & Aldeman, M. (2020). Middle grades teachers' content knowledge for renewable energy instruction design. *Research in Science & Technological Education*. https://doi.org/10.1080/02635143.2020.1767048

Ayala, S. P., & Jordan, M. (Eds.). (2018). *QESST solar outreach activities handbook*. Bookmobile Craft Digital.

Barab, S. A., Thomas, M. K., Dodge, T., Squire, K., & Newell, M. (2004). Critical design ethnography: Designing for change. *Anthropology & Education Quarterly*, *35*(2), 254–268. https://doi.org/10.1525/aeq.2004.35.2.254

Barajas-López, F., & Bang, M. (2018). Indigenous making and sharing: Claywork in an indigenous STEAM program. *Equity and Excellence in Education*, *51*(1), 7–20. https://doi.org/10.1080/10665684.2018.1437847

Berkel, C., Knight, G. P., Zeiders, K. H., Tein, J. Y., Roosa, M. W., Gonzales, N. A., & Saenz, D. (2010). Discrimination and adjustment for Mexican American adolescents: A prospective examination of the benefits of culturally related values. *Journal of Research on Adolescence, 20*(4), 893–915.

Birmingham, D., Calabrese Barton, A., McDaniel, A., Jones, J., Turner, C., & Rogers, A. (2017). "But the science we do here matters": Youth-authored cases of consequential learning. *Science Education*, *101*(5), 818–844. https://doi.org/10.1002/sce.21293

Biswas, S. (2020). *Creating social value of energy at the grassroots: Investigating the energy-poverty nexus and co-producing solutions for energy thriving* [Doctoral dissertation, Arizona State University]. ProQuest Dissertations Publishing.

Bogdan, R., & Biklen, S. (2007). *Qualitative research for education: An introduction to theory and practice*. Allyn and Bacon.

Boucher, K. L., Fuesting, M. A., Diekman, A. B., & Murphy, M. C. (2017). Can I work with and help others in this field? How communal goals influence interest and participation in STEM fields. *Frontiers in Psychology*, *8*, 901. https://doi.org/10.3389/fpsyg.2017.00901

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 31–42. https://doi.org/10.3102/0013189X018001032

Calabrese Barton, A., Kang, H., Tan, E., O'Neill, T. B., Bautista-Guerra, J., & Brecklin, C. (2013). Crafting a future in science: Tracing middle school girls' identity work over time and space. *American Educational Research Journal*, *50*(1), 37–75. https://doi.org/10.3102/0002831212458142

Calabrese Barton, A., & Tan, E. (2010). We be burnin'! Agency, identity, and science learning. *Journal of the Learning Sciences*, *19*(2), 187–229. https://doi.org/10.1080/10508400903530044

Calabrese Barton, A., & Tan, E. (2018). A longitudinal study of equity-oriented STEM-rich making among youth from historically marginalized communities. *American Educational Research Journal*, *55*(4), 761–800. https://doi.org/10.3102/0002831218758668

Calabrese Barton, A., & Tan, E. (2019). Designing for rightful presence in STEM: The role of making present practices. *Journal of the Learning Sciences*, *28*(4–5), 616–658. https://doi.org/10.1080/10508406.2019.1591411

Calabrese Barton, A., & Tan, E. (2020). Beyond equity as inclusion: A framework of "rightful presence" for guiding justice-oriented studies in teaching and learning. *Educational Researcher*. https://doi.org/10.3102/0013189X20927363

Calabrese Barton, A., Tan, E., & McDaniel, A. (2020). Becoming in STEM: Developing a culture of criticality in the space between person and institution. *Frontiers in Education*, 5. https://doi.org/10.3389/feduc.2020.00037

Cole, M. (1996). *Cultural psychology: A once and future discipline*. Harvard University Press.

Cole, M., & Wertsch, J. V. (1996). Beyond the individual-social antinomy in discussions of Piaget and Vygotsky. *Human Development*, *39*(5), 250–256. https://doi.org/10.1159/000278475

Conlon, E. (2008). The new engineer: Between employability and social responsibility. *European Journal of Engineering Education*, *33*(2), 151–159. https://doi.org/10.1080/03043790801996371

Coyle, E., Jamieson, L., & Oakes, W. (2006). Integrating engineering education and community service: Themes for the future of engineering education. *Journal of Engineering Education*, *95*(1), 7–11. https://doi.org/10.1002/j.2168-9830.2006.tb00873.x

Craig, C. A., & Petrun Sayers, E. L. (2019). Building clean energy support with young millennials in the United States. *Electricity Journal*, *32*(1), 18–24. https://doi.org/10.1016/j.tej.2019.01.007

Cunningham, C. M. (2009). Engineering is elementary. *Bridge*, *30*(3), 11–17.

