Reframing the Problem and Reworking the Design: Learning from Youth Engineering Design Experiences

by:

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DEDICATION

I dedicate this dissertation to the brilliant focal youth I worked with – I am so grateful to have gotten to know and learn from each of you. This is for you. You deserve the world!

And to my family – Nick, Mama Llama, Dada, Oskee, Babu, and Lumi – for helping me go one day at a time, one minute at a time, and one foot in front of the other in this process. Thank you! I love you all!

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TABLE OF CONTENTS

DEDICATION	ii
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF APPENDICES	x
ABSTRACT	xi
CHAPTER 1 Introduction	1
CHAPTER 2 Literature and Conceptual Framing	11
CHAPTER 3 Research Methods and Design	51
CHAPTER 4 Meeting Focal Youth Through Their (Engineering) Stories	75
CHAPTER 5 Exploring Focal Youths' Engineering Design Practice in *Sensors*	126
CHAPTER 6 Stability and Shifts in Focal Youths' Engineering Discussions	177
CHAPTER 7 Implications and Conclusions	227
APPENDICES	250
REFERENCES	257

LIST OF TABLES

Table 2-1 Comparing critical STS theories of design 48

Table 3-1 Outlining *Sensors*' projects and processes over time 58

Table 3-2 Outline of *Sensors*' programming contexts 60

Table 3-3 Participant demographics 60

Table 3-4 Data collected per focal youth 61

Table 3-5 Sample engagement codes 66

Table 3-6 Sample engineering “best” practice codes 67

Table 3-7 Example coding process 68

Table 3-8 Example small story narrative codes 68

Table 5-1 Sample problem spaces raised by youth 159

Table 6-1 Comparing Rodrigo’s discussions of different engineering practices 186

LIST OF FIGURES

Figure 3-1. A proposed theory of action for the larger *Sensors in a Shoebox* DBR project 55

Figure 3-2. Overviewing *Sensors* iterations and design process 57

Figure 3-3. Key linkage chart 74

Figure 4-1. Elizabeth's logos for the future business. 78

Figure 4-2. Adina's self-researched recommendations 96

Figure 4-3. Sample of Mariabella's field notes 104

Figure 4-4. Rodrigo's data-driven sketches for benches with questions for the team 111

Figure 4-5. Red's early data analysis 122

Figure 5-1. First section of key linkage chart 127

Figure 5-2. Cesar and Red's working paper for exploring a potential problem space 142

Figure 5-3. The front and back of the focal youths' survey 144

Figure 5-4. Focal youths' final design poster 147

Figure 5-5. Examples of the ideated problem spaces (a), data collection ideas (b) and findings (c) that emanated from Ava and Mariabella's questioning 164

Figure 5-6. Images of Cassidy and Elizabeth's planning for prototyping 173

Figure 6-1. Second section of key linkage chart 178

LIST OF APPENDICES

Appendix A Sample Stimulated Recall Interview 251

Appendix B Sample Focus Group Interview 253

Appendix C Sample Walking Interview 255

ABSTRACT

The purpose of this study was to examine how to develop meaningful engineering experiences for youth that might counter decontextualized, building-centered, and often exclusionary approaches. I argue that engineering design with young people could be a very youth-centered space, addressing the concerns of young people through engineering design practice. However, youth are often not invited into real-world, flexible, front-end engineering design work. By inviting youth into these often-obscured practices, we might better imagine engineering design spaces that are meaningful to youth and cognizant of the ways the engineering field historically and currently excludes so many. This dissertation study explores the experiences and discussions of youth engaging in defining, exploring, and ideating design directions that matter to them. Drawing on critical sociocultural learning theories and critical science and technology studies (STS) of design, I examined seven focal youths' engagement in and discussion of the particular ways engineering design practices were adapted in the context of a community engagement program, entitled *Sensors in a Shoebox* (henceforth, *Sensors*). This qualitative study was informed by design-based research methods that center participants' experience as crucial data for informing design. Across three years of interview, observation, and video data, I asked:

1. In what ways do youth engage in the design practices of the *Sensors* program?
2. How do youth talk about their engineering design experiences?

I analyzed the data using constant comparative analysis, moving between the specific data and major assertions. Seeking to contribute to the design of meaningful engineering experiences, I

sought to learn from youth about who they are, their experiences, and center them as stakeholders in their learning.

From my analysis of the data, I assert that design work in *Sensors* created opportunities for youth to engage in increasingly recognizable design practice and move design toward more liberatory directions. Focal youth drew upon their experiences and personal knowledges as important assets to engaging in skilled design work. In this, youth also engaged in moments of liberatory design possibility that moved design toward more just directions. Together, each youth saw moments of their design work as personally meaningful and imagined new meanings for design in their lives. As youth reflected on their experiences in the *Sensors* program, they discussed distinctions between the front-end design work and building-focused or technocentric activities. They shared these practices were meaningful to them in different ways. These discussions also revealed how youth experienced other engineering design spaces as heavily math and science-dependent and potentially raced, gendered, or classed.

Taking youths' engagement and discussions together, the findings imply a need to center youth as critical stakeholders in their engineering education. This reframe requires an expansion of "what counts" as engineering design work with youth. Creating opportunities for youth to engage in flexible, people-focused design work invited youths' experiences, interests, and voices more explicitly into design practice and supported informed, liberatory participation in the designed world. For developing meaningful engineering learning environments, engaging youth in problem framing and exploration may create opportunities to build critical skills and see design work and the designed world as personally meaningful.

CHAPTER 1 Introduction

Motivated by desires to diversify science, technology, engineering, and mathematics (STEM) fields and grow the skilled engineering workforce, calls to engage youth in more and earlier engineering work increased efforts to engage all young people in engineering have notably increased (Educate to Innovate, n.d.; National Science Foundation, 2017). Often framed around growing the engineering pipeline or addressing pipeline leaks, these efforts focus on skill or experience deficits preventing historically marginalized youth from pursuing engineering (Maltese & Tai, 2011). Ultimately, the goal of these efforts is to attract more youth to the field of engineering. From pipeline perspectives, opportunities youth have to engage in engineering may reflect the interests and goals of those already in the field or the ways those in the field experienced engineering. Although attempting to broaden participation and diversify the field, efforts to engage youth from these perspectives often represent narrowed versions of engineering work, such as prescribed building challenges. They also risk reproducing exclusion by not critically examining engineering. Because the lack of diversity within the field remains, I argue that there is an urgent need to reframe and rework the ways we design engineering experiences for youth. One way this might be achieved is by decentering the engineering fields' assertions of what youth need to know and be able to do to be future engineers, and instead focus on *learning from* youth as participants in the designed world. Moving from a youth-centered perspective requires exploring new ways to invite, celebrate, and honor the diversity of youths' experiences, interests, and identities in engineering contexts. Through my dissertation work, I seek to contribute to this goal by learning from youth about their engagement in an engineering design experience. Specifically, in the qualitative study that I report on here, I analyzed youths' engagement in and discussion of flexible, real-world design work[1] driven from their interests within the context of a community research and engagement program developed by myself and colleagues. Focusing on community action through research and design, this program used engineering design tools and concepts to address youth-identified community problems and engaged youth in defining, exploring, and ideating a problem. The research questions guiding my study are:

1. In what ways do youth engage in the design practices of the program?
2. How do youth talk about their engineering design experiences?

In the following section, I provide a brief narrative to ground my questions in personal experience before framing the core problem of my study.

A Brief Prelude: The Story of My Questions

out·reach: (1) the act of reaching out; (2) the extent or limit of reach; (3) the extending of services or assistance beyond current or usual limits

Late in 2014, I sat in the back seat of a gold Honda Accord, crammed in next to another biosciences graduate student. I was holding a giant jug of Elmer's glue on my lap and trying not to jostle the open box of Borax next to me. We were heading to afterschool science in a nearby neighborhood. Driving us was the head research scientist who managed a core lab at our institution. His job, among other things, was to help scientists characterize the various materials engineered within the hallowed laboratory halls. He also liked to engage in community outreach in his spare time. His division had just received an extensive National Science Foundation (NSF)

[1] There are distinctions between engineering, engineering design, and design. This study focuses on youths' engagement in the front-end design practices of a specific context to inform inviting youths' experiences into engineering or engineering design spaces. In Chapter 2, I clarify the overlap and distinctions drawn between engineering, engineering design, and design. In Chapter 3, I discuss the program in depth.

Grant to support all these projects. Included within the grant's *Broader Impacts* provision was a plan for community outreach.

As we drove, the research scientist chatted about the club. "It's an invite-only science club," he said, "so the kids are really good. It's this teacher's reward for the best students in her class." I remember thinking "good" was an odd choice of words, but not uncommon. "What are we doing today with the kids?" the graduate student next to me asked. "Slime," the research scientist replied, pulling off the highway. "What's the purpose of slime," I asked, "To talk about polymer engineering?" "Yeah, and the kids love slime," the researcher replied. I asked where the students were in their understanding of materials engineering and for chalk to do some drawings during my lecture. "I'm not sure," the research scientist said, "I wouldn't worry about it too much. The main thing I think about with these clubs is to expose these kids to STEM, to make it fun. They often don't like science class and don't have much opportunity to do engineering. We can leave them with fun memories of slime."

I include this experience to represent the sentiment that is often behind research-directed, agency-funded outreach, or "the current or usual limits." This sentiment can, and often does, originate from a good place. There might be a want to help, a concern about the diversity within science, technology, engineering, or math fields, or a desire to connect to the community. Enjoyment, engagement, and interest are also important considerations for designing STEM-related learning experiences. However, issues arise as I reflect more deeply on what common statements like the one above mean: *these* (read: low-SES, Black) kids do not have science or engineering, and we (read: high-SES, often white) researchers can bring them valuable experiences. In the example above, our outreach team was white and operating out of a wealthy institution with a problematic relationship to the surrounding neighborhoods, "preparing" an experience for Black youth attending a Public School. Thus, *we* needed to take engineering to *them* and dress it up in appealing, bite-sized ways. Further, these were the "good" kids (read: high achieving in science class), meaning not all youth were even physically invited to the club. Some questions we had never considered in our group while planning included:

- What if *these* kids have had positive STEM experiences and liked science and engineering?
- What if they have built complex, nuanced understandings for years interacting with the designed and natural world?
- What if "liking" science or engineering is not the issue at all?
- What if they are not the monolithic demographic group that a one-hour slime experience assumes they are?
- What does it mean to be a "good" student? Who was "reaching out" to those who were not considered "good"?
- What programs were those youth experiencing?
- What do all youth want from these experiences? What is meaningful to them?
- What if we were not the experts we thought we were?

Outreach driven by a narrow understanding of the diversity issues in STEM fields runs the risk of negating positive intention by creating ineffective or harmful experiences for youth. As a white outreach team, we assumed that "these youth" did not care for science or know about engineering based on where they went to school. We recreated a pervasive tableau within STEM by not engaging these youth in any development or planning: the white, often male scientist or engineer as the ultimate knowledge holder and giver, (over)developing an experience without youth input. The structure of the club was not set up to require intellectual engagement. From the example above, youth could make slime without learning anything about the materials engineering that made that possible. The club's purpose was hands-on, not minds-on. In the example above, we may have reached out, but the extent to which we did so was limited.

Two things became clear in working in this outreach setting: (a) These experiences were designed from a dominant white, engineering perspective, lacking a socio-technical, socially engaged design mindset for engineering design work, and (b) there was little to no attending to who youth were, what they did, what was meaningful to them, or what meaning they made of us being there. Recognizing these points and understanding why they are troubling begs the question: Did this outreach club actually invite youth – not just physically, but through their experiences, knowledges, and identities – into engineering work? My answer is no, it did not. If my experience is representative of how "broader impacts" work is done across academia, then much work is to be done to "extend services beyond the current or usual limits" in a different, deeper way. To start, those developing engineering experiences for youth might define what it means to center youth in this process and invite all youth to engage with the designed and built world actively.

Framing the Problem

As a graduate student in pathology and engineering, the outreach efforts I participated in reflect the continued calls to increase and diversify the STEM workforce (Chubin et al., 2005; *Educate to Innovate*, n.d.). On a national level, NSF commitments and policy initiatives, like the NGSS, undergird these aims. In addition, the specific attention paid to engineering and design disciplines seems to represent a call to create equitable engineering opportunities for students earlier in their educational trajectories, given the need for diverse perspectives in engineering *writ large*. How then have engineering educators answered this call – to develop engineering programs for and with youth that engage a diverse range of youth in engineering problems and experiences, hoping that a broader spectrum of youth will want to enter the engineering workforce?

