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Abstract

Learning spaces, the practices in which people engage, and the representations they use are ideological. Ideologies are coherent constellations of values, beliefs, and practices that impose order on how disciplines like engineering operate. Historically, engineering spaces have been dominated by a relatively technocratic, rationalistic, and exclusionary ideology, but more recent attention to asset-based approaches to engineering education offers transformative promise. Asset-based ideologies can reshape images of legitimized engineering practice, recasting engineering education to disrupt dominant exclusionary ideologies. This paper describes an assets-based learning space, SETC, that recaptures the imagination of engineering for technological and social change. Drawing from extensive ethnographic observational data, interviews, and artifacts produced in SETC, we describe aspects of this learning space, including the use of representations and practices that specifically support expansive forms of engineering practiced by youth of color. We also explore how SETC's commitment to antiracist and liberatory practices, including shifting relationships to technology and engineering design in service of enhancing life, manifests in its transformative mission to design programs and activities for youth that disrupt dominant ideologies. SETC centers making and tinkering as legitimate expressions of engineering, and we present a case of a youth participant to illustrate the rich engineering learning that the space makes possible. The case features Naeem engineering a gear-based project that expresses his interpretation of Black Lives Matter. Situated in his long history in the learning space, we explore how youth's interactions with conventionalized representations—which serve to maintain dominant ideologies—are enhanced by asset-based commitments. This paper contributes specific recommendations for designing spaces for new ideologies, making engineering education more equitable for youth of color while also expanding notions of what engineering is and the forms that it can take.

Keywords

representations, making, ideologies, equity

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More than Mechanisms: Shifting Ideologies for Asset-Based Learning in Engineering Education

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Abstract

Learning spaces, the practices in which people engage, and the representations they use are ideological. Ideologies are coherent constellations of values, beliefs, and practices that impose order on how disciplines like engineering operate. Historically, engineering spaces have been dominated by a relatively technocratic, rationalistic, and exclusionary ideology, but more recent attention to asset-based approaches to engineering education offers transformative promise. Asset-based ideologies can reshape images of legitimized engineering practice, recasting engineering education to disrupt dominant exclusionary ideologies. This paper describes an assets-based learning space, SETC, that recaptures the imagination of engineering for technological and social change. Drawing from extensive ethnographic observational data, interviews, and artifacts produced in SETC, we describe aspects of this learning space, including the use of representations and practices that specifically support expansive forms of engineering practiced by youth of color. We also explore how SETC's commitment to antiracist and liberatory practices, including shifting relationships to technology and engineering design in service of enhancing life, manifests in its transformative mission to design programs and activities for youth that disrupt dominant ideologies. SETC centers making and tinkering as legitimate expressions of engineering, and we present a case of a youth participant to illustrate the rich engineering learning that the space makes possible. The case features Naeem engineering a gear-based project that expresses his interpretation of Black Lives Matter. Situated in his long history in the learning space, we explore how youth's interactions with conventionalized representations—which serve to maintain dominant ideologies—are enhanced by asset-based commitments. This paper contributes specific recommendations for designing spaces for new ideologies, making engineering education more equitable for youth of color while also expanding notions of what engineering is and the forms that it can take.

Keywords: representations, making, ideologies, equity

Introduction

Engineering's history is one of great possibility, imagination, and vision (Goldberg & Somerville, 2019). Inventing new social possibilities once fueled engineers as they designed for transforming human experiences. A confluence of factors shifted the power relations between engineering and science, and engineering morphed into a technocentric, male, and largely exclusionary discipline over time (Oldenziel, 2001; Secules, 2019). At present, engineering education seeks to recapture the allure, vision, and hope that engineering once provided for social and technological change (Duderstadt, 2008), which includes contending with engineering education's history of exclusionary practices (Holly, 2020).

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In this paper, we examine how ideologies shape engineering learning spaces, and how shifting ideologies toward equity and asset-based approaches can support engineering for social change with youth of color.

Naeem ventured to engineer a gear system that would represent and share his views on critical elements of Black Lives Matter ideologies. Motivation for the project was personal and political. Naeem was inspired by activism through art in the 1960s Civil Rights Movement, and he was interested in exploring gears. His high-school art teacher showed videos of Black Panthers and illustrations of the mutually amplifying relationships between art and social movements. As a young African American male living in a city saturated with academic–technology partnerships (Simha, 2005), and plagued by anti-Black racism (King, 1981), Naeem wanted to use engineering and technology to engage others in thinking more critically and consequentially about social movements and systems of oppression. Naeem articulated his motivations this way:

> *Basically, I wanted to challenge the idea that all lives matter since Black lives mattered. And I wanted to show that all lives can't matter until Black lives matter or those that are feeling underrepresented matter. So, I had this idea of gears surrounded by four equal gears…basically they all revolve around that central gear to show that…this is like all lives matter, and you take out one gear and the project would stop working. I haven't figured out how to do that yet but that's what I want to do…And it won't work until you put it all back in.*

The proposed project was not only an opportunity to share a message about equity and justice, but also a place to learn by using engineering to address community issues. Naeem was an integral member of a community technology center, and his experiences learning with and from peers, teaching others, and developing relationships to technology and social change were assets in his engineering work. For this project, he said he wanted to "do something with gears," because he wanted to learn more about gears and how to use them in design. He envisioned a gear system that included an outer "chassis" which housed a central gear surrounded by four smaller planetary gears (Figure 2). The smaller gears represented the lives of people that have been oppressed in the United States, including Black and Latinx people. The large inner gear represented the all lives matter ideology. If one of the smaller gears was removed the system would not function; this represented Naeem's idea that "all lives can't matter until Black Lives Matter."

Naeem worked at South End Technology Center (SETC), a community making space and education laboratory committed to asset-based approaches that emphasizes building projects that address community issues. SETC provided Naeem with material resources (such as acrylic, wood, computers, and a laser cutter) and positioned him as a teacher and a Fab Lab facilitator. He held leadership roles, negotiating the policies, practices (Klimczak et al., 2016), and technologies of the space (Millner et al., 2020). Naeem assumed different roles within a multilayered mentoring structure where his expertise was shared with others, and, in turn, others shared their expertise with him.

The community at SETC fostered an ideology focused on justice and liberation in science, technology, engineering, and mathematics (STEM). Ideologies are coherent constellations of concepts, practices, and representations that impose order on the world (Hall, 1986); they are the systems people use to "make sense of, define, figure out and render intelligible" the ways social activities work (Hall, 1986, p. 29). SETC upheld an asset-based ideology, described below, that positioned youth as brilliant, capable, and committed, with unbridled potential for transforming the world with engineering and technology.

Our paper argues for the critical importance of asset-based approaches for supporting youth learning in engineering contexts. By asset-based approaches, we mean pedagogical, material, and social structures designed to value, center, and promote cultural and heterogeneous ways of knowing and doing (Alim et al., 2020; Emdin, 2016; Nasir et al., 2014). Youth learn with varied and dynamic repertoires of practice (Gutiérrez & Rogoff, 2003) and rich funds of knowledge (Moll et al., 1992); learning spaces that cultivate and nourish heterogeneity, or those varied and dynamic ways of being, encourage asset-based approaches (Rosebery et al., 2010). Of particular importance is intentionally counteracting deficit-oriented approaches to engineering education (Mejia et al., 2018) that have systematically excluded and harmed people of color in engineering (Holly, 2020). A vision of engineering that transforms the human experience cannot be achieved unless forms of racial discrimination and hostility are dismantled (McGee, 2020). Asset-based approaches disrupt the dominant ideologies that narrow the ways of being and doing in engineering education spaces, and they offer ways to reimagine the forms of participation and practice that constitute dynamic, meaningful, and expansive engineering learning.

This article analyzes how engineering spaces committed to asset-based approaches foster sophisticated engineering learning. We issue a challenge to the engineering education community to question deep-seated ideological assumptions about what counts as engineering practice and to encourage expansive visions of engineering for the purposes of imagining new possibilities for building equitable and just engineering learning spaces. We describe one particular learning space—a community center and education laboratory—that recaptures the imagination of engineering for social transformation, outlining the characteristics that specifically support expansive forms of participation in engineering for youth of color.

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The learning space in this study is imbued with asset-based ideologies, offering insights into how engineering education can be recast to disrupt dominant exclusionary practices (Secules, 2019).

We illustrate how making, tinkering, personal expression, and forms of justice-oriented design shape expansive notions of engineering engagement by elaborating on the story of Naeem's Black Lives Matter project. A case study of how Naeem navigated dominant representational systems provides evidence for how asset-based ideologies support engineering learning. The case illustrates how Naeem's project reflects more than a fascination with gears as mechanisms, but rather a meaningful example of how engineering learning can be directed at social transformations. This research makes contributions to the field's understanding of designing asset-based spaces, and how engineering learning is re-mediated through expansive visions of engineering practice. We also discuss the implications for the future design and research of spaces that shift ideologies toward more just and equitable engineering learning opportunities.