Darling, A. L., & Dannels, D. P. (2003). A report on the role of oral communication in the workplace. *Communication Education, 52,* 1–16. doi:10.1080/03634520302457

Dasgupta, C. (2019). Improvable models as scaffolds for promoting productive disciplinary engagement in an engineering design activity. *Journal of Engineering Education*, *108*, 394–417. https://doi.org/10.1002/jee.20282

Drehobl, A., & Ross, L. (2016). Lifting the high energy burden in America's largest cities: How energy efficiency can improve low income and underserved communities. https://www.aceee.org/sites/default/files/publications/researchreports/u1602.pdf

Engle, R. A. (2012). The productive disciplinary engagement framework: Origins, key concepts and developments. In D. Y. Dai (Ed.), *Design research on learning and thinking in educational settings: Enhancing intellectual growth and functioning* (pp. 161–200). Routledge.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, *20*(4), 399–483. https://doi.org/10.2307/3233901

Erickson, F. (1984). What makes school ethnography "ethnographic"? *Anthropology & Education Quarterly*, *15*(1), 51–66.

Feaster, S. (2020, May 4). IEEFA update: Renewables surpass coal in U.S. power generation throughout the month of April 2020. Institute for Energy Economics and Financial Analysis. Retrieved from https://ieefa.org/ieefa-update-renewables-surpass-coal-in-u-s-power-generation-throughout-the-month-of-april-2020/

Fisher, E., & Mahajan, R. (2010). Embedding the humanities in engineering: Art, dialogue, and a laboratory. In M. Gorman (Ed.), *Trading zones and interactional expertise: Creating new kinds of collaboration* (pp. 209–230). The MIT Press.

Gay, G. (2010). *Culturally responsive teaching: Theory, research, and practice* (2nd ed.). Teachers College Press.

Geertz, C. (1983). *Local knowledge: Further essays in interpretive anthropology* (Vol. 21). Basic Books.

Greenberg, D., Calabrese Barton, A., Turner, C., Hardy, K., Roper, A., Williams, C., Herrenkohl, L. R., Davis, E. A., & Tasker, T. (2020). Community infrastructuring as necessary ingenuity in the COVID-19 pandemic. *Educational Researcher*, *49*(7), 518–523. https://doi.org/10.3102/0013189X2095761410.3102/0013189X20957614

Greeno, J., Collins, A., & Resnick, L. (1996). Cognition and learning. In R. Calfree & D. Berliner (Eds.), *Handbook of educational psychology* (pp. 15–46). Macmillan.

Gutiérrez, K. D., & Jurow, A. S. (2016). Social design experiments: Toward equity by design. *Journal of the Learning Sciences*, *25*(4), 565–598. https://doi.org/10.1080/10508406.2016.1204548

Hall, R., & Jurow, A. S. (2015). Changing concepts in activity: Descriptive and design studies of consequential learning in conceptual practices. *Educational Psychologist*, *50*(3), 173–189. https://doi.org/10.1080/00461520.2015.1075403

Hernández, D., & Siegel, E. (2019). Energy insecurity and its ill health effects: A community perspective on the energy-health nexus in New York City. *Energy Research & Social Science*, *47*, 78–83. https://doi.org/10.1016/j.erss.2018.08.011

Holland, D., & Lave, J. (2001). *History in person: Enduring struggles, contentious practice, intimate identities*. School of American Research Press.

Holland, D., & Lave, J. (2009). Social practice theory and the historical production of persons. *Actio: An International Journal of Human Activity Theory*, *2*(1), 1–15.

Hynes, M., & Swenson, J. (2013). The humanistic side of engineering: Considering social science and humanities dimensions of engineering in education and research. *Journal of Pre-College Engineering Education Research (J-PEER)*, *3*(2), 31–42. https://doi.org/10.7771/2157-9288.1070

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences*, *4*, 39–103.

Jordan, M. E., & McDaniel Jr., R. R. (2014). Managing uncertainty during collaborative problem solving in elementary school teams: The role of peer influence in robotics engineering activity. *Journal of the Learning Sciences*, *23*(4), 490–536. https://doi.org/10.1080/10508406.2014.896254

Jordan, M. E., Wakefield, W., DeLaRosa, M., Miller, C. A., & Altamirano-Allende, C. (2019). Building youths' socio-technical engineering knowledge through engagement in a community solar energy project. In *ASEE 2019 Conference Proceedings,* Tampa, FL. https://www.asee.org/public/conferences/140/papers/27295/view

Jurow, A. S., Teeters, L. A., Shea, M. V., & Van Steenis, E. (2016). Extending the consequentiality of "invisible work" in the food justice movement. *Cognition & Instruction*, *34*(3), 210–221.