Within the current landscape of engineering in pre-college contexts, there exists a wide range of ways engineering educators have developed experiences for youth. The design and study of formal engineering curriculum, such as *Engineering is Elementary* (Cunningham, 2009) or *Project Lead the Way* (Bottoms & Anthony, 2005; *PLTW Engineering | PLTW*, n.d.), has built a significant portion of this literature swath. Scholarship on formal engineering curriculums has contributed understandings of the nature of youth engineering (e.g., Cunningham & Kelly, 2017), youth engineering practice (e.g., Wendell et al., 2017), engineering identity work (e.g., Kelly, Cunningham, & Ricketts, 2017), and ways of teaching engineering content (e.g., Cunningham & Carlsen, 2014; Cunningham & Lachapelle, 2014). Study of informal engineering activities, such as robotics teams or makerspace programming, has offered similar findings around the nature of youths' work (Gomez et al., 2016), motivating interest in STEM (Bethke Wendell & Rogers, 2013; Pinkard et al., 2017), and their growing STEM identity (Calabrese Barton et al., 2016; Pattison, Gontan, Ramos-Montañez, et al., 2018). However, looking across this important empirical work, it was less common to see youth invited into messy, ill-defined engineering design that begins with the work of problem definition. More commonly, youth engaged in prescribed, predefined design challenges. This raises the question: What is the potential of inviting youth to design work that they identify and define?

The need to consistently interrogate and reframe engineering programming for youth emerges, in part, from the ongoing lack of diversity in the discipline. The architects of the NGSS acknowledge that they specifically included engineering to address diversity issues within STEM fields. On including engineering content and practices, the authors of the NGSS asserted that "[b]y asking questions and solving meaningful problems through engineering …diverse students deepen their science knowledge, come to view science as relevant to their lives and future and engage in science in socially relevant and transformative ways" (NGSS: Lead States, 2013, Appendix H, p. 2). Within this text is the acknowledgment that, at minimum, science and engineering were not made socially relevant to many. In fact, looking at engineering specifically, many persons have historically been, and currently are, excluded from shaping the recognized engineering enterprise (Benjamin, 2019; Bix, 2004; Riley, 2017). Currently, engineering programs struggle to attract and retain individuals who identify as BIPOC, women, LGBTQ+, and/or from disenfranchised socioeconomic groups (National Science Foundation, 2017). Within the field, engineers from historically marginalized backgrounds point to a wide range of oppressive concerns, including "chilly climate," stereotype threat in success, inequitable or exclusionary material supports, and the privileging of practices and ways of knowing of the historically (and still) dominant group (Gaskins, 2019; Holly, Jr., 2020; Ong et al., 2018; Riley, 2019). Simplifying, much of recognized engineering[2] has been developed from the participation, experiences, knowledge, and identities of predominately white, upper-class men. Yet, interrogating or challenging the effects of this, or engaging with any issues of social justice, is often demarcated as not central to engineering work (Cech, 2013). Acknowledging the power of educational experiences to meter acceptability, position youth in deficit, and/or reproduce the exclusion part and parcel to the field raises an imperative to address the oppression of the engineering field and explore ways to trouble and expand recognized engineering practice in

[2] Here, I refer to "recognized engineering" as we know it in the United States context. Recognized engineering in other global contexts has been developed and evolved from other types of participation, and reflects related – but distinct – concerns around diversity of the discipline (Williams et al., 2013).

youth engineering design experiences (Barajas-López & Bang, 2018; Vossoughi et al., 2016). Aiming to contribute to this work, I offer that engaging youth in practices that bring their experience and identities to the fore may open new educational opportunities that deconstruct exclusion. Thus, there is a need to evaluate how engineering design experiences might be improved for *youths' needs* and to speculate how these programs might be reframed to center and celebrate youths' experiences.

Research Questions and Overview of Study

Moving toward a youth-centered reframe of engineering requires engineering educators to develop experiences that do not replicate past exclusionary practices or perpetuate injustices (Benjamin, 2019a; Gaskins, 2019). We need to sustain and support the diversity of all learners' cultural experiences and interests, thus necessitating a close study of youth from cultural backgrounds and experiences not typically privileged in engineering (cf. Nasir et al., 2014). What does it mean to invite youth into engineering design contexts as the whole people they are? Through my dissertation work, I seek to contribute to this goal. In my qualitative study, I examined how youth whose social identities are underrepresented in engineering engage in flexible, real-world front-end design work and discuss their experiences in a social science and community research program that I co-designed with colleagues, called *Sensors in a Shoebox* (henceforth, *Sensors*). This program was not intended to be an engineering recruitment experience; instead, *Sensors* aimed to engage youth in civic action through research and design. In this program, problem definition, exploration, and ideation were included as a tool to engage in community improvement. This context was a powerful space to interrogate how design practices might be enacted and adapted to support all youths' informed connection to the designed world, not just as future engineers. Having collected data through interviewing and observing seven focal youth over three years, I examined the multiple ways youth engaged in *Sensors* design, as both skilled and liberatory work drawing on their personal experience. I also examined how youth talked about what was meaningful in their *Sensors'* design experiences, how they saw *Sensors* work, and their engineering experiences thus far.

My dissertation addresses the gaps in the literature by qualitatively investigating an emerging way we might better connect youths' experiences and identities to design, engineering design, and engineering. It also illuminates the often invisible work that historically marginalized and minoritized youth do in engineering programs designed to provide access and opportunity. Finally, this work aims not to generalize to other groups of youth but to showcase patterns of experience that can guide the development of future programs and help frame future empirical research. The research questions guiding my study are:

1. **In what ways do youth engage in the design practices of the *Sensors* program?**
    a. What does this look like *within* and *across* the *Sensors'* experiences?
2. **How do youth talk about their engineering design experiences?**
    a. What do youth narrate as compelling moments in a shared engineering experience, if anything? Why are these meaningful to them?
    b. What tensions arise between narration and engagement?
    c. How do they narrate engineering in relation to themselves, if at all?

This study follows seven focal youth from underrepresented backgrounds over time as they engage in engineering design work through the *Sensors* out-of-school community program. I present details on the *Sensors* program and the specifics of research design in Chapter 3.

Organization of the Dissertation

Through the following chapters, I explore what I have learned thus far from these focal young peoples' engagement *Sensors*' design work and discussion of their engineering design experiences. In Chapter 2, I present the literature review and conceptual frame for my study. I define engineering design practice as called for with youth learners and present an overview of current literature on engineering education for youth. Next, I situate my study as building on previous work exploring youths' experiences in informal STEM program development, bringing these perspectives to engineering-specific contexts. I introduce the critical sociocultural theories and critical science and technology studies (STS) of design I use to explore youths' engagement and discussions. I conclude with an argument for how this framing resists perpetuating harmful pipeline models for designing engineering experiences for youth, offering new directions for design work. Chapter 3 discusses research methods, detailing the *Sensors'* research context, modes of data collection and analysis, and study trustworthiness. In Chapter 4, I introduce youth (some youth introduce themselves) in the context of our experiences together and while narrating their ongoing engineering stories. In Chapters 5 and 6, I present findings on focal youths' engagement in *Sensors'* design work, including how and when youth offered and used their everyday knowledges, experiences, and interests (Chapter 5), and youths' discussions of their engineering design experiences, in *Sensors* and beyond (Chapter 6). Chapter 7 puts these findings in conversation with one another and offers implications for meaningful engineering program design and the engineering field.

CHAPTER 2 Literature and Conceptual Framing

This study critically focuses on designing engineering experiences for youth, interrogating how we might learn from youth – from their engagements and discussions – to explore new possibilities. I zoom in on front-end design practices, particularly youths' interaction with front-end design practices within the *Sensors* community engagement program, to speculate about these practices as a site where youths' experiences are purposeful and necessary. I ask, "*how are youth engaging in the design practices of the program?"* to think about what it means to engage youth in open-ended design work and the opportunities it affords for inviting youth to other dimensions of engineering work. I then ask, *"how are youth discussing their design and engineering experiences?"* to make youths' experiences the building blocks for future programs, informing inclusive design.

To lay the groundwork for this study, I first analyze the current expectations of engineering learning at K-12 levels and raise some tensions these expectations pose when thinking about the fields of design, engineering design, and engineering. I then situate engineering as a culture, thinking about its historical shifts and current concerns. Next, I review current frames for engaging youth in engineering and design and findings from youth-centered STEM work to introduce my argument for studying youths' experiences with *Sensors*' front-end design. In the second half of the chapter, I unpack sociocultural theories of learning and critical STS theories of design as the theoretical base for my study. I end the chapter with my argument for examining engineering learning from critical sociocultural perspectives, demonstrating how these theories could allow the field to extend and expand recognized disciplinary engineering work. Specifically, I argue that designing engineering programs from these perspectives could offer inroads to addressing the long-standing marginalization that is part and parcel of engineering cultural practice.

Expectations for Earlier Engineering Education

The development of *The Framework* (NRC, 2012) and the creation and adoption of the Next Generation Science Standards (NGSS, NGSS: Lead States) represents multiple shifts toward a new vision of science education in formal settings (Ford, 2015; NGSS: Lead States, 2013; Pruitt, 2014). One of the more striking features within these standards is the addition of engineering design practices and content. The architects of *The Framework* and the NGSS offer:

> We use the term "engineering" in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems. Likewise, we broadly use the term "technology" to include all types of human-made systems and processes—not in the limited sense often used in schools that equates technology with modern computational and communications devices. Technologies result when engineers apply their understanding of the natural world and of human behavior to design ways to satisfy human needs and wants (NRC, 2012, p. 11-12).

The national gravity of the NGSS introduces new expectations to P-12 settings. The first is that all youth will be engaged in engineering design work before college. The inclusion of engineering design in the NGSS was motivated by the goal of increasing access and interest, with the hope that "[p]roviding students a foundation in engineering design allows them to better *engage in and aspire to* solve the major societal and environmental challenges they will face in the decades ahead" (NGSS: Lead States, 2013, emphasis added). Including engineering design practices within NGSS represents, potentially, a more unified effort to introduce engineering design to students earlier in their educational trajectories, given the necessary calls to diversify the engineering field and develop increased engagement with the designed world. Less obviously, the second expectation the NGSS may set up is that "engineering design" constitutes the practice of engineering. Although many argue that engineering design is not the entirety of engineering work (Figueiredo, 2008; Vincenti, 1990; Williams et al., 2013), the writers of the NGSS discuss these design practices as important for problem solving, an important function of engineering (Dym et al., 2005). The standards writers also included, "…only [the] practices and ideas about engineering design that are considered necessary for literate citizens," which were *problem definition*, *designing solutions*, and *iteration* (NGSS: Lead States, 2013, Appendix I). Taken together, the inclusion of engineering design in the NGSS opens an opportunity to think critically about design, engineering design, and engineering in practice with all youth. It also lays the foundations to rethink how we invite youth to engage with the designed world.

The American Society for Engineering Education also released a vision for engaging young people in engineering work, titled the *Framework for P-12 Engineering Learning* (2020). This document presents a detailed vision for engineering learning to systematize and unify the efforts of practitioners, curriculum developers, and researchers within the emerging pre-college engineering field. Engineers, educators, and engineering education researchers developed the *Framework* to:

> …foster an engineering learning community with a shared focus, vision, and research agenda that ensures that every child is given the opportunity to think, learn, and act like an engineer. The goal of this framework is to provide a cohesive and dynamic guide for defining engineering learning for students and for establishing the building blocks that set the foundation for a coherent approach for states, school systems, and other organizations

> to develop engineering learning progressions, standards, curricula, instruction, assessment, and professional development that better democratize engineering education across grades P-12 (AE3 & ASEE, 2020, p. 4).