Ideologies and Representations in Engineering Education Spaces

Engineering learning spaces, like all learning spaces—including the practices in which people engage and the representations they use—are ideological (Apple, 1979; Villanueva et al., 2018). That is, engineering learning spaces are organized, and co-constructed, with particular systems of values, representations, and ideas (Hall, 1986; Lemke, 1990) about how activities like engineering operate and what counts as engineering, including what methods, tools, and representations people use. Historically, these ideologies have presented engineering as primarily technical (Sheppard et al., 2007; Trevelyan, 2010) and masculine (Oldenziel, 2001), while backgrounding heterogeneous processes (Gravel & Svihla, 2021; Law, 1987; Suchman, 2000) and inherent political and ethical dimensions (Philip et al., 2018). Those systems of values, representations, and ideas define the legitimized forms of engineering (e.g., Pawley, 2012; Rohde et al., 2020; Stevens et al., 2014) in ways that uphold dominant, historical ideologies that have long shaped the exclusionary practices that disproportionately affect people of color in the field (McGee, 2020).

Ideologies are maintained, in part, through representations and practices for interpreting and creating them (Gramsci, 1997). Dominant ideologies in engineering—i.e., engineering as a primarily technical activity—surface in the specific systems of representations permeating professional practice, such as computer-aided design (CAD) software like SOLIDWORKS. These representations are conventionalized through the social histories of the discipline's development (for instances, see Johri et al., 2013). As such, they are "socially shared systems of representations" (Philip et al., 2018, p. 186) that mediate engagement with design and sensemaking. The processes for interpreting and using CAD both reflect and reify the dominant ideologies. That is, representations help to order the ways people engage in engineering (Hall, 1986). Therefore, both ideologies and the ways in which they manifest representationally are critically important to how learning takes form in engineering (Volosinov, 1986; Vygotksy, 1981).

But, ideologies are not static: they are enacted through dynamic social practices, and constituted through contested relationships of knowledge and power (Foucault, 1980). Shifting ideologies for engineering, toward those that embrace asset-based approaches and work toward disrupting, or counteracting, dominant exclusionary forces, can illuminate the contested relationships between conventionalized representations (e.g., software, problem sets) and the heterogeneous ways in which they are used (Tucker-Raymond et al., 2017). These contested relationships between people-in-practice, representations, and ideologies provide testimony for how to remake learning spaces with asset-based approaches. Examining how learners navigate tensions with interpreting and using conventionalized representations, where dominant ideologies are expressed, provides insights into how new, shifted ideologies expand opportunities for learning engineering (Philip et al., 2018). We examine prior research on asset-based approaches to engineering education, including making and tinkering and engineering for social transformations, to explore how new ideologies for engineering learning can be enacted and maintained.

Asset-Based Approaches to Engineering Education

Literature focused on experiences in STEM education for learners from Black, Latinx, and Indigenous communities demonstrates how asset-based approaches can be more equitable and dignified when they simultaneously question the "settled expectations" of the disciplines (Bang et al, 2012; Warren et al., 2020). Research from critical theory perspectives argues against the long history of deficit orientations in engineering education by shifting focus from individuals to institutionalized and systemic considerations (Mejia et al., 2018). Promising contributions to equity-focused engineering education research center care, ethics, and justice (e.g., McGee & Bentley, 2017), and draw attention to racialized identities (Wright et al., 2020) in enacting asset-based commitments. Calls for increasing engagement in engineering offer possible directions forward in expanding the space of engineering by broadening the focus beyond "technical problem solving" (Adams et al., 2011, p. 49). We argue that critical reexaminations of what is considered engineering (e.g., Pawley, 2012), and the practices that constitute it, are also needed. As such, we draw from the broader literature in STEM, and not just engineering, to describe asset-based approaches, because part of our goal in this article is to expand what is meant by engineering, to desettle what is commonly considered engineering within engineering education discussions so that educators might recognize engineering as heterogeneous and inclusive of different kinds of identities and practices.

Commensurate with an expansive view of engineering education, our case study takes place in what some have called a "STEM-rich" making (Calabrese Barton & Tan, 2018) context. Making encompasses transdisciplinary practices often considered to be science, mathematics, or tinkering, but related to engineering education nonetheless (Jones, 2019; Wang et al., 2013). As Oldenziel (2001) and others have noted, the dominance of engineering by men, mostly of European descent, is entangled with economic and power distributions; men control how engineering is practiced and taught as a measure of maintaining forms of superiority (Freehill et al., 2008; McGee, 2020). Engineering as a discipline possesses a great deal of power, and thus declarations of what is or is not engineering have significant and lasting consequences in terms of participation and opportunity. By positioning STEM-rich making, including its history in heritage practices (Barajas-López & Bang, 2018) and relationships to technologies through constructionist approaches (Holbert et al., 2020a; Papert, 1980), as a legitimate manifestation of engineering, we aim to expand definitions of engineering and STEM to include youth's dynamic and varied repertoires of practice.

Resources and Heterogeneity in STEM Learning

A long history of research in STEM education has established that learners draw from a host of resources in learning STEM, including epistemological resources (Hammer & Elby, 2003; Marin & Bang, 2018), linguistic resources (Brown, 2006; Warren et al., 2001), and identity resources (Nasir & Cooks, 2009; Nasir & Hand, 2008). A resources perspective has propelled research on listening and attending to student thinking (Robertson, et al., 2015), teacher noticing of students' disciplinary learning (Rosebery et al., 2016; Sherin & Jacobs, 2011), and shifts in designing learning environments (Bell et al., 2017). Resources perspectives, however, also have complex relationships to disciplinary practices, whereby disciplines order the ways resources are determined as productive or not (Agarwal & Sengupta-Irving, 2019), often excluding heterogeneous ways of being and knowing from discussions of legitimate disciplinary learning. Conversely, asset-based perspectives fundamentally position learners' communicative, social, and cultural practices as assets in learning and sensemaking (Rosebery et al., 2010). That is, all resources that learners bring to the learning context are considered useful for sensemaking and thus are productive in learning activities. Learning environments designed to nourish those assets can transform learners' relationships to disciplinary practices (Nasir et al., 2014). When learners' heterogeneous ways of being and knowing are valued, including their multiple intersecting identities (Burt et al., 2018; Ross et al., 2017), their participation in engineering is sustained and nourished (Flowers, 2015; Godwin & Kirn, 2020). Thus, research on asset-based perspectives punctuates the critical importance of heterogeneity in terms of practices, including how one uses different representations, as well as the need to design spaces that foster transformative ideologies (Philip at el., 2018).

Assets in Engineering Disciplinary Learning

One of the more significant advances in research on asset-based approaches in engineering has been an emphasis on ill-structured design challenges (Dringenberg & Purzer, 2018; Gravel & Svihla, 2021; Jonassen, 2014) focused on community-based issues (Dalvi et al., 2016; Wendell et al., 2019). "Authentic" engineering design challenges (Mejia et al., 2015) are rooted in problems identified and framed within the communities with which students identify (Mejia & Wilson-Lopez, 2015). Addressing design challenges related to issues of equity and justice can expand how learners' funds of knowledge (Moll et al., 1992) become assets in problem framing (Svihla et al., 2016) and problem solving (Kabo & Baillie, 2009; Stevens et al., 2008; Wilson-Lopez et al., 2016). Situating engineering education in communities, focused on addressing problems for social good, has expanded who participates and how we understand forms of participation. For example, Smith and Lucena (2016) spotlighted the particular skill and sophistication with which low-income, first-generation engineering college students negotiated issues of resource scarcity in design contexts. The historical practice of reinventing and repurposing existing technologies for new designs outside the intended use (Eglash, 2004) has roots in communities with resource constraints, making these practices assets with respect to efficiency and elegance. Thus, asset-based learning spaces configure disciplinary learning expansively and heterogeneously.

Making as an Asset-Based Approach to Engineering Education

Making represents an asset-based manifestation of design and engineering. Making's promise for STEM education in schools, including engineering, has been accepted by many in engineering education (Martin, 2015) and more broadly (Peppler et al., 2016). In "STEM-rich" making (Calabrese Barton & Tan, 2018), opportunities abound for youth to be designers of projects that interest them (Halverson & Peppler, 2018), for multimodal and transdisciplinary inquiry and production (Tucker-Raymond & Gravel, 2019), for expansive notions of participation and engagement (Frank et al., 2020; Vossoughi et al., 2016), for the development of engineering discourses (Martin & Betser, 2020), as well as focused and deliberate engagements (Dixon & Martin, 2017). In making, desettling engineering disciplinary ideologies is possible, for example, where indigenous ways of knowing, including textile and other cultural practices (Barajas- López & Bang, 2018; Searle et al., 2020), are assets. Furthermore, making spaces can foster social relations that support sustained engagement in activities and projects that individuals find interesting (Azevedo, 2013; Tucker-Raymond et al., 2016). We position making and tinkering as essential engineering activities, which have been to date largely marginalized in educational discussions of what "counts" as engineering practice (e.g., Moore et al., 2014). Making locates agency in the designer and in the materials (Gravel & Svihla, 2021), fundamentally transforming makers' resources into assets. We argue that the shift to embracing making as a manifestation of engineering requires examining the ideologies of engineering learning spaces.