Kandpal, T. C., & Broman, L. (2014). Renewable energy education: A global status review. *Renewable and Sustainable Energy Reviews*, *34*, 300–324. https://doi.org/10.1016/j.rser.2014.02.039

Karwat, D. M. A., Eagle, W. E., Wooldridge, M. S., & Princen, T. E. (2015). Activist engineering: Changing engineering practice by deploying praxis. *Science and Engineering Ethics*, *21*, 227–239. https://doi.org/10.1007/s11948-014-9525-0

Kelly, G. J., & Cunningham, C. M. (2019). Epistemic tools in engineering design for K-12 education. *Science Education*, *103*(4), 1080–1111. https://doi.org/10.1002/sce.21513

Koretsky, M., Nolen, S., Volet, S., Vauras, M., Gilbuena, D., & Tierney, G. (2015). Productive disciplinary engagement in complex STEM learning environments. *2015 ASEE Annual Conference and Exposition Proceedings*. https://doi.org/10.18260/p.24595

Koretsky, M. D., Vauras, M., Jones, C., Iiskala, T., & Volet, S. (2019). Productive disciplinary engagement in high- and low-outcome student groups: Observations from three collaborative science learning contexts. *Research in Science Education*. https://doi.org/10.1007/s11165-019-9838-8

Lammi, M., Denson, C., & Asunda, P. (2018). Search and review of the literature on engineering design challenges in secondary school settings. *Journal of Pre-College Engineering Education Research (J-PEER), 8*(2), Article 5. https://doi.org/10.7771/2157-9288.1172

Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life*. Cambridge University Press.

Lawson, T. (2011). Young people want renewable energy. *Positive News*. Retrieved from https://www.positive.news/society/youth/young-people-want-renewable-energy/

Lee, S., & Roth, W.-M. (2003). Science and the "good citizen": Community-based scientific literacy. *Science, Technology, & Human Values*, *28*(3), 403–424. https://doi.org/10.1177/0162243903028003003

López, F. A. (2017). Altering the trajectory of the self-fulfilling prophecy: Asset-based pedagogy and classroom dynamics. *Journal of Teacher Education*, *68*(2), 193–212. https://doi.org/10.1177/0022487116685751

Lozano, G., Franco, M., & Subbian, V. (2018). Transforming STEM education in Hispanic serving institutions in the United States: A consensus report. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3238702

Mälkki, H., & Paatero, J. V. (2015). Curriculum planning in energy engineering education. *Journal of Cleaner Production*, *106*, 292–299. https://doi.org/10.1016/j.jclepro.2014.08.109

McCormick, M., & Hynes, M. (2012). Engineering in a fictional world: Early findings from integrating engineering and literacy. *2015 ASEE Annual Conference and Exposition Proceedings* (pp. 25.549.1–25.549.15). https://doi.org/10.18260/1-2--21307

McDermott, R. P., & Webber, V. (1998). When is math or science? In J. G. Greeno & S. V. Goldman (Eds.), *Thinking practices in mathematics and science learning* (pp. 321–339). Erlbaum.

Medin, D. L., & Bang, M. (2014). *Who's asking?: Native science, western science, and science education.* MIT Press.

Miller, C. A., Iles, A., & Jones, C. F. (2013). The social dimensions of energy transitions. *Science as Culture*, *22*(2), 135–148. https://doi.org/10.1080/09505431.2013.786989

Miller, C. A., Moore, N., Altamirano-Allende, C., Irshad, N., & Biswas, S. (2018). *Poverty eradication through energy innovation: A multi-layer design framework for social value creation*. ASU-AE4H Joint Working Paper.

Mitchell, T. (2011). *Carbon democracy: Political power in the age of oil*. Verso.

Nasir, N. I. S., Hand, V., & Taylor, E. V. (2008). Culture and mathematics in school: Boundaries between "cultural" and "domain" knowledge in the mathematics classroom and beyond. *Review of Research in Education*, *32*(1), 187–240. https://doi.org/10.3102/0091732X07308962

National Academy of Engineering. (2008). Changing the Conversation: Messages for Improving Public Understanding of Engineering. Washington, DC: The National Academies Press. https://doi.org/10.17226/12187

National Academy of Engineering. (2020). NAE grand challenges for engineering. http://www.engineeringchallenges.org/GrandChallengeScholarsProgram.aspx

National Center for Science and Engineering Statistics. (2017). *Women, minorities, and persons with disabilities in science and engineering: 2017*. Special Report NSF 17-310. Arlington, VA. Retrieved from www.nsf.gov/statistics/wmpd/

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press.

Next Generation Science Standards Lead States. (2013). *Next Generation Science Standards: For states, by states*. The National Academies Press.