Driven more specifically by objectives of the engineering discipline (Adams et al., 2011), the ASEE's framework defines engineering with more dimensions than the NGSS, trying to mirror the discipline's work more closely. Like the NGSS, the *Framework for P-12 Engineering Learning* provides a 3-dimensional (3D) model for engineering learning with the subcomponents of *Engineering Habits of Mind*, *Engineering Practices*, and *Engineering Knowledge Domains*. However, contrary to the NGSS, this framework positions *Engineering Design* as one of four *Engineering Practices*. As an *Engineering Practice*, the writers define engineering design with nine sub-practices connected to various presented *Habits of Mind*. Relatively new to the scholarly ecosystem, this framework reflects the breadth of ways engineers may define themselves and their work. It also raises several questions: In engineering programs for youth, how do decide what dimensions of engineering to address? What are and should be our goals be? Where are youths' experiences in any of these conversations? Both frameworks presume that a focus on engineering design is worthwhile and engaging, raising the question: On what basis is this claim made? What do we know about how young people experience engineering design activities and whether these experiences are as engaging as the adults who crafted the frameworks—often far removed from the experiences of a diverse group of youth—believe the experiences to be?

Emerging Challenges

The push for formalized engineering design within K-12 contexts has widely been noted as novel for both learners and teachers (Pruitt, 2014). However progressive, this effort is not without challenges. Envisioning educators working with youth as early as kindergarten on a simplified engineering design cycle could be considered exciting and daunting, especially given the potential lack of apprenticeship in teaching engineering design in K-12 (Brophy et al., 2008). Historically, many engineering or engineering design experiences for youth have been offered in informal, afterschool, or through research partnerships (Purzer et al., 2014; Roehrig et al., 2012). Often, these experiences are designed by or with current engineers' input and may not attend specifically to current theorizations of learning (Ozogul et al., 2016). On the other hand, current educators raise misgivings about their understandings of engineering design for teaching, alongside logistical concerns such as time and material management (Cunningham & Carlsen, 2014; Hardré et al., 2017). Building on scholarship necessarily bridging between the learning sciences and engineering (e.g., Cunningham & Lachapelle, 2014; Giroux & Moje, 2017; Johri & Olds, 2011; Kelly & Green, 2018; McGowan & Bell, 2020), I argue that bringing these fields into conversation creates an opportunity to build more robust, inclusive learning environments. That said, thinking with such specificity about engineering design in pre-college contexts is still a relatively new idea (Carlsen, 1998). Although important strides have been made (e.g., Capobianco et al., 2011; Crismond, 2001; Crismond & Adams, 2012; Wendell et al., 2017), there is still much to know about what young people think engineering is, why they are attracted to engineering programs, and what might attract more youth. Further, even less work has explored what makes engineering design work consequential or meaningful for youth (Gutiérrez & Vossoughi, 2010), interrogating what they want to learn and experience in engineering spaces (e.g., Greenberg & Calabrese Barton, 2017; Nazar et al., 2019). I argue it is critically necessary to build on and expand this area of scholarship to develop inclusive engineering experiences for youth that both invite them to engage in and design the designed world.

Defining and Delimiting Engineering in Society and History

Conversations about youths' engineering experiences do not happen in a vacuum. What is valued or devalued, emphasized, or deemphasized in K-12 spaces has some root in the larger engineering enterprise as it has evolved. In this, histories of participation in engineering are directly implicated in engineering programs for youth (cf. Gutiérrez & Rogoff, 2003). Thus, as we seek to explore and expand *engineering* as a discipline for young peoples' learning, defining and delimiting engineering, engineering design, and design practice is important.

Today, engineering is a related but distinct discipline from science (Bix, 2004; Kirby, 1990; Vincenti, 1990). Having historical roots in art and craft trades, engineering emerged as humans raised needs or desires to alter or traverse their surroundings (Grayson, 1977; Vincenti, 1990). The term "engineer" derives from the Latin word *ingeniator*, meaning one who devises, capturing the thinking or planning associated with *engineering* something (Lethaby, 1925; Petroski, 1985; *President's Perspective*, n.d.). A constant, historical through-line in conceptualizing engineering is a commitment to building, designing, exploring, or solving problems for a particular purpose. In this current moment, efforts to define engineering reflect a summation of component parts. For example, Figueredo (2008) argued that engineering knowledge comprises four dimensions: *design*, *human science*, *basic science*, and *the crafts* (p. 45). In this view, the practice of engineering – what engineers do – is the traversing of all these dimensions (R. Adams et al., 2011). Along with outlining dimensions of engineering knowledge and habits of mind, The *Framework for P-12 Engineering Learning* defined engineering practice as constituted by *professionalism*, *engineering design*, *materials processing*, and *quantitative analysis* (ASEE & AE3, 2020, p. 19). These definitions suggest that engineering is not just one thing and that there is room to think broadly about "what counts" in engineering work. Further, design remains a common dimension of engineering practice (Daly et al., 2012; Dym et al., 2005a; Layton, 1976).

Design Within Engineering

What, then, is *engineering design*? It can be defined as a design process situated within the technical milieu of engineering spaces or contexts, within constraints, and for outcomes. Across the many engineering disciplines, engineering design has been understood as "…the systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy certain constraints" (Dym, 1994). Some practicing engineers describe engineering design as the *doing* of engineering (Petroski, 1985). Engineering design also appears in national messaging around engineering, as the National Academy of Engineering defines engineering as:

> … "design under constraint," because to "engineer" a product means to construct it in such a way that it will do exactly what you want it to, without any unexpected consequences (NAE, n.d.).

This definition echoes historians of engineering that point to design as the embodiment of engineering work:

> From the point of view of modern science, design is nothing, but from the point of view of engineering, design is everything. It represents the purposive adaptation of means to reach a preconceived end, the very essence of engineering (Layton, 1976, p. 69).

Stemming from an ongoing conversation with the engineering field, it is imperative to note that not all engineering work is design work, just as not all design work is engineering (Adams et al., 2011; Figueiredo, 2008). However, the ubiquity of design work in engineering means design lives across all sub-disciplines of engineering, and some may use "designing" and "engineering" interchangeably (Petroski, 1985). Another way of conceptualizing this is locating design as a core element of engineering, situated at the intersection of practice and society (R. Adams et al., 2011; Figueiredo, 2008; Williams et al., 2013). Engineering design, or design within engineering, is how to do engineering in interaction with the surrounding world.

Design Beyond Engineering

Broadening out from engineering, designing is one of the most long-standing and ubiquitous practices in our society. From anthropology to zoology, engineering to education, most disciplinary cultures engage in design as a means to a purposeful end (Bang & Vossoughi, 2016; Cross, 2001; Dym, 1994; Schön, 1984). As a discipline, design or design science concerns itself with concretizing the knowledge and practices part and parcel to design work (Cross, 2007). These practices operate as ways of knowing, doing, and being for the designerly enterprise (Cross, 2001; Schön, 1984). That is to say, that design is both a discipline of study and a process, and our understandings of the design process come from the reflective, iterative integration of the two (Cardella et al., 2006; Crismond & Adams, 2012). Designers explore and define some existent problem or gap relevant to some stakeholder population (Johansson-Sköldberg et al., 2013; Murray et al., 2019). Variably, depending on their motives, they seek to know more about their problem spaces and those invested in the solutions (Costanza-Chock, 2020; Rosner, 2018). They make decisions to clarify focus (Bethke Wendell et al., 2017). They may collaborate and construct ideas in teams or as individuals (Daly et al., 2012). Presumptively, the design work will yield *something*, be it an idea, a question, a process, a project, or a physical product (Simon, 1988). As a word, design signals both process and product, action and item. A product can be designed, and itself becomes a design—designers design designs.

Engineering as a Disciplinary Culture

In my work, I adopt the perspective that disciplines are cultures built on historical norms, practices, and social decisions (Cetina, 1999; Harding, 1992; Moje, 2007, 2015). Culture can be defined as "…the constellations of practices communities have historically developed and dynamically shaped in order to accomplish the purposes they value, including the tools they use, social networks with which they are connected, ways they organize joint activity, and their ways of conceptualizing and engaging with the world" (Nasir et al., 2014, p. 686). Understanding engineering as a culture makes visible the social negotiations of what has – and has not – been considered engineering and how that has changed over time. For example, societal movements and events, like enlightenment, U.S. industrialization, and World War II have significantly shaped the way engineering is constructed in U.S. contexts (Layton, 1976, 1986; Pawley, 2009; Schon, 1984; Vincenti, 1990). Over time, these events moved engineering toward the privileged position we see today, rejecting notions of engineering as vocational "applied science" and seeding the distinctions between trade "builders" or "technologists" and educated "designers" or "engineers" (Pawley, 2009; Riley, 2008; Vincenti, 1990). A growing military connection post-World War II and the U.S. response to Sputnik deepened this shift, with college engineering programs further obscuring notions of engineering work as "working with your hands" by structuring curriculums with a heavier emphasis on physics, mathematics, and technological creation (Duderstadt, 2010; Riley, 2008; Tadmore, 2006). Thus, what is considered engineering has shifted with time at the influence of societal needs and desires, mainly of those in power (Harding, 2015; Pawley, 2009; Riley, 2017). The history of engineering, particularly in the U.S., emphasizes how socially changeable practices within this discipline could be.

Yet, many practicing engineers may take issue with the above statement. The historical movement to position engineering as an esteemed discipline, on par with but distinct from science, created ongoing narratives and debates about what engineering *is not* (Pawley, 2009; Rohde et al., 2020; Vincenti, 1990). Some argue that engineering is not just design work (Dym, 1994; Pawley, 2009), although others argue that design work is *the* practice of engineering (Petroski, 1985). Others argue that engineering is not just applied science (Vincenti, 1990), although science importantly informs engineering work (Layton, 1976). For some, despite evidence to the contrary, engineering is not a social enterprise (e.g., Wichman, 2017). Across industry, university, and K-12 settings, some seek to put distinct demarcations around engineering-specific work, what types of problems, experiences, or knowledges are – or are not – engineering (Antink-Meyer & Brown, 2019; Brophy et al., 2008; Pawley, 2009; Pleasants & Olson, 2019). For some, this might even translate into what is considered "good" engineering work (Pawley, 2009; Riley, 2017; e.g., Wichman, 2017). The tension between narrow and expanded views of engineering (e.g., Adams et al., 2011; Gaskins, 2019) raises important considerations for developing engineering experiences for all young people: For what goals or purposes are we developing these programs? What concerns are we trying to address?

Engineering's Lack of Diversity

Beyond reflecting the new standards, exploring engineering in K-12 is significant considering the historical concerns within the field of engineering itself. On including engineering, the authors asserted that "[b]y asking questions and solving meaningful problems through engineering …diverse students deepen their science knowledge, come to view science as relevant to their lives and future and engage in science in socially relevant and transformative ways" (NGSS: Lead States, 2013). This sentiment acknowledges that engineering programs have historically excluded many perspectives from shaping engineering (Bix, 2004; Harding, 1991, 2015; Riley, 2019). National reports continue to show that significantly fewer white women, those identifying as Black, Indigenous, People of Color (BIPOC)[3], people with different abilities, people in marginalized socioeconomic classes, LGBTQ+ persons, and people with all manners of identities intersecting across these groups do not pursue or persist within engineering (National Science Foundation, 2017). Not only a matter of representation, but those holding these identities within engineering spaces are also at risk of experiencing engineering as a space of exclusion, marginalization, oppression, or violence (Avraamidou, 2020; McGee & Martin, 2011; Miller et al., 2020; Ong et al., 2018, 2020). If we consider that engineering culture and ways of knowing are socially constructed with a flawed human history, the ongoing issues are unsurprising (Harding, 2015). These reports exemplify how engineering work, knowledge, and culture were created and maintained for a select, dominant group (Riley, 2017; Trevelyan, 2010).

Nevertheless, those in positions of power within engineering ignore or reject engineering's historical exclusivity that serves Western, white, androcentric, and upper-class perspectives (Harding, 2015; A. Pawley, 2017). Some in the field take a culture-blind, identity-blind approach, offering, "[e]ngineering does not care about your color, sexual orientation, or your other personal and private attributes. All it takes to succeed is to do the work well..." (Wichman, 2017). These same individuals, however, fail to acknowledge their own cultures, identities, and values have been shaping their work and the field. Contentiously, the field is often at war with itself, grappling with the (in)ability to label and excise oppressive perspectives, dispositions, and practices entirely (Holly, Jr., 2020). Emerging amongst these contentions are

[3] The youth I work with in this study self-identify as Black and Latina/o/x (Table 3-3). Throughout the dissertation, I use the term BIPOC to describe racial identities marginalized in engineering spaces (Mitchell & Chaudhury, 2020). Further, for this work, I use the term Latina/o/x to describe participants of Latin American descent. Latinx is an often-debated term to describe people of Latin American descent and "appears to have been born out of the LGBTQIA community in the U.S. as a way to resist the gender binary" (Salinas & Lozano, 2019, p. 2). It is mostly used in the academic community to substitute Latino, Latino/a, or Latin@, affirming non-binary or genderqueer Latin identities (Salinas, 2020). Not all youth in this study self-identified as Latinx, but I am including the "x" to honor requests from queer youth.

continued calls to reach out broadly, increase diversity, and foster inclusivity (Allen-Ramdial & Campbell, 2014; Harding, 1991). Engaging all youth from younger ages in engineering work remains paramount to these goals.