We ground this paper in theoretical and empirical relationships between ideologies and representations, and between making and expanded visions of engineering. All approaches to teaching and learning are ideological. Focusing on asset-based approaches offers new visions of equity and justice-focused engineering learning. Yet, asset-based perspectives are not monolithic. Asset-based perspectives, those that recognize, honor, and build on learners' social, cultural, identity, and intellectual resources, can fall into two basic ideologies: assimilative and transformative. The former takes for granted the value of the institutionalized disciplinary representations and practices of engineering and engineering education. In this case, educators draw on learners' resources to "give oneself over" to engineering as it is without questioning the purposes and values of engineering (Moje et al., 2007) and without attempting to disrupt disciplinary values that contribute to exclusion. The latter, transformative approaches, seek to change what is valued as engineering, what can be known and what can be done, serving to desettle what it means to learn engineering. In practice, asset-based approaches are never wholly assimilative or transformative—they are both. Furthermore, representational practices are central to learning and to these ideological entanglements. Therefore, our paper explores a learning space imbued with asset-based ideologies, and a case study of engineering learning with dominant representational systems within that justice- and equity-oriented learning environment. We examine the relationships between representations and people-in-practice as we address the following questions:

In what ways can learning spaces promote expansive participation in engineering for youth of color through asset-based ideologies? Furthermore, how can youth access and transform conventional engineering representations in asset-based learning spaces?

Methodology

This case study is part of a multiyear ethnographic project identifying and describing the STEM literacy practices in making spaces (Tucker-Raymond & Gravel, 2019). The larger project sought to identify multiple forms of literacies, understood as social practices with representations (Cope & Kalantzis, 2000; Heath, 1983; Street, 2003). The focus on multiple forms of language and modalities (Heath & Street, 2008) provides insight into how representations contribute to creating disciplinary spaces (Foucault, 1980). This perspective allowed us to jointly attend to representations used and how they constructed and maintained the learning spaces we studied. In this paper, we focus on one space, SETC. We took a participatory approach to data analysis, involving key actors at SETC in analysis and authorship.

Author Positionality

Three of the authors, Brian Gravel, Eli Tucker-Raymond, and Aditi Wagh, were outside researchers, invited as participant observers (Erickson, 2011) during different programming at SETC. Susan Klimczak is the education organizer for the Learn 2 Teach, Teach 2 Learn program (L2TT2L, described below) which operated at SETC. Naeem Wilson was a youth teacher and is currently a mentor in L2TT2L. The outside researchers attempted to understand SETC as an exemplary space of learning that might inform future efforts in engineering education. Susan ran the program, spending 12–14 hours a day organizing behind the scenes and encouraging and teaching youth out front. Brian and Eli, co-principal investigators of the larger study, are White. Aditi, a postdoctoral researcher at the time, identifies as an Asian immigrant. Susan identifies as White. Naeem identifies as African American. We include our racial/ethnic backgrounds to acknowledge that the work takes place within histories of racist relationships between research groups, such as universities, and communities of color. For the researchers on the team who claim to value asset-based approaches, we acknowledge our responsibility to disrupt this history and to include the voices and perspectives of our participants. Our approach included spending a significant amount of time in the space talking with youth and others, sharing with them what we were doing: collecting data and understanding the ways in which they were learning and doing STEM. We also included the program leader, Susan, and the participant whose work we showcase, Naeem, as co-researchers and authors to deepen our shared interpretations.

Research Site

SETC is a community-based technology and engineering education center located in Boston. SETC serves members of the surrounding community—youth and adults of all ages—offering access to computers, design and fabrication tools, film editing equipment, and space for community meetings. The center occupies the garden level of two brownstone buildings, with three main spaces: computer lab, workshop, and Fab Lab. SETC is open daily to anyone, and it is home to specific programs that engage youth and the community in different forms of making, liberatory action, and engineering design. We describe SETC in more detail in the findings.

Data Sources

We observed approximately 100 hours of activity across nine months at SETC. Data sources include fieldnotes (Emerson et al., 2011), audio and video recordings, semi-structured and informal interviews, as well as artifact collection from participant observations (Table 1). Observations began in December, at weekly Thursday drop-in sessions (described below), where the Fab Lab was open to members of the community. When the Fab Lab was open, community members came in to use the tools and were supported by Fab Stewards, who organized their activities and taught skills and tool processes to beginners. January through March, we observed the interview and selection process for hiring youth teachers leading up to the summer program, as well as the intensive 7-week summer program that ran for 25 hours a week in which youth teachers participated.

We conducted three semi-structured interviews with Susan, one of which included the founder, Mel King. We also interviewed individual youth participants during the winter and spring, and project groups from the summer program. We collected all teaching materials from the SETC summer program to review how representations were constructed within and for the purposes of youth teaching other youth about designing with technology. Materials included worksheets, posters, troubleshooting guides, and coding “cheat sheets,” all co-designed by youth and the center education organizer. Together, these data sources were used to create descriptions of the context and surface the ideological commitments in which the case study is situated.

Data sources related to the case study of Naeem’s Black Lives Matter sculpture include four specific pieces of data. (a) The research team first encountered him working on this project on a few occasions in early winter, and we asked him to narrate his trajectory to that point. (b) We then observed him working on the project on his own. (c) We observed him working on the project in a substantial SOLIDWORKS design session supported by a friend and mentor, Derek. (d) Naeem was interviewed at the end of the summer on where the project stood, what he had discovered, and where he hoped the project would go (Table 2). In addition to video and audio recordings, we generated fieldnotes and transcribed all episodes and narrations.

Data Analysis

Analysis focused on characterizing aspects of ideological commitments in the space itself alongside events of youth collaborating in design and engineering projects. Interviews with participants, fieldnotes, artifacts, and observational data were first coded based on the STEM Literacies in Makerspaces Framework (Tucker-Raymond & Gravel, 2019), focused on how people used multimodal representations and communication as they participated in specific making processes, such as

Table 1
Data sources used to construct a description of SETC’s asset-based ideologies.

Source	Description	Contributions to analysis
Observational data	98 hours of observations with accompanying fieldnotes.	Coded using STEMLiMS framework, which included attention to values, episodes of teaching, and using and creating representations.
Video and audio recordings	40 hours of direct recording; transcribed for analysis.	Interaction analysis of particular episodes of student learning and interaction (including the case of Naeem’s BLM project).
Interviews	22 interviews: 2 with SETC leadership; 5 with youth about specific projects; 3 with College Mentorz; 8 with Youth Teachers; 4 with project groups at the end of the summer program.	Analysis of the history and mission of SETC, youth experiences at SETC, and programmatic structures and operations; participants’ understandings of ideological commitments of SETC.
Collected materials	Teaching materials (e.g., worksheets, posters, tutorials), project photographs, project design files.	Analyzed for evidence of disruptive approaches to engaging with technology, teaching, and developing projects for the community.

Table 2
Data sources used to construct the case of Naeem's Black Lives Matter project.

Episodes (chronological)	Focus of interactions	Contributions to analysis
Initial Interview about BLM project (February 25, 2016)	Aditi identifies Naeem's BLM project and inquires about its origins and vision.	Identified project origins and message that Naeem hoped to share with gear project.
Independent work session (March 11, 2016)	Naeem describes his design process to this point, and what challenges he has encountered requiring new approaches.	Interactions with Inkscape, emergence of performance problem with current gear system design.
Work session with friend Derek exploring SOLIDWORKS (March 31, 2016)	Naeem and Derek explore SOLIDWORKS to design spur gears.	History and relationships in SETC as assets as Naeem contended with conventionalized representations.
Follow-up interview (June 29, 2016)	Aditi interviews Naeem about what he has learned, revealing his revised description of gear tooth interactions.	Evidence of deepened understanding of engineering ideas and learning about gear tooth dynamics.

designing, fabricating, seeking/offering assistance, and generating representations. This initial coding produced insights into how representations were generated and used, while also offering illustrations of particular ideological commitments in the space. For example, we drew excerpts from the coding of observational data that described particular events, like a morning circle where a student read poetry about gun violence to others, and analyzed elements of the event relative to the mission and vision of SETC, as initially identified in interviews with SETC leadership. Borrowing from processes in grounded theory (Charmaz, 2006), we iteratively developed characterizations of the space alongside examples of how those commitments were enacted in programs and activities. These iterative refinements of the descriptions of the space were intended to not "simply describe existing realities but…to explain them" (Fairclough, 2013, p. 9). We expanded the analytic frame beyond only looking at talk to include the nature of interactions within mediated activity, and pedagogical materials from the summer youth program to gather evidence of reconfigured relationships between engineering and representational artifacts. This comparative approach enabled us to consider histories and expressed ideological commitments in the interviews with the founder, Mel King, and education director, Susan, and to trace those ideas through discourse and interactions observed at SETC. This analysis produced layers of description of SETC, including the mission and purpose of activities, embodiments of that mission in the form of programs and participation structures, and specific activities where the mission of transforming engineering participation was evident.

To construct the specific case of Naeem's project, we first identified the series of episodes where Naeem worked on the Black Lives Matter project, comprising a representationally rich, multimodal, and collaborative set of data (Yin, 2017), situated within Naeem's history at SETC (Table 2). Using repeated viewing within the research team (Jordan & Henderson, 1995), analysis focused on identifying Naeem's engagements with representations in the design and fabrication of his project. We presented excerpts from the data to several disciplinary experts in engineering, mathematics, and science education to check our ongoing interpretations and to gain new insights from their interpretations about what he was doing and its relation to disciplinary work in those fields.

Consistent with naturalistic inquiry methods that value emic perspectives (Lincoln & Guba, 1985), we explored preliminary findings with Susan and Naeem, whereby they began participating in analysis. Specifically, their participation helped to focus and shape the themes by responding to them relative to their experiences operating and working in SETC.