Packer, M. J., & Goicoechea, J. (2000). Sociocultural and constructivist theories of learning: Ontology, not just epistemology. *Educational Psychologist*, *35*(4), 227–241. https://doi.org/10.1207/S15326985EP3504_02

Penuel, W. R. (2016). Studying science and engineering learning in practice. *Cultural Studies of Science Education*, *11*(1), 89–104. https://doi.org/10.1007/s11422-014-9632-x

Penuel, W. R., Clark, T. L., & Bevan, B. (2016). Infrastructures to support equitable STEM learning across settings. *Afterschool Matters*, *24*, 12–20.

Pleasants, J., & Olson, J. K. (2019). What is engineering? Elaborating the nature of engineering for K-12 education. *Science Education*, *103*(1), 145–166. https://doi.org/10.1002/sce.21483

Plumer, B. (2020). In a first, renewable energy is poised to eclipse coal in the U.S. *New York Times*. Retrieved from https://www.nytimes.com/2020/05/13/climate/coronavirus-coal-electricity-renewables.html

Reder, W., Bose, A., Flueck, A., Lauby, M., Niebur, D., Randazzo, A., Ray, D., Reed, G., Sauer, P., & Wayno, F. (2010). Engineering the future. IEEE Power and Energy Magazine, 8(4), 27–35.

Rodriguez, A. (2015). What about a dimension of engagement, equity, and diversity practices? A Critique of the Next Generation Science Standards. *Journal of Research in Science Teaching*, *52*, 1031–1051.

Sadler, P. M., Coyle, H. P., & Schwartz, M. (2000). Engineering competitions in the middle school classroom: Key elements in developing effective design challenges. *Journal of the Learning Sciences*, *9*(3), 299–327.

Sakellariou, N. (2013). A framework for social justice in renewable energy engineering. In J. Lucena (Ed.), *Engineering education for social justice* (Vol. 10, pp. 243–267). Springer Netherlands. https://doi.org/10.1007/978-94-007-6350-0_12

Samuelson, C. C., & Litzler, E. (2016). Community cultural wealth: An assets-based approach to persistence of engineering students of color. *Journal of Engineering Education*, *105*(1), 93–117.

Sen, P. K. (2011). Electric power and energy engineering education in USA: A status report, issues and challenges. *2011 Rural Electric Power Conference*, A1-1-A1-6. https://doi.org/10.1109/REPCON.2011.5756711

Strobel, J., Wang, J., Weber, N. R., & Dyehouse, M. (2013). The role of authenticity in design-based learning environments: The case of engineering education. *Computers & Education*, *64*, 143–152. https://doi.org/10.1016/j.compedu.2012.11.026

Svihla, V., Datye, A. K., Gomez, J. R., Law, V., & Bowers, S. (2016). Mapping assets of diverse groups for chemical engineering design problem framing ability. Proceedings of the ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.25675

Tatar, D. (2007). The design tensions framework. *Human-Computer Interaction*, *22*(4), 413–451. https://doi.org/10.1080/07370020701638814

Taylor, K. (2021, January 24). Renewables overtook fossil fuels as EU's main power source in 2020. *EURACTIV*. Retrieved from https://www.euractiv.com/section/energy/news/renewables-overtook-fossil-fuel-as-main-source-of-eus-electricity-in-2020/

U.S. Congress. (2003). Twenty-First Century Nanotechnology Research and Development Act of 2003, Public Library, 108-153, 2, Dec. 3., 2003, 117 Stat.1923.

U.S. Department of Energy. (2017). *Energy literacy: Essential principles and fundamental concepts for energy education*. https://www.energy.gov/sites/prod/files/2017/07/f35/Energy_Literacy.pdf

U.S. Energy Information Administration. (2021). Renewables account for most new U.S. electricity generating capacity in 2021. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=46416

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wakefield, W., Jordan, M. E., & DeLaRosa, M. (2018). "We were on the same level": Young engineering researchers taking up agentive positions in a diverse learning community. In J. Kay & R. Luckin (Eds.), *Proceedings of the International Conference of the Learning Sciences (ICLS) 2018*. International Society of the Learning Sciences.

Wilson-Lopez, A., Mejia, J. A., Hasbún, I. M., & Kasun, G. S. (2016). Latina/o adolescents' funds of knowledge related to engineering. *Journal of Engineering Education*, *105*(2), 278–311. https://doi.org/10.1002/jee.20117

Wilson-Lopez, A., Sias, C., Smithee, A., & Hasbún, I. M. (2018). Forms of science capital mobilized in adolescents' engineering projects. *Journal of Research in Science Teaching*, *55*(2), 246–270. https://doi.org/10.1002/tea.21418

Wright, C., Wendell, K. B., & Paugh, P. P. (2018). "Just put it together to make no commotion": Re-imagining urban elementary students' participation in engineering design practices. *International Journal of Education in Mathematics, Science and Technology*, *6*(3), 285–301.