Accounting for Engineering's Realities in Youth Programs

Although engineering diversity is often studied at undergraduate and professional levels, the historical exclusion within engineering and engineering education exists as a dialectic: pre-college engineering experiences—or lack thereof—have material implications for post-secondary engineering diversity, and the lack of post-secondary diversity has implications for pre-college engineering spaces. In line with the growing work examining consequential, expansive engineering practice (Hall & Jurow, 2015), more work is needed to examine how we invite all youth – girls, BIPOC youth, youth of marginalized class statuses, LGBTQ+ youth, and youth of all intersections within these identities – to engineering learning environments, in ways that value their experiences. Further, it is necessary to explore the impact of design from youths' perspective, examining how they participate in and experience these contexts and how these experiences shape their understanding of themselves and learning in engineering (Nazar et al., 2019; Pinkard et al., 2017; Wilson-Lopez et al., 2016). Work in the disciplines of math and science learning has highlighted that K-12 STEM education has a consistent history of "othering" students holding non-dominant racial and class identities via content and practice (Bang et al., 2012; Calabrese Barton & Tan, 2009; Emdin, 2011; Gholson & Martin, 2014; Nasir & Saxe, 2003; Rosebery et al., 2010). As Rosebery et al. (2010) describes, STEM environments have historically excluded non-dominant youth:

> …first, by locating diversity in otherness—in deviations from a presumed mainstream Euro-American, middle-class norm—and, second, by flattening the complex and varied

> ecologies of everyday life into an essentialized group trait, often linked with academic deficits or disadvantages (p. 323).

Flattening aspects of youths' identities or experiences in STEM spaces and ignoring any role of systemic oppression within the social or environmental context may recreate the same color-blind, gender-blind, class-blind perspectives that dominate the greater STEM cultures (Nasir & Hand, 2006). For example, there have been ongoing attempts to determine what about engineering distinguishes it from "other," less-technical design or disciplines in K-12 spaces (e.g., Antink-Meyer & Brown, 2019; Pawley, 2012; Pleasants & Olson, 2019; Vincenti, 1990). Whereas this work may offer interesting analysis and thoughtful insight into principal engineering dimensions for K-12 spaces, this work also raises questions about demarcation. If the historical and current exclusion of certain groups is not critically reckoned with, what does that mean for our understanding of engineering knowledge and practices (Rosner, 2018)? As opposed to assuming engineering work is acultural, context-less, and identity-blind, I argue it is necessary to explore how youth holding marginalized identities know and do engineering in ways that do not separate *who* they are from *where* they are and *what* they are doing. Centering youths' experiences and voices offers one way the field might account for the realities of engineering. Further, it offers the tools to support drawing connections between how youth engage in engineering work and the meaning they make of their experiences.

Empirical Perspectives on and for Engineering with Youth

To further situate my study in literature, it is essential to understand the current framing of engineering programs – both design of and youths' experience in. This limited literature review explores recent scholarship on engineering and design experiences for youth. Specifically, I look at the goals and outcomes of engaging youth in engineering or design work.

Looking over the past ten years of academic research in the K-12 science and engineering education space, I explore how youth are positioned to engage in design practices, if at all. How are we currently seeking to engage young people in design work or engineering design work? How is it framed in relation to engineering? For what purpose? Reviewing the literature, I overview how empirical work with youth explores (a) engineering and design for science learning and (b) engineering and design for engineering learning, while not distinguishing between the sub-practices of design, and (c) expansive, informal design work as a road toward socially just STEM.

Next, I overview literature centering youths' experiences in STEM spaces to inform how we might understand engineering-specific spaces. I summarize empirical studies of youth-centered, informal STEM that compels the continued study of youths' experiences within programming. By analyzing these current discussions, I sought to better understand where we are (and where we hope to be) in inviting youth to do engineering and design work. This review led me to conclude that significant work has explored young people's engagement in STEM-rich work, their increasing interest in STEM, and their achievement outcomes. Still, more work is necessary to expand our understandings of youths' experiences within engineering-specific programming, the nature of their design-specific engagement, and how youth understand these experiences to be relevant (or not) to their lives.

Exploring Engineering Design for Science Outcomes

Although there appears to be at least some consensus that engineering experiences should support all youth in engineering design practices, among other engineering practices, the purposes for studying youth in engineering experiences varied. One conversation within empirical studies explores engineering design as a pedagogical tool for science or greater STEM learning. In this, researchers studied, and practitioners used, engineering design experiences to service other goals, such as science learning or increased motivation (Swarat et al., 2012). These studies tended to focus on the later design practices, such as building and iterating solutions. For example, Schnittka and Bell (2011) looked at how using engineering design-like tasks could promote conceptual change related to physics misconceptions. In the intervention, students were given a pre-framed design task "…to build a dwelling for the penguin-shaped ice cube to keep it from melting in a test oven" (Schnittka & Bell, 2011, p. 1869). As this task had an implied solution, the experiences relied on trial-and-error solution building and failure positivity to support physics learning. Similarly, Bethke Wendell & Rogers (2013) evaluated how a LEGO-based engineering design curriculum influenced students' attitudes and science achievement. This intervention also started with set design tasks (e.g., designing a musical instrument), starting later in the design process. In both examples, teaching engineering or design content was not emphasized; however, engaging youth in parts of engineering design, like ideation and iteration, was in service of science learning.

Within this literature conversation, robotics emerged as a common topic as researchers explored how these experiences supported youth beyond competition spaces. Robotics programming is one of the oldest, most recognizable engineering-related activities in K-12 settings (Hendler, 2000). Robotics competitions and clubs were established to introduce youth to tech-centered engineering content and contexts (Hamidi et al., 2017; Hendler, 2000; Mead et al., 2012; Miller & Nourbakhsh, 2016). Although consistently positioned as an engineering activity, robotics clubs often aim to increase general STEM achievement or increase interest in STEM fields (Barker & Ansorge, 2007; Gomez et al., 2016). Research focuses on these specific outcomes or "transferrable skills" support students in future engineering endeavors, or more broadly, in STEM. (Nelson, 2014; Nugent et al., 2010). For example, Nugent et al. (2016) reported the effect of the First Robotics Teams' engineering design process on students' self-efficacy toward engineering science. Gero & Danino (2016) similarly looked at the effect of a LEGO Mindstorms robotics class on systems thinking and science motivation. Like the above studies, the "engineering design" was studied as a pedagogical tool for other outcomes. The actual design work students were engaging in seemed fixed to later steps in the design process given the robotics competition constraints and Mindstorm Kits (Gero & Danino, 2016; Nugent et al., 2016). The positive outcomes reported in these studies, and those like it, reveal using a design cycle to teach a science topic is beneficial. Looking towards areas of expansion, these learning environments obscured the front-end of design work. Further, these studies sought outcomes aligned with recognized versions of practice, rather than *how* youth engaged in the design work they were being tasked with.

Investigating Engineering Design for Recognized Engineering

Another conversation within the literature explores how to support students in developing recognizable engineering behaviors. Emphasizing the disciplinary work of engineering as heavily dependent on design, these frames for engineering experiences seem aligned to the emerging vision of K-12 engineering design. Although these studies exist in formal and informal settings, a large swath focuses on youths' experiences with formal engineering curricula. In the current historical moment, formal engineering curricula are evolving mediums through which young people experience engineering and design. *Engineering is Elementary* (EiE) and *Project Lead the Way* (PLTW) are two prominent curricula developed from this goal.

With initial work starting in 2003, EiE has significantly pushed for engineering design work as young as kindergarten. The underlying assertion for this work was that "[c]hildren (and many adults) know shockingly little about technology and engineering" and the acknowledgment that, "[t]o understand the human-made world in which we live, it is vital that we increase engineering and technological literacy among all people, even young children" (Cunningham, 2009, pp.11-12). In this, Cunningham stresses that teaching engineering has more to do with understanding engineering *separate* from science, given its prominence in society. Similarly, PLTW began as a high school engineering curriculum in 1999, whose authors noted that "[o]ne of the goals of the PLTW program is to encourage more students to pursue further education and careers in the field of engineering and related fields at the technician level" (Bottoms & Anthony, 2005, p. 13). Today, this curriculum continues to be defined by this goal and its' significant connection to the discipline of engineering through its advisory board of academic and industry engineers (*Our Impact | PLTW*, n.d.).

Scholarship from the study of these curricula has generated understandings of the nature of engineering work with youth (Antink-Meyer & Brown, 2019; Cunningham & Kelly, 2017). In addition, studies of the EiE curriculum have supported designers and practitioners in understanding what developmentally appropriate engineering may be across K-12, both in theory and practice (Cunningham & Carlsen, 2014; Cunningham & Lachapelle, 2014; Hardré et al., 2017; Lachapelle et al., 2018). Further, partnerships with the curriculum developers and learning science scholars have supported emerging work on how youth begin to know and do engineering work (Capobianco et al., 2015; Kelly et al., 2017; Kimmel & Carlone, 2018; Wendell et al., 2017). Indeed, formal engineering curricula represent vital contexts for understanding engineering learning. However, given the growing but still limited adoption of these curriculums (they remain relatively regional), they currently occupy only a fraction of the engineering landscape for youth.

Further, given the often curriculum-specific nature of this type of study, the findings may only capture a limited snapshot of engineering experience or miss moments of potential criticality. The unit of analysis of these studies is often the engineering design process (as defined by the curriculum), with less attention paid to design work's sub-practices. Although there are some notable examples to the contrary (e.g., Wendell et al., 2017), authors predominately discuss engineering design as one extensive process rather than the sum of smaller processes, such as problem definition, ideation, and iteration. For example, Hertel, Cunningham, & Kelly (2017) explored how design notebooks might scaffold engineering practice. They found, "[t]he notebooks took on roles scaffolding student work and supporting engagement in epistemic practices as related to the educational goals of learning science concepts, applying the engineering design process, and developing identity as learners of engineering" (Hertel et al., 2017, p 1214). The outcome was applying an engineering design process generally and not the aspects within.

Similarly, Kelly, Cunningham & Ricketts (2017) explored how classroom discourse between students and teacher mediated youth engineering identity development. They used discourse analysis to "examine the ways that participation in engineering practices [Ask, Imagine, Plan, Create, and Improve] and talk about actions and themselves as learners provided opportunities for identity work" (Kelly et al., 2017, p. 58). The class engaged in a full design cycle in the "Ask" and "Imagine" discussions. In both examples and others (e.g., Capobianco, Yu, & French, 2015), significant work is done to think about learning and identity development in engineering experiences. However, because the focus is on the broader design process, little is learned about the role of individual design practices, particularly those as important in framing as front-end design work, mediate and contribute to learners' experiences. This scholarship suggests that more work needs to be done to understand better specific disciplinary practices, such as front-end design work. Further, the study of these experiences focused on recognized, curriculum-defined design practices to constitute engineering design work. As such, this literature conversation creates room to question: How might we think about and design toward more consequential, expansive versions of engineering and design work?

Exploring Unconstrained Design for Social Justice

Another conversation informing engineering experiences for young people is around unconstrained design experiences, like making or tinkering. Making, tinkering, and building are adjacent engineering design practices (Vossoughi & Bevan, 2014). They are common in informal spaces and have been explored in relation to engineering learning (Wang et al., 2013). Sometimes framed as undefined or unconstrained design work, making and "maker spaces" have emerged for various goals and purposes (Bevan, 2017). The Maker Movement describes "a growing movement of hobbyists, tinkerers, engineers, hackers, and artists committed to creatively designing and building material objects for both playful and useful ends" (Martin, 2015, p. 30). Making and tinkering have been studied as means to engage youth in STEM-rich work while also combatting the inequities that students traditionally marginalized in engineering may face in classroom spaces (Calabrese Barton, Tan, & Greenberg, 2016). In these spaces, traditional engineering design (e.g., Dym et al., 2005) is not the explicit goal, but rather engineering-like behaviors arise naturally amidst the work.