Findings

We present the findings in two primary sections. First, a detailed description of SETC's asset-based ideology captured in its mission and purposes, the ways in which ideology manifested in programming and participation structures, and finally examples of how activities were organized to transform engineering engagement. The description narrates the commitments of this expanded ideology—e.g., justice, liberation—while also describing the particular structures that supported the sustained and deepening engagement in engineering and technology projects by youth of color, like Naeem. Second, we present a case study of Naeem's work developing his Black Lives Matter project, and how situated within the asset-based ideology of SETC, he navigated a conventionalized representational system as he learned about designing with gears.

SETC: "Creating community and {r}evolution"

Susan considers SETC to be a "community-based education laboratory" (individual interview). Nestled in Boston's storied South End neighborhood with a deep, complex history of racial diversity and struggles for housing and economic justice, SETC was built with the mission of increasing access to learning with technology and recasting youth relationships to technology as opportunities to enhance lives and communities. SETC's mission statement reads "Our aim is to facilitate using technology in ways that encourage people to become innovators and producers, tell their stories, and learn ways of creating just and humane communities." This mission is situated within and speaks to the historical freedom struggles of communities of color and embodies calls for the "normalization of Black excellence" in engineering and technology (Holly, 2020, p. 2).

We describe three central elements of SETC as a learning space that function together to foster an asset-based approach to engineering education: (1) mission and purpose; (2) embodiments; and (3) activities that disrupt and reimagine engagement. We then present a case study of Naeem's iterations on his Black Lives Matter project, described in the introduction, to illustrate how SETC's asset-based approach informed, supported, and transformed how Naeem engaged in engineering.

Mission and purpose: "Turning swords into ploughshares"

The founding of SETC by Boston activist and retired MIT senior lecturer Mel King was built on the idea that technology can enhance life. King was originally approached by community members at a time when internet cafes were popular in gentrified White neighborhoods around the city, and he was asked to provide similar opportunities for communities of color living with low incomes. King negotiated with city developers and MIT to open his emeritus office within a housing development known as "Tent City," named after an uprising organized by King and others against the destruction of affordable housing in Boston's South End neighborhood. King has a history of activism in Boston, fighting on behalf of communities of color for just and fair housing, employment, and education policies (King, 1981). King's commitment to justice and activism is evident in SETC's inception and those principles are core to its mission, positioning youth as central to social transformation. SETC upholds unwavering commitments to amplify and nourish the intellectual, social, and cultural assets that youth of color bring to transforming the world through technology.

SETC was founded, in part, to challenge dominant ideologies about engineering and technology. King's time at MIT led him to critique techno-rational ideologies in engineering and science. In an interview with us, he said, "Anything that takes life is low tech. High tech enhances life. And so, you'll hear all these folks from engineering [and] science [talking about high tech weapons], and if you listen to what [the phrase from the bible] said, you'd beat your swords into ploughshares and your spears into pruning hooks." SETC was built with an ideological commitment to humanize engineering, a {r}evolution of engineering learning spaces, grounded in technology-mediated enhancements of the lives of youth and their communities. Similar to Grace Lee Boggs's work in Detroit, Michigan, designing and learning with technology is a form of activism that positions youth as change-makers (Boggs & Kurashige, 2012), equipped with assets to be "innovators and producers, to tell their stories, and to learn ways of creating just and humane communities" (Klimczak & Mayer, 2020). To achieve the purpose of expansive and liberatory interactions with technology, SETC became the first public installation of a Fab Lab (Gershenfeld, 2005), realizing the mission of providing community access to learning with technology. However, unlike dominant individualistic messages that pervade discussions of "making" (see Vossoughi et al., 2016), this making space is situated, historically and geographically, to support and sustain asset-based commitments to collective engineering learning that challenge dominant ideologies in engineering.

The Fab Lab is a context for youth "making liberation," and tinkering and expression are channels through which youth assets are realized, "using STEAM to provide opportunities for…youth to explore and express possibilities for change" (Klimczak et al., 2016, p. 62). In contrast to engineering spaces organized around "clients" and "solutions" (Moore et al., 2014), the Fab Lab was installed with a commitment to expression, grounded in constructionism (Papert & Harel, 1991), where engineering design practices and digital fabrication support youth-constructed narratives of social change. A long history of youth-developed projects (see Millner et al., 2020 for compelling examples) evidence asset-based commitments, where youth identify issues in their communities to address through design and engineering. SETC practices asset-based approaches through positioning youth as knowledgeable about their communities while also reorganizing relationships to technology—from "swords to ploughshares"—to engage in engineering directed at changing the world, where youth knowledge shines. These practices are illustrated in particular programs and structures constructed and populated by youth at SETC.

Embodiments: Asset-based programs that support engineering education at SETC

SETC's purpose and mission are embodied in how making and engineering are organized in the Fab Lab, but also through certain programs of the Center, namely the Learn 2 Teach, Teach 2 Learn (L2TT2L) program (Klimczak et al., 2016) and their community "drop-in" sessions. By embodiments, we mean programs designed to express and advance ideological commitments to community and to transforming relationships to technology for social change in different learning arrangements. The L2TT2L program was created to "amplify [youth] voices through technological processes in ways that give them political platforms and an audience when they otherwise would have neither" (Millner et al., 2020,

p. 153). Youth in the program are positioned as knowers, designers, teachers, and decision makers. The primary audience for the program is high-school youth, called *Youth Teachers*, who work in groups to engineer technology projects that address community needs.

We observed a group named WaterWorks who prototyped a water piano for kids to use in public parks to encourage explorations of music while being active (Tucker-Raymond et al., in press). Their design proposed a remedy for schools' funding cuts in the arts, encouraged youth to stay active, and reflected their belief in music being "good for the brain" (Fieldnotes, 7/12). The youth teachers worked together and taught each other about digital fabrication, coding microprocessors, soldering, troubleshooting, and iteration; L2TT2L positioned them as knowledgeable designers, capable of supporting themselves as they achieved their design goals. Teams included at least one returning participant who could offer support, and members of the community with specific expertise frequently visited SETC to offer support where needed, but youth drove the design and decision-making processes. The WaterWorks project exemplifies the expanded ideological commitments of this work: first, engineering is a *learning* activity, one directed toward supporting their community (enhancing life); second, teaching others what they know situates youth as experts responsible for sharing their knowledge with their communities; and finally, youth developed innovations not generally conceptualized within the dominant uses of engineering.

L2TT2L youth are participants in a cascading mentorship structure where participation includes finding ways to teach and mentor others; all youth have knowledge and expertise to share, and the mentoring relationships become channels for sharing knowledge through apprenticeship relations. Returning participants, some of whom are college students, are called *College Mentorz*, and they support first-time youth by working together to design learning experiences for younger children in summer STEAM camps offered around the city. In teaching, their assets are recognized and acknowledged by others in the community, building a belief in themselves as designers and engineers (Joo et al., 2015). The dual role of learner and teacher embodies the asset-based ideology that disrupts notions of who can know what and how decisions are made. Returning youth teachers organize the recruitment and hiring process for new participants, including attention to equity and representation, and they contribute to the decisions about the technologies used at SETC and the development of emerging technologies (Millner et al., 2020). Youth engage in engineering as a humanizing activity, directed at issues important to them and their community. They teach others, they showcase their work in a Project Expo, and their assets become recognized and acknowledged. The ideology at SETC reflects an asset-based commitment, which includes acknowledging the critical importance of building and sustaining relationships within one's community. Through this commitment to relationships, community membership is an asset that supports learning, teaching, and engineering new social futures.

The L2TT2L program is an embodiment of the mission and purpose of SETC, and now a nearly 15-year-old cornerstone of the Center's activities. The program makes possible other, year-long engagements such as community drop-in nights, called Fab Inventor Lounge, where people of all ages in the community visit SETC, and youth teachers serve as Fab Stewards. As Fab Stewards, youth are positioned as experts, sustaining their engagement through developing their own projects and supporting newcomers from their community interested in exploring different projects and technologies. Fab Stewards grow their own expertise, their own responsibility for teaching others, and their own commitments to the Center itself, embodying the mission of "creating community and {r}evolution" (Tucker-Raymond et al., in press).

Activities that disrupt dominant ideologies and recast engineering as transdisciplinary and for personal expression

Within the embodiments of the mission, there are numerous structures intentionally developed to recast participation and engagement in engineering activities. First, the very nature of engineering and technology design is conceptualized as transdisciplinary work:

> *As they were learning the different technologies, they should rap, do poems, [or] songs, about it so that the other children understood the significance of it. Because I'm a firm believer in those forms play a good role in getting people to think creatively…as part of this process to be about encouraging other youth. (Mel King, interview)*

Historically, engineering is perceived as technical (Trevelyan, 2010), and focused on "clients" as others (Moore et al., 2014). At SETC, engineering is largely perceived as an activity to grow one's own learning and relationships with others, and to see oneself as an engineer, programmer, or designer. Using rap, poetry, and even dance as part of SETC's daily "circle ups" disrupts narratives about how to engage with engineering and technology, and about who the work is serving. A transdisciplinary approach amplifies youth assets by supporting an expression of social relations and evolving relationships to technology and its possibilities for enhancing life (see also Allen-Handy et al., 2020).