In research related to making, recognized design work is not the goal, so particular practices are not distinguished. Instead, "[p]roblems or challenges are not assigned but are surfaced and pursued by the learner through initial exploratory engagement with the materials, people, practices, and ideas available in the tinkering setting" (Bevan, Gutwill, Petrich, &

Wilkinson, 2015, p. 99). For example, youth may research and establish their own problem spaces in different contexts, engaging in work parallel to front-end design work. Calabrese Barton, Tan, & Greenburg (2016) followed young girls over time in maker spaces and explored "[h]ow youth leverage their knowledge of community concerns and values could be positioned by the teacher/adult facilitator or peers as either important or not…" in this community of practice (p. 5). Drawing on sociocultural-historical theories of learning, they argued that the autonomy afforded in maker spaces allows youth to "work on problems that are defined through interactions with others and leverage others' experiences and struggles – which they see themselves as a part of – towards making," (Calabrese Barton et al., 2016, p. 24). Although not framed as making and not engineering, scholarship in this literature conversation surfaces questions about the purpose of design work and how we might expand "what counts."

Similarly, DiGiacomo & Gutiérrez (2016) ethnographically investigated out-of-school maker spaces for a year to understand how they might promote a more equitable engineering learning experience. They define tinkering as "...activities [that] provide a context for connecting youths' everyday interest and practices with new forms of activity and participation, through engaging youth in an interest-driven collaborative process of (re)design, (re)production, reflection, and remixing" (DiGiacomo & Gutiérrez, 2016, p. 141). These, and other complementary studies (Evans et al., 2014; Sheridan et al., 2014), suggest that defining problems is a possible way to create more connection, even hybridization, between youths' personal and disciplinary experiences (see Calabrese Barton & Tan, 2009; Bevan et al., 2015; Moje et al., 2004). Although youth are not necessarily engaged in "formal" engineering work, the authors discuss this practice – determining the course of the make, build, or design - as a way for marginalized youth to better identify with broader STEM practice, eventually. Learning from this literature raises ways engineering-specific educators might think more expansively about engineering experiences.

Learning from Informal, Youth-Centered STEM Contexts

Starting from the perspectives of the field, ascertaining what types of things youth need to know and be successful in the designed world remains an important task. However, what has historically lacked from engineering-specific conversations are youth-centered approaches, attending to questions of "why" and "how" youth do and experience engineering work. Building knowledge about how youth experience engineering, specifically informally, supports developing programs that include youth as whole people in engineering work. In this section, I continue building on the previous section to overview empirical work from youth-centered, informal STEM spaces.

Work that empirically engages with youths' knowledges, practices, and experiences offers important ways of understanding and developing designed spaces. For example, Moje et al. (2004) traced Latina/o/x youths' funds of knowledge in and out of school, analyzing the ways youth leveraged these funds across settings. Exploring the ways youth brought their knowledges to science classrooms, whether acknowledged or not (p. 53), allowed the researchers to theorize about better connecting marginalized youths' lived experiences to science work and how these spaces might transform to better accommodate them (Moje et al., 2004). As other scholars have argued, understanding how to develop these robust connections is essential for youth to see themselves in STEM work (Archer et al., 2021; Moje, 2007; Nasir et al., 2014). Exploring youths' experiences in spaces can transform thinking about what spaces are and could be (Gutiérrez et al., 2019; Gutiérrez & Vossoughi, 2010; Hall & Jurow, 2015; Moje et al., 2004; Moje, 2015). For example, Barajas-López & Bang (2018) explored the making stories and practices of three Indigenous youth, Sarah, Jen, and Henry, within an Indigenous STEAM program. By exploring how youth shared about their making and building in the program, the researchers developed principles of Indigenous making, intertwining making and sharing, with youth that could inform future program development. Fron youths stories, into their principle development, the authors argue, "Indigenous making and sharing can chart new possibilities and perspectives toward equity in making and for self-determination if onto-epistemic heterogeneity and the cultural and political purposes are explicitly part of making" (Barajas-López & Bang, 2018, p. 18). The study of youths' practices not only supported ways of connecting to marginalized youths' everyday knowledges but informed new directions for design.

Emerging Expansive Views of Engineering and Design for Youth

In a space as contentiously negotiated as pre-college engineering, scholarship examining youths' experiences and practices has begun to create spaces to imagine. For example, Nazar and colleagues (2019) developed an in-depth case study analyzing the ways an African-American boy, Christopher, took up engineering practice, expanding and transforming practice beyond a "master narrative" of engineering work (p.6). They documented how he re-envisioned design purpose and process in app development, creating a hybrid space between his engineering design work and his community. Studying Christopher's practices supported theorization about what engineering work could and should be. They suggested engineering experiences should support youth "…in ways that take up not only their individual concerns, but that also support and position their community's sociocultural, sociopolitical, and sociohistorical underpinnings as legitimate resources for STEM learning" (p. 25). Similarly, Greenberg & Calabrese Barton (2017) closely followed the engineering efforts of Keke and René, two Girls of Color in a STEM club. The researchers found that as the youth developed solutions towards a meaning problem to them, sexual violence against women:

> [t]hey became their own heroes, taking on positions as leaders and solution makers in a situation they feared could deliver them into victimization. Their engagement transformed as a result of their license to produce new knowledge and action that mattered to them and their community (p. 21).

Studying these youth's experiences confirmed the importance of consequential learning to engagement *and* imagined new ways youth might connect to engineering work. This growing space of critical, expansive engineering work that centers youths' experiences is an area ripe for continued study. These examples and others (e.g., McGowan, 2018; Pattison et al., 2018; Svarovsky et al., 2018) demonstrate how learning from youths' experiences within programming might support learning environments that do not recreate the inequities of the engineering field. Rather, by exploring the meaning of these experiences for youth, these studies have informed how we might inclusively and equitably invite youth to engage in the designed world. A relatively emergent literature conversation, I draw upon this literature to ground my exploration into youths' practices within *Sensors*.

Importantly, this growing swath of scholarship echoes an argument made by McGowan and Bell (2020):

> In this sense, we argue that equitable models of engineering are not simply designed to give students more access to engineering opportunities at earlier ages, but about re-envisioning engineering as a situated set of practices that depend on diverse types of knowledge to solve novel problems both in and outside of K-12 settings (p. 988).

In this literature conversation, scholars are studying and designing to expand normative versions of engineering and design to think critically about inclusion beyond the "more" and "earlier" models that some outreach experiences and curriculums adopt. Instead, it suggests that the work of inviting youth from marginalized backgrounds into engineering practice is to invite their practice, shaped through experience, even if that means expanding or disrupting "what counts" in engineering programs to reflect these connections. The diversity of youths' experience and how this emerges in practice and discussion is an asset "…fundamental to everyday life and learning" (Rosebery et al., 2010, p. 351). This literature supports the idea that disciplinary engineering design work could be agentic, sociotransformative, and a place for youth to feel connections or inclusion within engineering (Rodriguez & Berryman, 2002). Given the historical inequities and exclusion of engineering culture (e.g., Harding, 2015), it also strongly motivates a need to learn *from* youth in their engineering practice to better invite youth, as whole people, to engineering work. Aligning with these goals, I seek to expand work in this area by exploring youths' experiences and interactions with *Sensors'* front-end design work, interrogating the nature of these practices to new ways of meaningfully inviting youth into engineering work and the designed world.

Power in Front-end Design Work

Design has been described as having two parts: the *analytical* problem definition, or front-end, and the *synthetical* problem solution, or back-end (Johansson-Sköldberg et al., 2013). Designers and engineers alike describe front-end design as open and investigative (Downey, 2005; Dym et al., 2005). Generally, it includes identifying, framing, scoping, and exploring a problem through stakeholder analysis and research, leading to early ideas about problem solutions (Borgianni et al., 2018; Cross, 2007; Murray et al., 2019). In the NGSS, the term *problem definition and delimitation* refers to front-end work (Dym et al., 2005; NGSS: Lead States, 2013). Front-end design encompasses significant uncertainty and is often deemed the "fuzzy front-end" (Borgianni et al., 2018). Analyzing the problem, its stakeholders, and contextual constraints through research helps shape this ambiguity and assures an optimal engineering solution (Crismond & Adams, 2012). Spending time in front-end work is widely recognized as a dimension of design best practice (Crismond, 2001; Crismond & Adams, 2012; Murray et al., 2019; Schön, 1984). Yet, front-end design work may not hold the same weight in college engineering programs or professional engineering settings as technocentric work (Dym, 1994). Students, faculty, or practitioners may devalue these processes within engineering design, or worse, actively dismiss them as not being part of recognized engineering design work (Atman et al., 2007; Cardella et al., 2006; Murray et al., 2019). As such, the inclusion of front-end design practices in the NGSS or the ASEE's frameworks may not have as much disciplinary heft behind them as other design practices might.

Although described innocuously by some or dismissed entirely by others, front-end design work is a site of significant power negotiation in technology development. As Costanza-Chock (2020) asserts, "…much of the time, powerful institutions frame problems for designers to solve in ways that systematically invisibilize structural inequality, history, and community strategies of innovation, resilience, and organized resistance" (p. 121). Regrettably, front-end design work can be a site of applying deficit lenses to communities instead of asset-based lenses (e.g., problematizing a lack, as opposed to problematizing why there is a lack, Costanza-Chock, 2020). It can be a site of deciding who counts as stakeholders in the design, how they count, and at what points in the design their input matters (Benjamin, 2019b; Gaskins, 2019). As early as identifying the problem of interest, front-end design work has significant consequences for design outcomes, particularly if these outcomes are just. Engaging, exploring, framing, and researching a problem space is not just a matter of design best practice (Crismond & Adams, 2012); it is also where the ethics of design are negotiated, and designs might be developed toward just and liberative ends (Benjamin, 2019b; Costanza-Chock, 2020).

Although scholarship exploring how youth engage in front-end design practices is limited, scholars that have done so continue to champion the front-end's value. For example, Cunningham and Kelly (2017) articulated several epistemic practices of engineering that relate to the practice of front-end design. They assert that engineering knowledge is constructed and negotiated, in part, through: "1) Developing processes to solve problems, 2) Considering problems in context, and 3) Envisioning multiple solutions" (Cunningham & Kelly, 2017, p. 7), suggesting front-end design work helps youth build engineering knowledge. Critical of the NGSS ignoring issues of justice within engineering, Gunckel and Tolbert (2018) argued for a dimension of care in engineering design work with youth. Engineering with care, the authors argued, required "attention to contextualizing and even re-contextualizing the problem space to transcend the ways that problems, constraints, and choices are often portrayed in technocratic, utilitarian, and neoliberal terms," a core of socially-engaged front-end design work (Gunckel & Tolbert, 2018, p. 954).

Similarly, McGowan and Bell (2020) recently centered front-end design work in developing a framework around the question, "How can we design learning environments to help students critically understand the intrinsic and systemic sociotechnical relationship between people, communities, and the built environment?" (p. 983). For several purposes, engineering education scholars, science education scholars, and curriculum developers alike argue not only that problem definition and exploration – the front-end of design - is a part of authentic engineering practice and that youth *can* and *should* be engaging in this work. This suggests developing educational experiences that create opportunities for youth to do front-end work. What youths' engagement in front-end work looks like and the meaning they make of such an experience is an area ripe for continued research and development.

The Potential of Front-end Design Practices

Beyond its specific inclusion in the NGSS, front-end work presents itself as interesting practices to study in youth engineering contexts for several reasons. Fundamental to learning, engaging in problem framing creates purpose in doing engineering work. Previous work in literacy has shown that "[w]ithout the question or problem to study, the work is virtually meaningless" (Moje, 2015, p. 262). As such, without doing the work to identify, frame, and explore an engineering problem in context, the subsequent work may appear to youth as nothing more than a building activity (Purzer et al., 2014). Further, expert designers and engineers continually acknowledge that front-end practices are fundamental and crucial to successful design (Crismond & Adams, 2012; Dorst, 2006; Dym et al., 2005). Thus, front-end design presents itself as both a foundational set of disciplinary practices and an exciting space to explore youths' practice expansively and consequentially.

By drawing lines around the particular histories of "what counts," engineering is inherently political (Riley, 2017; Rosner, 2018). Although front-end design practices that socially engage the context of design may be contested by some engineers as "not engineering enough," their inclusion may offer new ways that experience, identity, and self may be made present - and even celebrated - in engineering work. In an increasingly technocentric world, centering such practices may humanize design and offer the same to broader engineering. In my work, I seek to explore youths' interactions and experiences with these practices. By centering youths' engagement in and discussion of these practices amid other engineering experiences, I interrogate the power and potential of these types of socially centered, purpose-driving design practices as a means to invite youth to engineering work in design.