Foregrounding expression as central to engineering activity is important. It shifts how representations are positioned in the space—both those that youth produce and share in these "circle ups" and their engagements with representations when teaching. Youth at SETC identified the challenges that many of the support websites and documentation around coding and

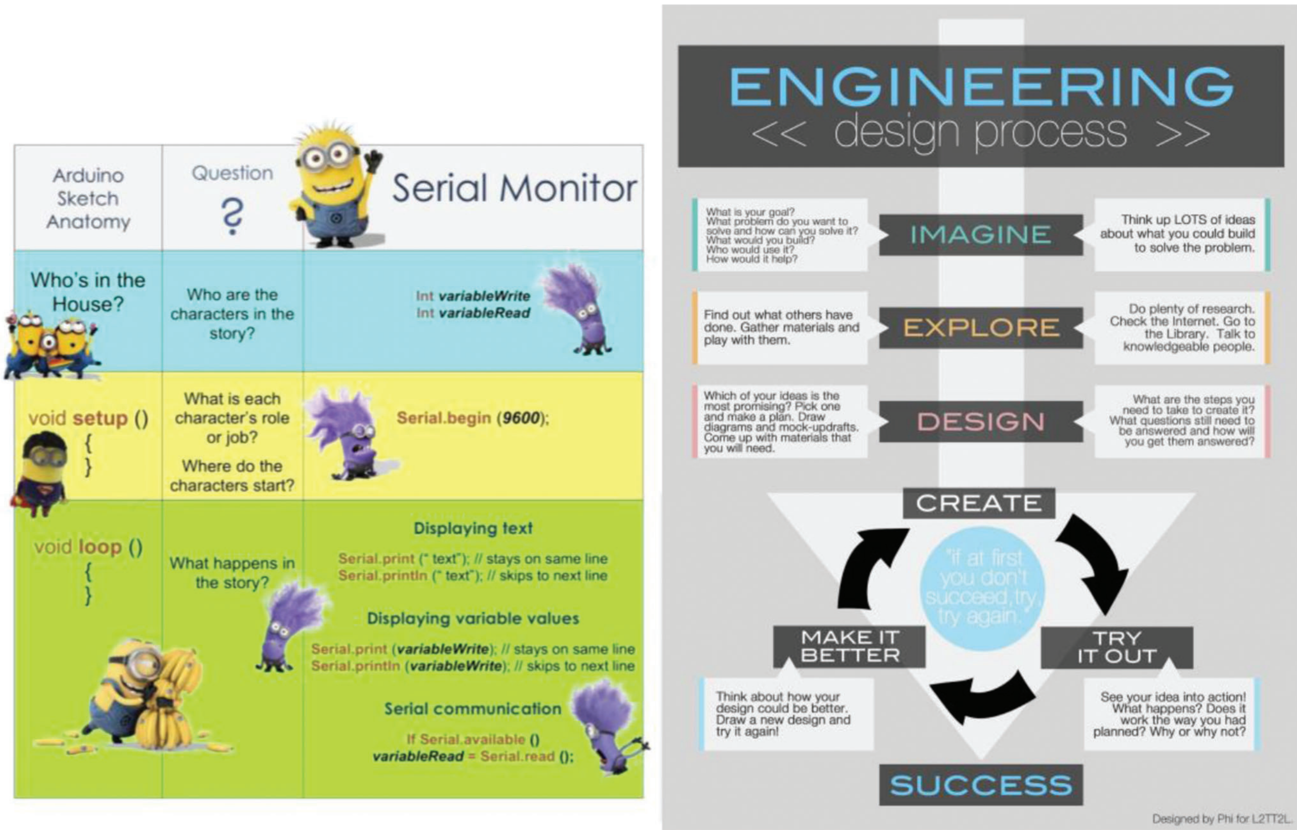

Figure 1. Youth-designed posters: to support Arduino programming using a metaphor of a story and "minions" (left); reimagined engineering design process based on their experiences (right).

physical programming pose, as they are laden with technical, specific, and unwelcoming vernaculars (Susan, interview). Many technology platforms, coding languages, and support materials remain spaces where dominant ideologies are expressed in representations and can serve to maintain exclusion. To counteract the effect of representations discouraging participation (Larson & Gatto, 2004), SETC youth developed entirely new pedagogies for engaging in engineering and coding based on their experiences and shared cultural references. For instance, they constructed a means for teaching Arduino coding using the idea of telling a story (i.e., Who are the characters in the story? Who is in the house?), and reimagined an engineering design process reflective of their experiences working on projects (Figure 1). These supports build on learners' assets as resources and support personal expression in the navigation and sensemaking of more conventional forms of representations (e.g., programming languages, CAD). They illustrate how expression transcends personal narratives to include new ways to support each other's learning in and with conventionalized representations.

While engineering with technology is a central target in the learning ecology of SETC, it is not the end. Learning at SETC is a complex entanglement of personal interests, teaching others, and enhancing life. In this way, is it centrally asset-based, organized around expression and disrupting dominant narratives so that youth author their own forms of participation in engineering activity. Through commitments to others and community, to a relational vision of learning, and to expression, engineering is recast as deeply humanizing. We support this finding further in the following section by demonstrating how Naeem developed a project focused on his message about Black Lives Matter, and how he used conventionalized representations in his evolving engineering learning.

Personal Expression and Navigating Engineering Representations: Naeem's Black Lives Matter Gear Project

We present a case of Naeem's working on a project at SETC in the spring and summer of 2016. Naeem began at SETC as a Youth Teacher two years prior, and continued his participation at SETC through the summer L2TT2L program as a College Mentor (i.e., a returning youth teacher supporting first-time participants), and during the fall and winter as a Fab Steward. Naeem's iterations on this project independently and in collaboration with a former SETC participant illustrate how, through learning arrangements supported by the asset-based approaches of SETC, he came to engage in complex engineering as he navigated and made sense of a dominant representational system (i.e., SOLIDWORKS). The design and

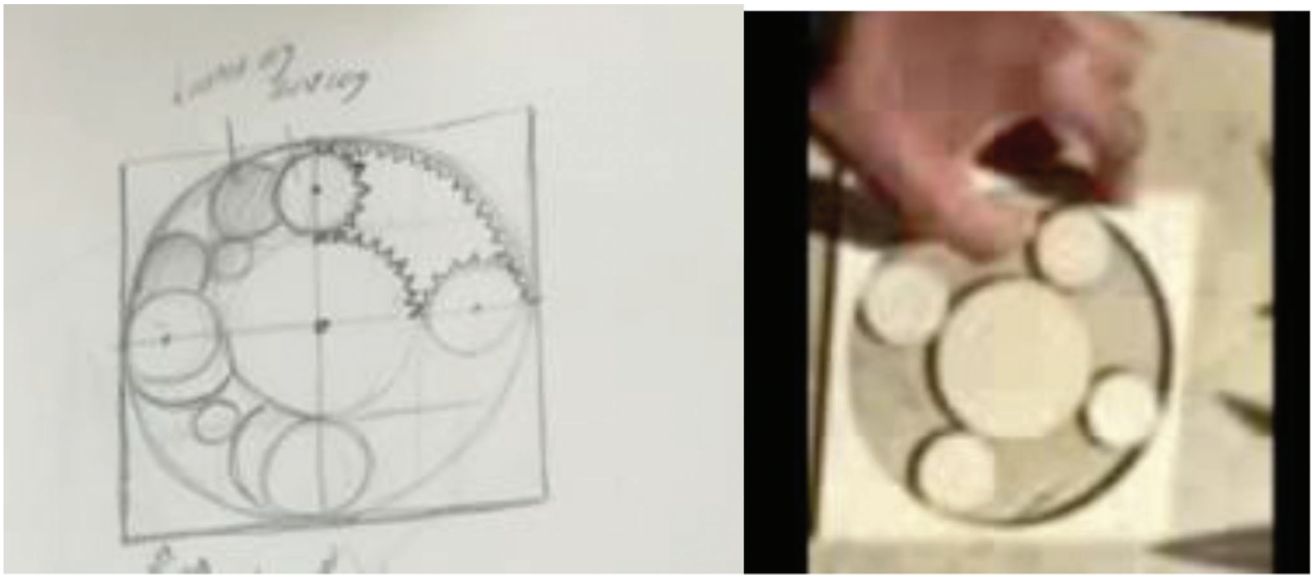

Figure 2. Naeem's drawing of what he imagined the Black Lives Matter gears project to look like (left), and an early prototype of a planetary gear system produced on a laser cutter using circles drawn in Inkscape (right).

fabrication of a planetary gear system to represent the importance of the Black Lives Matter movement is the context for engineering engagement within a different ideological landscape.

Engaging with complex design tools: When "eyeing it" is not enough

Naeem's Black Lives Matter project had roots in a high school art class, where his teacher asked students to explore the art of the Civil Rights Movement. However, much of his ongoing making was done of his own volition at SETC, where he often worked helping others use the space. The previous year, Naeem had also participated in *Beyond Black Lives Matter, Towards #makingliberation* at SETC[1], a participatory action research and education project at the intersection of STEM, Ferguson, hip-hop expression, and future possibilities (Klimczak et al., 2016). Naeem's vision for the project was included in the opening vignette of the paper:

> *Basically, I wanted to challenge the idea that all lives matter since Black lives mattered. And I wanted to show that all lives can't matter until Black lives matter or those that are feeling underrepresented matter.*

His design was driven by communicating a message to his community: all lives cannot matter until Black lives matter, until those "that are feeling underrepresented matter." He also sought to challenge himself by "doing something with gears," which he admitted he wanted to learn more about. His design consisted of a planetary gear mechanism operating as a "closed system," in which each smaller gear represents different ethnic/racial communities (Figure 2). If one of the gears were removed, the artifact would not work. This was intended to represent the interdependence of communities, and the importance of each in a just society. At the time of the first interview, Naeem was in the early stages of his project. Over the next five months, he worked through several iterations, identifying and resolving issues, and spawning new insights along the way.

Working from familiarity with Inkscape (a free vector-based graphics software that was frequently used at SETC), Naeem prototyped his planetary gear design using a gear rendering feature and a laser cutter (Figure 2). Inkscape was introduced to youth at SETC as a tool that enabled the quick creation of multiple prototypes. Comfort and expertise with digital fabrication from his sustained participation at SETC allowed him to produce quick prototypes from scrap pieces of cardboard, wood, and acrylic (Fieldnotes, 3/11). These prototypes offered a material beginning to realize his Black Lives Matter project, but they did not function as he hoped; gears would "pop out" as they spun, and did not rotate as "smooth" as he had hoped (Fieldnotes, 3/11). Naeem sought help in designing a better system that relied less on "eyeing it," as he said (i.e., the gear ratios), and more on "redoing the scaling to try and scale it the right way" (Fieldnotes, 3/11). Inkscape's

[1] Naeem presented this work on a panel at the Harvard Graduate School of Education, serving to further recognize and amplify his assets as a young man of color, an engineer, and an activist.

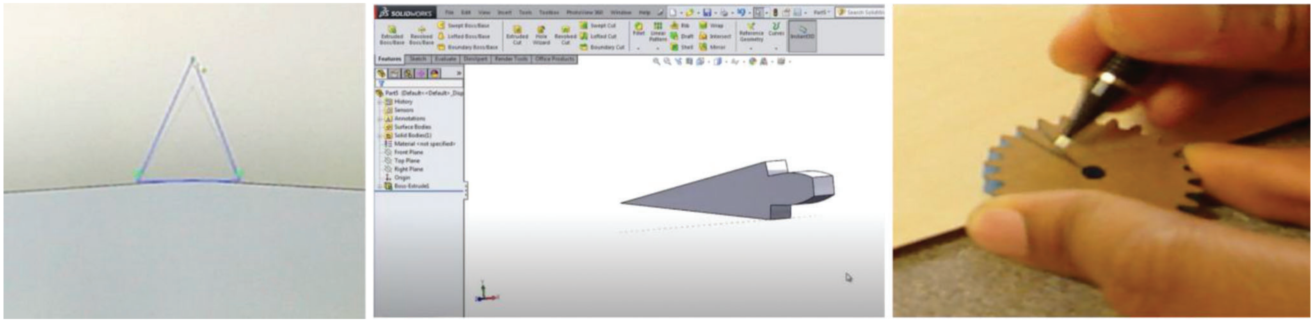

Figure 3. Naeem s initial design placing a triangle on the perimeter of a circle (left), the spline gear tooth design from a YouTube tutorial (center), and Naeem drawing the new approach to designing one spline on the prototype gear (right).

gear rendering feature provided a place to begin, but the problems he encountered with the prototype's performance led Naeem to begin refining his approach.

Help came through a relationship fostered at SETC with Derek, a former Youth Teacher. Naeem contacted him asking for support exploring SOLIDWORKS as a more precise tool for designing gear systems. Derek was studying engineering at a local college, but had spent time working on projects at SETC with Naeem in previous summers. A close description of Derek and Naeem's efforts to design gears in SOLIDWORKS reveals how Naeem encountered particular ideologies in this professional design tool, and how his long history at SETC, including relationships forged with peers like Derek, was an asset in engineering a gear system for his Black Lives Matter project.

Making sense of CAD representations with Derek

Naeem used Inkscape's gear rendering feature to produce gears by simply defining the number of teeth for each spur gear. That approach did not produce a system that functioned up to his standards, and Naeem wondered whether the professional engineering design tool SOLIDWORKS might be a better option. Derek used SOLIDWORKS in a prior engineering class. We observed them working on Naeem's project next to each other at separate computers.

Naeem began in SOLIDWORKS by drawing a circle with a triangle placed on the edge (Figure 3) before Derek called up a YouTube tutorial on drawing involute gears. Different from Naeem's drawing, the tutorial recommended producing gears by constructing a single gear tooth that extended from the center of the circle of the gear through the tooth itself, called a spline. Derek explained to Naeem:

Derek: Yeah, so pretty much what they did was they drew lines, so the two outer lines are how wide they want the gears to be, and the two inner lines are where they want the gear to start, and the middle one is where they want it to end. So by doing that, they were able to, able to just make one gear, and then they just re-do the circulate…pattern it // circular pattern it to make the gears, so…do you think that would be easier?
Naeem: It makes more sense.
Derek: Yeah. Alright.
Naeem: Technically, it's the same thing.

After viewing the tutorial, and hearing Derek describe it, Naeem said, "Technically, it's the same thing," suggesting he saw a similarity between this rotated spline approach and his initial attempt to place triangles on the periphery of a circle. While these approaches might not appear to the reader as "the same thing," the tutorial offered a template for thinking differently about gear design, shifting from defining the number of teeth on a gear, as he had done in Inkscape, to thinking about designing gear teeth relative to the geometries of the spur gear typology. To design one tooth, Naeem explained to the researcher, "we're going to try making this section right here." As he spoke, he traced out a spline on an acrylic gear he had on the table in front of him (Figure 3). This new approach led to two crucial observations for Naeem: (1) his attention was drawn to the shape of the gear tooth itself, not as triangular, but as something more trapezoidal, or "quad" as he called it, and (2) he needed to account for the spacing between each of the gear teeth. The drawing he produced on the prototyped gear (Figure 3) highlighted not only the tooth, but the "gap" to the right of that tooth.

Derek pulled up another image (Figure 4) of an "involute gear profile" and described that this is the "theory behind it" (i.e., the SOLIDWORKS method they are exploring). Naeem responded, "Oh my goodness!" and the two examined the dimensions labeled with conventionalized abbreviations in the image (Figure 4). This moment was followed by a long pause in their conversation, and Naeem offered the following reflection:

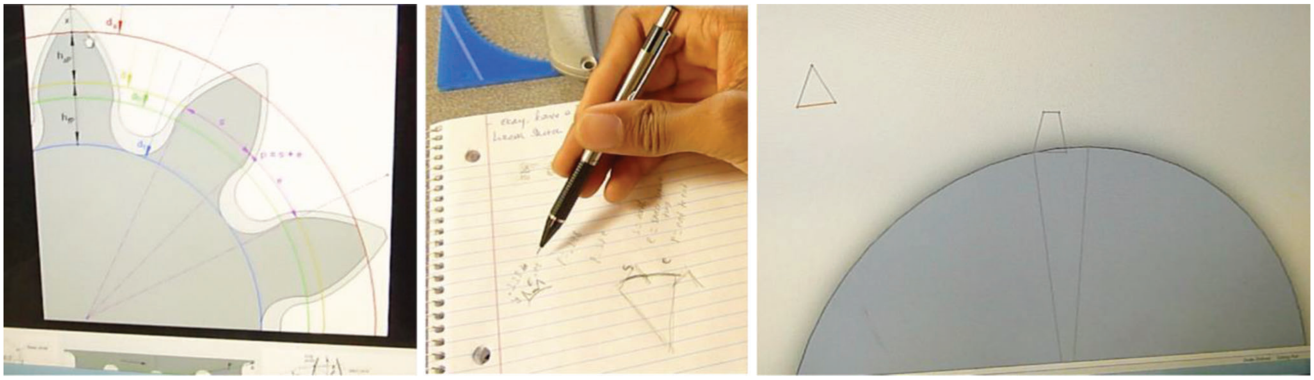

Figure 4. The image listing parameters of involute gear design that Derek shared (left), Naeem describes dimensions S, E, and P—the triangle at the bottom of the image—in his model (middle), and one tooth spline in SOLIDWORKS, which was eventually rotated circularly to create a complete spur gear (right).

> *It's like, when did we learn any of this? My teacher went through it, it all made sense, they just worded it differently. But it's my initial reading at first, I'm just like, we never did any of this. Conceptually I get everything that's going on. Like calc, it's my favorite class, but I just hate that I'm helping everyone and tired all the time.*

Between the tutorial that Derek originally shared and the image listing the parameters of involute gear design (for which at least 16 different dimensions are named; Oladejo & Ogunsade, 2014), Naeem encountered specific and conventionalized terminology in the representations of gear design. Thus far, the representations Naeem encountered in SOLIDWORKS provided few accessible entry points for how to construct gears. He related this experience to calculus in school, where we interpret his comment to suggest he was often presented with information that he was expected to know but had not been taught. He lamented how those efforts to decipher and to teach others felt laborious and exhausting. The SOLIDWORKS tutorials offered him little to connect with, reminding him of the struggles navigating calculus class. Yet, together with Derek, Naeem began interpreting the image to invent their own path forward in designing the gear system.

Using a pair of calipers, Derek read aloud measurements of the width of the tooth (labeled "S" in the internet image and in Naeem's drawing), the width between gears (labeled "E"), and the distance "P" from "end to end," covering the width of both the tooth and the space between teeth. Naeem clarified what he was doing:

> *Going by the formula, he found, for one piece, we have variable S, variable E, and variable P, which is this whole vector, P is this triangle right here [see Figure 4]. And to find this distance right here, it's the length of one tooth and the space between two teeth.*

We understand their work as reformulating a technique for drawing one gear tooth spline, where they constructed a template for designing the splines with the gear tooth on one edge and the gap between teeth on the other (Figure 4). Naeem suggested this could be one tooth, and he began calculating the relative length, P, if he wanted 50 teeth on one spur gear, exploring a ratio of 50:360 to determine the portion of the circle's circumference that each spline occupied. He followed along this path, eventually rotating the spline around in a complete circle in SOLIDWORKS, but not quite getting to fabrication before the end of this particular work session.