Conceptual Frame

Given the continued diversity concerns in engineering, it is crucial to design experiences at the K-12 level in ways that acknowledge how culture-free understandings of engineering have detrimentally affected diversity within the field. As was recently traced and argued, "[c]ontemporary images of engineering emerged from multiple and diverse historical pathways, which have increasingly narrowed what counts as engineering and who gets to be an engineer over time" (McGowan & Bell, 2020, pp. 1000-1001). Without acknowledging and attending to these ideas, there is a potential to investigate youth engineering work in ways that reproduce the same systems of inequity and exclusion seen in post-secondary settings (Johri & Olds, 2011; Riley, 2017; Secules et al., 2018). Instead, I look to learn from youth about how to better support engineering work for purposes meaningful to them. As Moje (2002) argued within the field of literacy, "[t]o fail to study youth literacies is to support narrow conceptions of what it means to learn and use literacy, which perpetuates the problem of studying only the struggles, rather than the potentials, of youth" (Moje, 2002, p. 224). In turn, I argue that to fail to design for and study youths' emerging, evolving, and likely expansive engineering practice is to study narrow conceptions of what it means to engage in engineering. Sociocultural learning theories help center the "diverse historical pathways" of learners and learning and assert that learning is a contextual, social enterprise. As a basis for future experience development, I look to critical sociocultural theories to explore young people's engineering and design work and the meaning they make of it in their own lives.

Introducing Sociocultural Theories

For my work, I use the term sociocultural theories to describe scholarship stemming from Vygotsky's theorization of the nature of development and learning. Shifting from other perspectives at the time, which centered on individualized cognition and intelligence theories, Vygotsky asserted, "…human learning presupposes a specific social nature and a process by which children grow into the intellectual life of those around them" (Vygotsky, 1978, p. 88). In his view, the mind extended "…beyond the skin," in that mental functioning was not an individual attribute but a socially evolved process organized through histories and tools of culture (Wertsch & Tulviste, 1992). Thus, Vygotsky's work makes visible the role of human interaction and activity in constructing what we know as cultures, like academic disciplines:

> The word "social" when applied to our subject has great significance. Above all, in the widest sense of the word, it means that everything that is cultural is social. Culture is the product of social life and human social activity. That is why just by raising the question of the cultural development of behavior we are directly introducing the social plane of development. (Vygotsky, 1981, p. 164)

In this, sociocultural theorizing renders "culture-free" or "identity-free" notions of academic disciplines, like engineering (e.g., Wichman, 2017), obsolete. Instead, sociocultural theories provide a lens to meaningfully ask how human interaction and activity can shape learning and what is valued through history and the current day.

By asserting learning as a social, interactional process that is dependent on relationships with others, Vygotsky's theorizing laid the groundwork for decades of sociocultural scholars to theorize about, explore and complicate the nature of learners and learning (e.g., Cole & Wertsch, 1996; Gutiérrez & Rogoff, 2003; Lewis & Moje, 2003; Nasir & Hand, 2006; Wertsch &

Tulviste, 1992). Out of this scholarship grew the collective understandings of the dimensions of sociocultural theories, tied to Vygotsky's original theorizing. For example, Esmonde (2016, pp. 7-8) articulates six elements of sociocultural theories that distinguish them from individual cognitive perspectives, in that they attend to:

(a) cultural artifacts as mediating human activity

(b) learning occurring in everyday life

(c) the role of context in studying learning

(d) histories of participation as shaping learning

(e) learning as a developmental process, and attending the process (over outcomes)

(f) the roles of structures and agency in participation

Esmonde's (2016) framing raises what has made sociocultural theories so important for understanding learning, as these dimensions broaden the conversation from "whether" something has been learned to "how" and "why" that might be, as well as understanding the expansive milieu in which learning occurs.

Critical Sociocultural Theories

Exploring youths' participation through sociocultural lenses raises the importance of looking at the role of context and the cultural nature of the engineering discipline (Gutiérrez & Rogoff, 2003). An explicit attendance to power supports valuing youths' personal experiences within a program to inform more inclusive practice. Although these theories offer significant synergistic potential to contend with power, power was undertheorized within Vygotsky's original conceptualizing (Esmonde, 2016). Importantly, later sociocultural theorizing began to layer critical perspectives to explore learning a contextual, socially negotiated process operating within systems of power (Esmonde & Booker, 2016; Moje & Lewis, 2007). To take a critical sociocultural view means acknowledging that power is constantly at work within the process of learning. It is then necessary to critically engage with the potential tensions between the current culture of engineering and cultural practices and knowledge specific to youths' personal experiences and identities. As such:

> Learning is thus not only participation in discourse communities, but is also the process by which people become members of discourse communities, resist membership in such communities, are marginalized from discourse communities (or marginalize others), reshape discourse communities, or make new ones (Moje & Lewis, 2007, pp. 25-26).

I frame this study through critical sociocultural theories of learning that argue: (a) Learning work is not static; rather, it is complex and negotiated at the intersection of race, ethnicity, gender, and place (Esmonde, 2016; Lewis et al., 2007; Lewis & Moje, 2003; Nasir & Hand, 2006), and (b) The diversity and heterogeneity within epistemic perspective are authentic and necessary for meaningful repertoires of practice (Bang, Medin, & Atran, 2007; Barajas-López & Bang, 2018; Rosebery, Ogonowski, DiSchino, & Warren, 2010).

Critical Sociocultural Theories and Youth Engineering

Applying a critical sociocultural perspective to engineering education for youth necessitates interpreting "engineering" itself as a socially constructed culture or discourse community built on historical norms, practices, and social decisions. As explored earlier, the discipline of engineering *is* engineering because of the ways particular people historically participated in it over time, coming to organize activity and engagement around design. Similarly, discourse communities can be defined as "groupings of people—not only face-to-face or actual in-the-moment groupings, but also ideational groupings across time and space—that share ways of knowing, thinking, believing, acting, and communicating, or, in Gee's (1996) parlance, Discourses" (Moje & Lewis, 2007, p. 17). Thus, the engineering discipline *is* engineering through how participating humans have shared ways of knowing, doing, and being over time. Acknowledging this, we can see how "engineering work" is shaped by those participating in it. Thus, in Vygotsky's phrasing, engineering has socially constructed rules and meaning but can be subject to new imagination – should we so choose (Gutiérrez et al., 2017; Moje, 2015).

Not only can critical sociocultural perspectives shape how we understand engineering, but it also shapes the field of vision for both exploration and analysis in the design of engineering contexts. Borrowing from the science education literature, a critical sociocultural research trajectory:

> …should be focused on the constellations, or ecologies, of sense-making practices and processes of interaction that people participate in, particularly in everyday contexts, and the meanings, ideas, problem solving, and forms of social life that emerge in these contexts and across development (Bang, 2015, p. 223).

Similarly, Kelly (2012) argued, "[f]rom a sociocultural point of view, learning to be a member [of a discourse community] entails participating in social groups by building repertoires of discourse, and ways of being that are viewed as making sense within the relevant group" (Kelly, 2012, p. 189). As such, taking a critical sociocultural frame to youths' engineering work encourages researchers to examine the nature of participation within the community, capture the negotiated processes of knowing, doing, and being within that community, and/or make visible the meaning-making youth do as a group and individually. In calling for greater sociocultural framing to be brought to K-12 engineering contexts, McGowan and Bell (2020) posited:

> Sociocultural perspectives of learning in engineering would aim to situate learners along the boundaries of engineering communities of practice through partnerships, field trips, and the use of technology to extend learning beyond classroom walls, and to situate students' engineering practices within a larger social context (p. 1001).

Their assertion surfaces the need to think broadly about how youth participate in and explore engineering and how youth make meaning of these experiences within their lives.

My work is motivated by a desire to design better engineering experiences. I define "better" as addressing the ongoing lack of diversity, equity, inclusion, and justice within the field of engineering. The high attrition rates in engineering suggest a system that only works for a few and does not assert diversity as an asset (Holly, Jr., 2020; Pawley, 2017; Riley, 2019). The lack of diversity furthers narratives of engineering work of primarily one voice and type. As such, as we think about *what* youth should experience in engineering programs, we must ask: Are we seeking to *conserve* what is or *transform* toward what could be (Engeström & Sannino, 2010)? Exploring this does not have to be entirely dichotomous. It does, however, motivate a need for criticality to imagine what the transformation might be (Espinoza et al., 2020). Adopting such a perspective assists in resisting color-blind, gender-blind, class-blind notions of engineering that obscure marginalization issues and challenge dominant ideas around who can be a knower of engineering, identify as an engineer, and what is valued in engineering spaces (cf. Calabrese Barton & Tan, 2009, Gholson, 2016; Nasir & Hand, 2006). Borrowing from the field of science education, Bang and Medin (2010) argued:

> Central to the future of science and science education is to understand, support, and leverage the ways in which diversity—of people, practices, languages, meaning, knowing, epistemologies, goals, values, and the like…in learning environments and

professional practice are an asset and expand the possibilities for human knowing and meaning (p. 1009).

From a critical sociocultural perspective, I offer that it is necessary to understand and leverage the diversity of youths' design work, experiences, and discussions. Their experiences in design and engineering are valuable starting points for expanding and imagine future "good" engineering work. As such, I pair my critical sociocultural theorizing with other critical theories that (a) attend to the specifically powered history of the design and engineering disciplines and (b) seek to make visible the invisible within those communities. I look to critical science and technology studies (STS) of design as a grouping of critical scholarship exploring power and oppression overtly within engineering design culture and implicitly within design practice.

Critical STS Perspectives on Design

The field of Science and Technology Studies (STS) concerns itself with studying the anthropological study of STEM disciplines as cultures. Aligned with sociocultural theories, STS asserts:

> "…that science and technology are thoroughly social activities. They are social in that scientists and engineers are always members of communities, trained into the practices of those communities and necessarily working within them" (Sismondo, 2009, pp. 10-11).

The theories I am calling "critical perspectives within STS" pair the cultural study of a STEM discipline with an interrogation of structural power. For example, feminist epistemologies of science, a critically-oriented STS perspective, asserts that "sciences share their societies' fundamental assumptions about what is interesting and important to know. Thus racist, sexist, and imperial societies will tend to sponsor sciences that, in turn, provide resources for racist, sexist, and imperial societies" (Harding, 2015, p. 19). Thus, historically, as dominant "Western scientific institutions" were being formed, they were not impervious to the "institutionalized, normalized politics of male supremacy, class exploitation, racism, and imperialism," because they were, and still are, social constructs (Harding, 1992 p. 568). Critical STS theories contend that these structures are allowed to persist because STEM fields' rejection of work as "political" or "social" (Cech, 2013). The dominant ideology of STEM fields is that the *discipline* is separate from the *humans* who do the work. This assumption of neutrality, framed as "objectivity," continues an indefensible cycle within STEM disciplines of being oppressive and exclusionary (Harding, 1992; McGee & Robinson, 2019). Critical STS theories help name how systems of oppression are working at all levels and grain sizes of STEM work.

Because my work focuses specifically on the design dimension of engineering work, I was interested in critical STS work that posed a precise critique to design. This overlap is particularly niche, and work in this area is evolving and ongoing, often citing one another. These theories, explored in greater detail below, helped me conceptualize a particular critique of engineering design that located systems of oppression interactionally and within the histories of design practice (e.g., what is being problematized?) and designs themselves:

1. Critical STS theories of design assert that systems of oppression live in practice in the doing of design.
2. Critical STS theories of design assert that, regardless of their bases, by not interrogating design practice or actively obfuscating the history and "how" of design, we risk designing unjust, oppressive, and/or discriminatory designs.
3. Alternatively, by reframing and broadening design, engaging in design that invites a diversity of experience in all facets of the design practice, we move toward liberative and just design that serves a heterogeneous interest.

4. Importantly, this starts at the beginning of design, defining and understanding the problem being designed toward. Then, these theories call for us to speculate about new ways to move forward in design work.

Drawing on Nasir and Hand's (2006) and Esmonde and Booker's (2016) questioning across theories, Table 2-1 overviews three critical STS theories of design that supported my development of a critical stance towards engineering design. Even though these theories exhibit significant overlap, particularly in their understanding of how historical systems of oppression have shaped what is celebrated in design (Rosner, 2018), design practice (Costanza-Chock, 2020), and design outcomes (Benjamin, 2016, 2019), I wanted to address the details in their specific formulations and purposes and to be clear about how they contribute to my thinking, analysis, or implications. Of important note, they were all born from the application of Black Feminist thought (e.g., Collins, 2009; Crenshaw, 1993.; hooks, 1994) to engineering and design space. Together, these theoretical perspectives supported a frame of the study to look expansively at youths' practice. Further, these perspectives support the importance of thinking about *whose* voice and experience are centered or marginalized in design work. Broadly, each theory suggests refocusing or reforming the design narrative – interrogating what information is pertinent to the design from the margins – moves us toward a more just and liberatory design.

As much as I value these assertions regarding engineering design practice broadly, I also see them as relevant to designing engineering experiences for youth. Reworking from the margins, youths' experiences, engagement, shifts, stabilities, discussions, and opinions become the pertinent information to move engineering educators toward designing equitable, just, and liberatory programs. These perspectives might help us reconceptualize engineering design norms for youth. For example, drawing on these and sociocultural critical theories, the *Sensors* program[4] was designed from the perspective that:

1. Youth participants should be engaged in design and research work from the beginning - defining and exploring a community problem that they wanted to study and for which they were interested in designing solutions.
2. Youth should be brought into the "how" of design to meaningfully shape practice. Thus, youth should be in charge of how the problem is explored, research is enacted, data is collected, and data is interpreted to address the problem. They select community partners with whom they wanted to work.
3. Facilitators should invite youths' voices and decision-making. Further, they need to ensure that community partners respect youth voices and recognize their capacity to make decisions rather than simply implementing someone else's design work.
4. Youths' engagement, research, and design should be located in a local place with accessible stakeholders not only so there are real-world implications for the work, but that heterogeneous interests might be explored.

Moving across these theories in Table 2-1, paired with critical sociocultural perspectives, might open more opportunities to interrogate *what* we ask youth to do in engineering design programs and *why* we ask youth to do it. Developing more inclusive programming requires the continued questioning that critical sociocultural theories and critical STS theories of design support.

[4] The *Sensors* program design and theory of action is further discussed in Chapter 3.

	Rosner's Critical Fabulations (2018)	**Benjamin's Discriminatory vs. Liberatory Design (2016, 2019)**	**Costanza-Chock's Design Justice (2020)**
What was the theory developed to explain?	"Critical Fabulations" was developed to interrogate, "desettle," expand, reclaim, and reassert what "counts" in design and design practice. The term "fabulations" derives from fables, as the goal of this theory is to re-story the "hows" and "whats" of design.	"Discriminatory Design" is a conceptual toolkit and lens developed to question bias in the objects and tools of everyday life. Benjamin (2019) offered discriminatory design as a way to interrogate "how social norms, policies, and institutional frameworks shape a context that makes some technologies appear inevitable and others impossible (p. 4). Focused on design outcomes, it asks why we have certain designs and not others.	"Design Justice" is a framework and community of practice conceived to analyze "…how design distributes benefits and burdens between different groups of people. Design Justice focuses explicitly on the ways that design reproduces and/or challenges the matrix of domination (white supremacy, heteropatriarchy, capitalism, ableism, settler colonialism, and other forms of structural inequality..." (p. 23). Design Justice aims to critique design culture through its values, practices, narratives, sites, and pedagogies in theory and practice.
How does the theory define design?	Rosner asserts, "I read design (its heritage, discourses, and practices) as a means of making the world different from how it is now" (p. 9). In this, Rosner takes up design as a practice of sub-practices (with significant histories of participation). Design practitioners have made choices to include and exclude knowledge and practices to maintain power and dominance in the tradition.	In Discriminatory Design, Benjamin focuses on the outcomes of design, the tools, objects, and processes resultant from design. These technologies are encoded and imbued with social particularisms that led to this finalized product over another. Looking at design as design outcomes also brings into focus the absence of design - what has not been designed within society's structured context?	Costanza-Chock asserts that design is a whole range of things, from an object or process (and its features) to the specialized expert knowledge of designing, to a way of "thinking learning, and engaging in the work" (p. 15). They assert that Design Justice serves as a framework to question all of these facets of design in society.

	Rosner's Critical Fabulations (2018)	Benjamin's Discriminatory vs. Liberatory Design (2016, 2019)	Costanza-Chock's Design Justice (2020)
What are the key concepts or themes of the theory?	Critical Fabulations indexes Feminist Technoscience (e.g., Haraway, 1991), Black Feminist Thought (e.g., hooks, 1994, Hartman, 2008), and STS perspectives (e.g., Suchman, 1987) to categorize and problematize "dominant design" and disrupt it along four canonical dimensions: Individualism, Objectivism, Universalism, and Solutionism.	Discriminatory design puts STS studies (e.g., Eubanks, 2018) in conversation with critical race studies and methodologies (e.g., Roberts). By putting these in conversation, Benjamin contends we might better see how racial discrimination is codified, objectified, and reproduced through our technologies.	Design Justice overlays the Black Feminist perspectives of intersectionality (e.g., Crenshaw, 1989) and the matrix of domination (e.g., Hill Collins, 1990) to interrogate how universalist perspectives on design erase the perspectives of and/or actively fail for particular groups. Taking these frameworks to design allows us to "see, engage with, account for, or attempt to remedy…" the reproduction of oppression in dimensions of design work.
How does this theory help us understand youths' engineering design?	Rosner argues for a future towards "[d]esign as a practice that serves heterogeneous interest" (p. 12). Rosner develops counter-tactics towards dominant design work: Alliances (vs. individualism), Recuperations (vs. objectivism), Interferences (vs. universalism), Extensions (vs. solutionism). She proposes these as ways of not replacing canonical design practice but redefining what counts within design and design practice (p. 82). These "unsettlings" offer ways focal youths engineering design practice might expand dominant design culture and "foot-holds" for educational design work seeking to also "unsettle" design norms.	Benjamin argues that identifying Discriminatory Design necessitates the question: "How, then, might we develop a justice-based approach to technoscience?" (p. 11). She asserts the answer comes from a design that is actively Liberatory and anti-Discriminatory. Liberative Designers "imagine and crafts the world you cannot live without, just as you dismantle the ones you cannot live within" (p. 14). Thus, discriminatory vs. Liberatory design provides a litmus test for the outcomes asked of youth in their design and necessitates design outcomes to be socially just.	Costanza-Chock defines "Design Justice" as a framework of critique and a community of practice attempting to move towards more just design. She proposes the ten principles of the "Design Justice Network" (see pp. 6-7), which might serve as a new starting place for K-12 engineering design education. Further, Costanza-Chock argues that design pedagogies carry the same weight as design values, practices, narratives, and sites. They argue that design education, at all levels, compels us to ask, "will this…advance our collective liberation? How do we ensure that it does?" (p. 208). Design Justice provides avenues to connect socially-just design practice to the speculative global purpose of design.

Table 2-1. Comparing critical STS theories of design

Summarizing: Youth Perspectives in Developing Engineering Programs

Across the landscape of motivations, values, and purposes represented in youth engineering programs, youth themselves remain a relatively forgotten stakeholder. Given the recent focus on pre-college engineering, it behooves the field to learn from other K-12 scholarship. As Moje (2002) argued with the context of adolescent literacy, the field needed:

> …to examine how youths' literacy practices reflect the intersection of multiple groups (e.g., ethnic groups, youth cultural groups, social class groups, to name just few), and to examine how the knowledges, ways of knowing, and identities they build from those group experiences intersect with the advanced, deep content learning teachers, parents, and administrators expect young people to do in secondary school classrooms (Moje, 2002, p. 213)

Similarly, I contend that a deep focus on youths' engineering practice, the meaning they make of this practice, and how this practice lives within the greater fabric of their lives serves as a necessary starting point for developing meaningful and equitable engineering experiences. Further, the work of connecting youths' practice to the field, while also holding the meaning youth are making, offers an opportunity to explore if we, engineering educators, are genuinely designing "engineering experiences for all" (*Framework for P-12 Engineering Learning*, 2020), or in what ways we might shift course.

CHAPTER 3 Research Methods and Design

Introduction to Study

Supporting the development of inclusive engineering experiences for youth, my dissertation addresses the gaps in the literature by qualitatively investigating how youth engage in and discuss design work in the *Sensors* program. My analysis looked at youths' interaction with *Sensors'* design work of defining, exploring, and ideating problems. Looking across both youths' engagement in and discussion of their experiences illuminates the hidden meaning making that youth may do in engineering programs designed to provide access and opportunity. The purpose of this work is not to generalize to other groups of youth but to showcase patterns of experience that can guide the development of future engineering programs for young people and help frame future empirical research. The research questions guiding my study are:

1. **In what ways do youth engage in the design practices of the *Sensors* program?**
    a. What does this look like *within* and *across Sensors* program experiences?

At a time when the particulars of engineering education for youth are rapidly evolving, I propose that engaging in front-end design practices – the work of design that defines and scopes the design problem – might create new connections to engineering work for youth. To explore this premise, I first explored the breadth of ways youth engaged in front-end design practices. Drawing upon parallel studies in science education (Bricker & Bell, 2012; Herrenkohl & Cornelius, 2013), this set of questions examined what it meant for youth to engage in design work and how their practice might have shifted over time. Further, to oppose narratives that underestimate youth's skills and engagement, I leveraged critical sociocultural theories of learning and critical STS theories of design to interrogate connections between focal youths' practice, recognized design practice, and expansive, liberatory versions of these practices.

2. **How do youth talk about their engineering design experiences?**
    a. What do youth narrate as compelling moments in a shared engineering experience, if at all? Why are these meaningful to them?
    b. What tensions arise between narration and engagement?
    c. How do they narrate engineering in relation to themselves, if at all?

This set of questions explored how youth discussed their design and broader engineering experiences to observe the interaction between youth and the Sensors program. They begin to examine how youth might begin to connect to or see themselves belonging within design, or engineering work. This portion of the dissertation centers youths' experiences, from their perspectives, as important building blocks for engineering programs.

Research Design and Methods

Though historically not always the case, the last decade has seen a growing number of scholars engaging in and calling for epistemically and methodologically diverse approaches to the study of engineering education (Case & Light, 2011; Holly, Jr., 2020). An increasing number of calls for "small 'n'" research focus on deep dives with fewer participants to explore the rich details of engineering realities (Slaton & Pawley, 2018, p. 134). This turn to qualitative work creates alignment with K-12 science and mathematics education scholarship, where in-depth interpretive and critical qualitative and design-based studies are commonplace (Bell, 2004; Erickson, 2012; Kelly & Green, 2018). Seeking to contribute to these calls, this study explores the proposed research questions through a design-based frame, studying a small group of focal participants to illuminate their experiences.

Drawing on Design-Based Research to Study Youth and Design

Design-based research (DBR) has different sensibilities and traditions, with the goal of projects guiding different types of design work (Bell, 2004). It is a tradition that can consider time and historicity and explicitly makes the researcher known (Engeström, 2005, 2011). It can grapple with problems of educational practice (be it teaching or policy) in ways that engage stakeholders (Gutiérrez & Vossoughi, 2010) or partner with them towards transformative ends (Bang & Vossoughi, 2016). The design might be the primary focus in research *on* design (Bell, 2004). Alternatively, the design might serve as a contextual space to study other questions or interactions, as is the case with research *through* design (e.g., Espinoza et al., 2020; Sengupta-Irving & Vossoughi, 2019; Vossoughi et al., 2021). What emerges from DBR may be a physical object (like curriculum) that transfers to a new context or theories that may shape and shift how we might see designed futures or some combination thereof.

This dissertation study is derived from a larger development and implementation DBR project (Penuel et al., 2011). The larger study was formulated as research *on* the development and enactment of the *Sensors* curriculum, *writ large*. As a subset of the larger project, this dissertation study researches through the design of *Sensors*. Through the nature of *Sensors*' design work, I studied youths' engagement and discussion of flexible, real-world front-end design practices. In this way, the study draws on collaborative ethnographic methods (e.g., "studying side-by-side" Erickson, 2006, 255) and social design experiment (Gutiérrez & Vossoughi, 2010) to both: (a) study youths' engagement within a designed space that I participated in as well (RQ1) and (b) learn from youths' experience through in-moment and reflective discussion to think about transforming engineering programs (RQ2). Seeking to dig deeply into youths' subjective experiences in the micro-space of front-end design practices (e.g., Davis et al., 2020; Sengupta-Irving & Vossoughi, 2019), I worked with seven focal youth and developed detailed profiles around their experiences in *Sensors* end design overtime and discussions of engineering. I then analyzed these profiles to research *through* Sensors' front-end design practices to explore future inclusive engineering program futures. In the next section, I describe the design the *Sensors* program more broadly, and locate front-end design practices specifically within this program.