Deepened understanding of gear dynamics

Following the SOLIDWORKS session with Derek, Naeem continued work on his Black Lives Matter project before a final interview of the summer. Naeem faced a challenge with his first prototype where the gears were not turning smoothly and they would "pop out" when he attempted to spin them. He wanted to design gears with "less teeth" as a means of addressing this issue with the gear's function:

> *Ok, so the main issue is that the gears fit too tightly. Um, the less teeth that's just for me cause I was counting all the teeth and everything by the amount of teeth that there is. Um, but I believe it's angle pressure, I forgot what the term is, but um, it's like if we have gears um, they have to fall in a certain amount or else they get locked in [uses fingers to gesture interlocking] so like you want your gears to be smooth like that [pulls fingers apart to show space between them], and, I believe if, angle pressure, whatever the term is, if it's too high, then like you basically have like rectangles, and like [gestures getting stuck again].*

Figure 5. Naeem's drawings of gear intersections where the teeth are "too tight" compared to more spread out, with the illustration of the "angle pressure" at the top (left), and his gestures showing how the teeth interlock to run smoothly, with teeth not "reaching all the way in" (center, right).

To address the problem of gears fitting "too tightly," Naeem described a plan to space the teeth apart so that each tooth would "fall in a certain amount." The space between teeth had become an important part of his thinking about how gears function. In focusing on the space between teeth, Naeem also focused his attention on the shape of the teeth themselves. As he described, an "angle pressure" that is "too high" means the teeth are basically "rectangles," and that would also contribute to the gears not spinning smoothly. He specifically mapped this work back to the session with Derek, "Umm, when Derek was showing me how to make gears with umm, SOLIDWORKS, that [angle pressure] was one of the things they were all mentioning, like, one of the measurements." There is evidence in his reflections of a deepened understanding of not only the terminology and representations, but the dynamics of how gears function. Furthermore, Naeem connected this new understanding back to his work with Derek, which suggests he viewed their relationship, forged through collaborating at SETC, as an asset in his engineering.

As Naeem spoke, he drew different examples of triangular gear shapes fitting too tightly, the newer conceptualization with larger spaces between the gears, and a drawing of a single tooth to demonstrate the involute shape (Figure 5). The drawing of the tooth was in response to the interviewer, Aditi, asking what he meant by "angle pressure":

> *Yeah, so [begins drawing] basically, there's like the two diagonal parts there [highlights the top curved sections of the gear tooth] and then the flat part 'cause you don't want it to reach all the way in [to the base of the space between teeth], and that's where the flat part comes in. But you still want, like, these two diagonal parts to, like, turn.*

Naeem described how the shape of the intersecting edges of the gear teeth supports the smooth rotation of a gear system, offering this as an explanation of the "angle pressure," or the angle of obliquity, which predicts the smoothness of gear operations.

Over the course of Naeem's work on his Black Lives Matter project, there were shifts in how he engaged with representational systems, and how that engagement supported his engineering learning. He began using a design tool with which he had ample prior experience, Inkscape, to tinker with possible designs. Rapid iterations were common at SETC and encouraged as part of how groups could learn in the processes of design and revision. As he encountered issues with his design, he moved to SOLIDWORKS, where he tangled with, and made sense of, complex and technical representations of gear designs. His efforts to make sense of these new representations, situated within a project he cared deeply about, led him to construct a strong understanding of the particular aspects of gear dynamics and how they contribute to the smooth function he desired for his project. Naeem's assets for learning and doing surfaced in these examples, amplified by the organizational structures at SETC, suggesting implications for conceptualizing engineering education through the production of spaces that challenge dominant, deficit ideologies. In sum, features of SETC, and Naeem's history as a member of that space, supported his engagements with representations in ways that amplified his assets for engineering learning.

Discussion

In this paper, we argue that asset-based approaches to engineering education come through the construction of learning spaces that challenge, disrupt, and shift the dominant ideologies inherent in the practices and representations of engineering. We presented evidence of SETC's explicit efforts to build an asset-based learning space, focused on supporting youth of color in designing and engineering for the betterment of their worlds. The space is grounded in people's freedom struggles, evidenced in Mel King's personal history and efforts to start SETC. The space is organized with political aims, towards shifting relationships to technologies as tools for enhancing life, and belief in youth as learners, teachers, and leaders, amplifying their voices in the community. SETC maintains strong commitments to community through cascading mentorship structures—where multigenerational relationships are forged and nourished—and to sustaining participation; SETC is a different kind of engineering learning space. This asset-based ideology—the constellation of values and practices—supported deep engagement in engineering learning for Naeem. We have discussed the particular ways that the learning space and larger sociocultural context supported Naeem's learning with conventionalized representations, and more broadly, how the space works to expand forms of engineering learning and engagement.

Engineering learning is mediated by ideologies, beliefs about learning, and encoded in the representations (Johri et al., 2013), spaces (Norris 2014), and social practices of learning environments (Tucker-Raymond & Gravel, 2019). STEM fields, including engineering, have been organized with particular ideologies that sustain White supremacy and disciplined epistemologies (Agarwal & Sengupta-Irving, 2019; Bang et al., 2012). For instance, schools of engineering, largely staffed by White males, continue to "weed out" students of color and women at much higher rates than White male peers (Bonous-Harnmarth, 2000; Maltese & Tai, 2011), where unwelcoming environments, racism, and sexism are often cited as reasons why students of color and women leave engineering (Geisinger & Raman, 2013). Dominant ideologies normalize these problematic, deficit-oriented approaches that fail to acknowledge and build from the assets that minoritized learners bring to engineering. The case of Naeem engineering the Black Lives Matter project, situated within SETC, complicates deficit ideologies and the familiar narrative of engineering as inaccessible and exclusionary. As we saw at SETC, ideologies form what is valued, what is lifted up, and what is diminished. Ideologies structure possibilities for learning, such as whether or not learning spaces take asset-based approaches for understanding, honoring, and building on learners' resources, or deficit-based approaches that fail to acknowledge assets that all learners bring to engineering work. The ideological commitments of spaces are vital for equitable engineering learning.

Shifting Ideologies to Support Engineering Learning with Conventional Representations

SETC shifts dominant ideologies toward asset-based approaches in specific ways, including centering personal interests and racialized identities, and building community through sustaining relationships within the learning space. Naeem's project reflected two personal interests: making something with gears and expressing his perspective on Black Lives Matter (Tucker-Raymond et al., 2018). As a sustaining member of a learning space that emphasized design and engineering as means of advancing social commitments, learning new tools and ideas was part of Naeem's practice. His expertise in digital fabrication and tinkering, and SETC's trust in youth capabilities as learners and teachers, positioned him to engage in a project that was an opportunity to further his learning while doing something personally and socio-politically meaningful. Designing with technology at SETC also meant imagining new futures and sharing that knowledge with the community. The summer program laid this foundation; youth concurrently occupy roles as activists, learners, and teachers, which explicitly disrupts dominant ideologies about the purposes of engineering work and who can know about and do engineering. Naeem's project was imbued with Mel King's message that technology can enhance life. In learning about gears, he was also producing art to teach the world about the importance of Black lives. Working in SETC, as part of this space and community, positioned Naeem's experiences and history as assets for engineering learning.

Naeem is a valued member of the space, having participated in multiple roles over many of his teenage years. Through this sustained engagement—as a youth teacher, Fab Steward, and mentor—he explored historicized narratives of technology and engineering and the underrepresentation of people of color in these fields. Art production—rap, dance, rhythmic poetry—provided a transdisciplinary space to explore and express his relationships to technology and society. Naeem's funds of knowledge, rooted in his history as a young African American man, were assets in his developing engineering practice (Mejia & Wilson-Lopez, 2015). As a member of SETC, he was supported in multiple ways to express his thinking about Black Lives Matter through a making project. However, more than a compelling example of exploring personal interests and racialized identities, the project reflected a commitment to social transformations with and through technology. Youth, whose inter-relations produce and maintain the learning space at SETC (Massey, 2005) interact with dominant, ideological representations within a disruptive, desettling ideology that positions their relationships as assets for engineering engagement. Naeem's sustained engagement at SETC fostered relationships that were assets for navigating the challenges he encountered. Derek, a friend and co-learner, was essential to furthering his project with SOLIDWORKS, where the ideologies of SETC enabled Naeem to transform how he used the conventionalized representational system in his project.

Naeem's exploration of SOLIDWORKS illustrates how he navigated ideological representations embedded in the software and in images of involute gear design. The terminology and notations of the tutorial reminded Naeem of his calculus experiences in school, where representations were often opaque and distancing. Yet, putting the frustration aside, Naeem charged ahead finding ways to build from the conventionalized forms. The tutorial Derek shared offered a template, or model, for how to rethink gear design—i.e., building individual splines rotated 360 degrees—and Naeem transformed the dominant form into a suggestion for a process to advance his design. As the case illustrates, this transformed process contributed to Naeem's deepening engagement and sensemaking around gear dynamics and terminologies. Considering the learning ecology of SETC, Naeem was encouraged to work on projects that were important to him, projects that expressed his thinking about justice and social transformations through technology. The space re-mediated his experiences with engineering (Gutiérrez, 2008), shifting the ways he engaged with projects, tools, and representations. His history exploring ideas with sketches, materials, and tinkering at SETC helped him to see the gear tutorial as a guide from which to build a new design process. And, his relationship with Derek meant he was supported socially to transform the conventionalized forms for his practice and purpose. SETC fostered expanded ideologies in sustaining an ecology that re-mediated "the way tools and forms of assistance function to incite and facilitate learning" (Gutiérrez et al., 2009, p. 1). Thus, the focus on social relationships, justice, and lifting up youth of color through personally meaningful engineering projects created conditions for Naeem to engage with the conventionalized representations that were previously inaccessible and distancing. The shifted ideologies of SETC are a component of what supported Naeem's learning, alongside expansive forms of engineering learning and engagement.

Expansive Visions of Engineering Learning and Engagement

Naeem's multiple roles—as a Lab Steward, Youth Teacher, and College Mentor—and history at SETC fostered deep comfort and familiarity with digital fabrication and making. Making foregrounds materiality and multimodal expressions (Tucker-Raymond & Gravel, 2019), repositioning tinkering as a form of sensemaking and learning within more complex design landscapes. While the promise of making has been accepted by some (Martin, 2015), the integration of making and engineering remains nascent, or even outright rejected (e.g., Resnick & Rosenbaum, 2013). Making, tinkering, and engineering are interrelated activities at SETC, organized under the moniker of "projects" (Fieldnotes, 7/12). Closer examination reveals Naeem's Black Lives Matter project had many of the hallmark features captured in engineering frameworks: driven by a problem/phenomenon, organized by constraints of materials and design, substantive mathematics and science principles undergirding function, and iterative testing and revision that balanced trade-offs. Naeem's work embodies the epistemic and professional practices outlined for engineering (Cunningham & Kelly, 1997; Stevens et al., 2014).

However, there is a significant distinction worth noting, which is the ways the "clients" and "problems," inherent in dominant engineering education ideologies, are understood in his project. For Naeem, we can imagine *he* is a client—an African American male living and facing the problem of police brutality and anti-Black racism. The problem in this sense is societal and structural. It goes well beyond technical challenges, albeit encompassing access to technology as evidenced by the story of how King started SETC. Art production has long served to draw attention to social movements and transformations (Gaskins, 2019). Naeem's Black Lives Matter project is a "message the world needs to hear," he said, and the project is a profound example of engineering design. Naeem's identity as an African American male and his experience at SETC were assets. SETC organizes engineering learning to shift notions of "client" and "problem," so that the assets that youth of color bring to the space are resources for learning.

We argued that learning spaces are ideological, and engineering education has had a historically technocratic and deficit-oriented ideology (Holly, 2020). We are encouraged by increased attention to asset-based approaches, while also hopeful that our work focuses attention on representations in designing for more equitable engineering participation. Conventionalized representations remain organized by disciplinary practice, which reflects dominant ideologies (Gramsci, 1997). Conventions are established, in part, because of their utility; in the case of SOLIDWORKS, the features and abbreviations are useful in digital design practices. Thus, embedded in these tools are histories of representations and their uses, which offer access to disciplinary practices in engineering. However, these same representations express the ideologies that have long excluded many from participation in engineering. Transformative asset-based approaches require attention to how learning spaces and expansive visions of engineering offer pathways for the re-mediation of learners' experiences with tools that can be both useful but also exclusionary. We do not deny the utility of systems like SOLIDWORKS for engineering design, but instead argue we must consider the ways in which these systems are encountered and positioned. Within the kinds of shifted ideologies of SETC, Naeem's introduction to SOLIDWORKS was situated within a larger project and goal. Thus, rather than learning CAD because it was a tool of engineering, he was able to direct it toward a project he cared about, and that provided the context to support his engineering learning.

Naeem's work was situated within a constellation of his sustained engagement at SETC, the personalized goals for expressing an idea, and layered forms of support that recast his encounters with the conventionalized representations. The materials on the table in front of him—prototyped gears, produced using tools and materials familiar to him from his time at SETC—shortened the distance between object and representation. Naeem's expertise with making and tinkering was an asset in his entanglement with the engineering representations he encountered. Materiality complicates notions of how representations are used in abstracted forms of design (Johri et al., 2013), and in this case, it supported Naeem developing understanding of the relationships between tooth shape and function, explained using "pressure angles." As he made different iterations of his project, drew annotations on prototyped gears, and was able to play with his thinking in different forms—all practices nurtured through his time at SETC—he was able to navigate, make sense of, and use conventionalized engineering representations to complete his project and to engage in engineering learning.

Implications and Future Directions

The findings presented in this paper suggest certain implications and future directions for the design and research of learning spaces that make asset-based approaches to engineering education a reality for youth of color. For Naeem, engineering was more than manipulating gear mechanisms; rather, his work was situated, nourished, and valued within an asset-based engineering and making ideology. We offer implications as well as visions of how to continue advancing and realizing the work of asset-based engineering education.

SETC is organized around the mission and purpose of shifting relationships to technology, of enhancing intergenerational learning, and of positioning youth as knowledgeable teachers and activists. This mission reflects an asset-based ideology that surfaces the inherent politics in engineering and design and what that can mean for youth of color. Embodiments of that mission and the activities intended to disrupt dominant ideologies suggest particular considerations for designing asset-based learning spaces. SETC's foundation in justice, equity, and social transformation is rooted in Mel King's vision for SETC as a site of political and ethical grounding. Future designs for asset-based engineering spaces would benefit from attention to the consequential political and ethical dimensions of both the ideological commitments and how engineering engagement is imagined. Many designs lead with discipline-specific objectives and goals of inclusion, which are often assimilatory (Warren et al., 2020). These approaches lack foundational commitments to equity, justice, and dignity as grounding principles, achieved through taking critical perspectives that make visible dominant ideologies and the exclusionary nature they purport. Establishing commitments that consider systemic forms of oppression, racism, and exclusion in the design of both spaces and the embodiments (e.g., programs, outreach efforts, policies) shows promise for building truly asset-based engineering education.

Commitments to equity and justice are coupled with taking expansive views of how we understand engineering practice. A narrow conception of engineering serves to reify historical and existing exclusionary ideologies (Holly, 2020; Pawley, 2017; Secules, 2019). Recognized forms of engineering work in engineering education classes must be expanded to embrace a flourishing heterogeneity. Reimagining what "counts" as engineering practice includes reframing who the clients are, the forms of problems—technical, material, and social—that are centered, leveraging interdisciplinary mutually informing practices, and legitimizing making and tinkering activities for learning in engineering. Naeem's project is one of imagination, possibility, and vision, where he was thinking with gears (Papert, 1980) as more than simply mechanisms. His personal interests and relationships, political commitments, and goals of social transformation propelled his engineering learning. Other examples of this expansive view include exploring relationships between Hip Hop, Afrofuturism, and STEM design and making work (Champion at el., 2020; Holbert et al., 2020b). Our hope is that this expansive sense of what engineering can be, and the role it can serve in addressing both technical as well as social challenges in society, is embraced by the engineering education community so that we can work toward more equitable, just, and asset-based opportunities for youth.

Finally, our challenge to the engineering education community opens opportunities for further research and theorization of disciplinary literacies in engineering. Representations express and preserve existing ideologies unless they are intentionally examined and problematized. Our research is grounded in a literacies perspective that explores the social practices of using and producing representations for particular purposes (Tucker-Raymond & Gravel, 2019). Ideological commitments are entangled with descriptions of how people learn with representations in social contexts. Naeem's work in SOLIDWORKS is situated in an asset-based context—SETC—where relationships to community, justice, and technology are core to the mission and embodiments. His reasons for exploring this professionally-accepted tool were born out of expressing his message for social transformation. Within a community of engineers and makers working together with tools, materials, and representations to achieve their goals, SETC fostered Naeem's engineering practice and purpose. Thus, the example of how Naeem came to engage with SOLIDWORKS, alongside Derek, in service of designing technology projects to enhance life, points to the importance of relational literacies (Burnett & Merchant, 2018). We argue future research and theorization is required to understand how engineering learners engage representations from this relational perspective, where knowledge and practice are constituted and shaped by shared, collective activity. Perhaps engineering education could deepen the exploration of collective efforts and shared practices of sensemaking to understand how assets are nurtured and amplified in educational contexts.

Finally, Naeem's work *is* engineering. It includes making and tinkering, often excluded from conversations about what is considered engineering disciplinary practice, which is an example of how ideologies drive assessments of legitimacy. This image of engineering includes a focus on social injustices as problems that can be addressed through designing public art. It includes Naeem as a client, engineering *for* himself and for his interest in expressing his perspective: "that all lives can't matter until Black Lives Matter." Situated within spaces committed to asset-based ideologies for engineering education, youth can and will engage in engineering practices that center themselves and their relationships to complex social contexts as resources for learning. We center Naeem's story, and his brilliance in engineering, because African Americans and other minoritized groups are often blamed for their own underrepresentation in STEM, just as they are often blamed for being killed by police. Blaming Black people for the consequences of racism perpetrated by a system based on Whiteness is endemic to the United States. It is long past time that symbolic, economic, educational, and physical anti-Black violence be addressed. However, more than just a response to harm, asset-based pedagogies honor the brilliance, beauty, and joy of learners and learning. We hope this work offers an example of that honoring.

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