Design of the *Sensors in a Shoebox* Program

This study's context is the *Sensors* community program developed by a partnership between the University of Michigan School of Education and the College of Engineering over the past five years. The project was developed to democratize the tech-dependent data collection happening in "smart and connected" cities through accessible technology and education (see Crawford, 2017). To do this, the education development team designed the programming for youth, seeking to work with youth as a resource in using new technology for community research. This program aimed to support young peoples' existing connection to their communities through community research, developing social science and STEM skills. Guiding the programming development was an emphasis on flexibility and transformation (Bang & Vossoughi, 2016; Gutiérrez & Vossoughi, 2010), figuring out what ways youths' interests and experiences could guide the direction of the program.

Further, the educational design team thought specifically about how community research, both tech-assisted and social science-based, would be meaningful to youth. In this, the motivation for designing *Sensors* (potentially) differed from a traditional engineering outreach effort or recruitment program: the primary goal of *Sensors* was not to broaden participation in engineering programs. Instead, we tried to design the *Sensors* program to develop skills to better participate in and critique an increasingly technology-driven society (see "Sensors in a Shoebox," n.d., Figure 3-1). As Moje described to the press, "[t]he real goal of this project is to engage young people in identifying problems in their community and learning to do scientific research to work on solutions" (Moje in Crawford, 2017). To create such a space, the education development team drew on people-focused, socially engaged design practices to structure the beginning of the *Sensors* program. After working with youth for two iterations, design became a bigger part of the program, as youth then used the findings from their problem identification and community research to develop an early solution (Figure 3-2). In the next section, I expand upon the conceptualization of design within the *Sensors* program.

Current Conditions	**If we engage youth in programming…**	**Then…**	**Vision**
• Greater calls for informal STEM programming to support broadening participation in STEM fields • Informal STEM programming should be dynamic, reflect learners interests and allow learners to engage with STEM phenomena • Critiques exist that engineering current K-12 engineering programming does not reflect the work of engineering	• Where youth define a community engineering problem that's of interest to them that drives the engineering design process • That centers the need to understand the community and its members through human-centered design principles • Is representative of the full engineering range of design cycles • Has real-world implications in implementing design outcomes	• There is greater opportunity for youth to see engineering as relevant to their lives and community • The work of engineering is authentically reflected to learners • Engineering and STEM-related skills are developed through doing the work of engineering and research • There is greater opportunity for engineering identity work	• Youth are connected to their community through research and engineering • Youth are empowered as future engineers, researchers and social scientists to address community needs, broadening STEM participation • Youth develop the skills needed to pursue these trajectories, while also supporting them as citizens of the natural and designed world

Figure 3-1. A proposed theory of action from the larger *Sensors in a Shoebox* DBR project

Front-end Design in the **Sensors** ***Program***

Drawing from principles of people-focused design (e.g., Buchanan, 2001), the programming guides youth, as a group, to first define a potential problem of personal interest in their community. To do this work, program facilitators engage youth in exploratory activities, such as community observation, sharing personal experiences, meeting with stakeholders, and root-cause analysis. Youth and facilitators generate a list of potential problem space and then work to narrow it down through pilot stakeholder needs assessments, problem (re)framing, and scoping exercises. These processes then guide a larger community data collection process, in which youth work as a team to design a coherent research plan to explore their problem space(s). To carry out the research, youth construct and pilot interview, observation, and survey tools. The youth also deploy a sensing toolkit designed at Large Midwestern University for "smart city" applications. The kit consists of ruggedized sensors that could be easily installed to allow communities to measure aspects of the world around them, including environmental parameters, vibrations, and motion. A user-friendly data portal provides students with access to insights about how their neighborhoods operate while empowering community-based decision-making.

In the next stage of the work, facilitators support youth in analyzing the community data and developing early ideas about potential recommendations or solutions. In early iterations, this looked like design recommendations. This looked like developing implementable prototypes (Figure 3-2, Table 3-1). Facilitators, community partners, and youth work together to prototype and test some possible solutions and implement these within the community where they have been working. Finally, youth develop a presentation in a format of their choosing that communicates their process, research findings, and final design. Community stakeholders, family, and civic leaders are invited to presentations and give input. Beyond youths' interests and experiences guiding the problem definition and framing, facilitators also try to respond to youths' in-moment input into the research plan and design process (see Table 3-1). The youth are invited to provide feedback on their experience at the end through focus groups. As such, youths' understandings and experiences inform the design of future programming iterations (Figure 3-2).

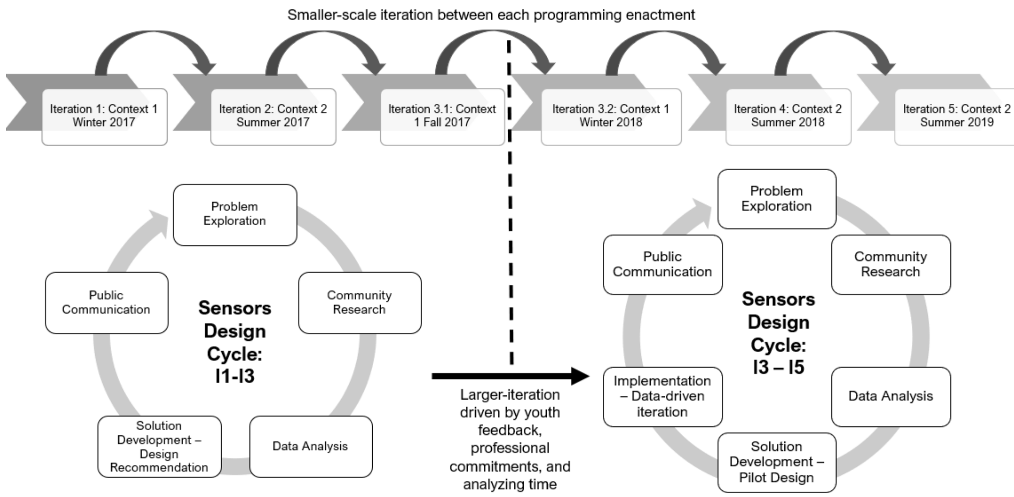


Figure 3-2. Overviewing *Sensors* iterations and design process

Programming Iterations and Project Foci

Due to the responsive nature of the program, youths' input, and the iterative development of the *Sensors* program, there are differences between each iteration. Although facilitators sought to engage youth in the same main steps – problem definition and framing, community research, and some solution ideation – the process through which that occurred shifted over each iteration. Each time the *Sensors* program ran, the youth defined and scoped a new engineering problem to pursue as their project. As a result, problem spaces might physically live in the same location across iterations but were defined differently across. Table 3-1 outlines the problem spaces and solutions youth proposed in each iteration and where their work was physically located in the community. It also details the shifts in specific design processes between each iteration.

Table 3-1. Outlining *Sensors'* processes and projects over time

	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5
Project Location	Walkway at a Local Riverfront Conservancy	Local Park in surrounding neighborhood	Park at a Local Riverfront Conservancy	Local Park in surrounding neighborhood	Local Park in surrounding neighborhood
Project Description	Improving walkway space usage	Improving park comfort and safety	Improving park seating for socializing	Improving park quality through welcoming, comfortable seating	Improving park quality through new welcoming features
Project Outcome	Design memo to conservancy presenting data and recommendations	Design meme to neighborhood business association	Benches and tables, arranged to encourage conversation	Sensor enabled bench, near park sign, painted brightly, surrounded by planters, suggested trash can placement	Restoring and moving sensor-enable bench, adding usable herbs to platers, inspirational rocks, suggested bench design
Front-End Process	• Community walk • Problem brainstorm • Stakeholder pitch • Research tool development • Community data collection • Sensor deployment	• Community walk • Problem brainstorm • Stakeholder pitch • **Park case study** • Research tool development • Community data collection • Sensor deployment	• Community walk • Problem brainstorm • Park case study • **5-Whys analysis** • **Scoping table plotting** • Stakeholder pitch • Research tool development • Community data collection • Sensor deployment	• Community walk • Problem brainstorm • **Stakeholder mapping** • ~~Park case study~~ • 5-Whys analysis • Scoping table plotting • Stakeholder pitch • Research tool development • Community data collection • Sensor deployment	• Community walk • Problem brainstorm • Stakeholder mapping • 5-Whys analysis • Scoping table plotting • ~~Stakeholder pitch~~ • Research tool development • **Pilot community data collection** • Research tool development • Community data collection • Sensor deployment
Back-End Process	• Data analysis • Needs identification • Design recommendations • Design memo	• Data analysis • Needs identification • **Design presentation to stakeholders**	• Data analysis • Needs identification • ~~Design recommendations~~ • **Design requirements** • **Solution brainstorming** • **Sketching** • **LEGO modeling** • **Prototype Implementation** • **Implementation data collection** • Design presentation to stakeholders	• Data analysis • Needs identification • Design requirements • Solution brainstorming • Sketching • ~~LEGO modeling~~ • **Solution build with sensor** • Prototype implementation • **Design experiment** • Implementation data collection • Design presentation to stakeholders	• Data analysis • Needs identification • Design requirements • Solution brainstorming • Sketching • Solution build with sensor • Prototype implementation • Design experiment • Implementation data collection • Design presentation to stakeholders

*Note: **Bolded text** indicates an additional process; ~~strike-through~~ text indicates a process was removed.

Local Contexts of *Sensors'* Programming

The community programming was run at two locations for three years within a large Midwestern city on the rebound of severe economic decline (Table 3-1). Both locations were in the same neighborhood of the city, roughly 15 minutes away from one another. The first context (Context 1) was an afterschool setting. In a given iteration, youth met once or twice a week in an afterschool space for 1-2 hours at their school. Programming would run for between 4 months to 6 months and include field trips to youth-determined research sites (e.g., a riverfront pathway in the city's downtown). These sessions ended with a final presentation to stakeholders.

The second context (Context 2) was a summer program setting in partnership with a well-known community organization serving a predominately Latina/o/x population. The organization lives in the oldest surviving neighborhood of the city. Our partnership with this organization was paramount because (a) it continues to be a trusted community organization that serves a population of youth historically marginalized in traditional engineering contexts; (b) it has a pre-established summer program for youth with flexible project time and (c) it has an interest in developing youths' science, technology, engineering, and math (STEM) skills. During the summer camp, youth select a programming option that they attend for four weeks. In a given iteration, programming would run three times a week for 1-2 hours at the organization and included research visits to neighborhood sites (e.g., a nearby community park of interest to the youth). These sessions ended with a final presentation to stakeholders.

	Context 1	Context 2
Setting	Charter school	Community organization
Program Timing	Afterschool	Summer
Session Timing	4-5 pm	1-3 pm
# Iterations Completed	2	3
Youth Participants	Cassidy, Elizabeth, Adina	Mariabella, Rodrigo, Cesar, Red

Table 3-2. Outline of *Sensors* programming contexts

Sampling and Participants

This study focuses on three youth who participated in Context 1 and four youth who participated in Context 2. These youth were purposefully sampled based on (a) their full participation in one or more iterations of the program, (b) the location at which they participated, (c) their expressed interest in the study. To further elucidate my sampling criteria, I aimed to sample interested youth with whom I had built relationships. I also attempted to reflect the average gender ratios within each context. Context 1 maintained predominately female-identifying youth, whereas Context 2 maintained roughly a 50% split representation of male- and female-identifying youth. I present the demographic information that youth shared with me in

Participant	Age (starting *Sensors*)	Age (final interview)	Racial or Ethnic Identity	Pronouns	Context	# Years in *Sensors*
Elizabeth	14	18	Latina, Hispanic, Mexican	She/her	1	2
Cassidy	14	18	African American, Black	She/her	1	2
Adina	13	17	African American, Afro-Latina, Afro-Puerto Rican	She/her	1	1
Mariabella	14	16	Latina, Mexican	She/her	2	2
Rodrigo	15	16	Latino, Hispanic, Mexican	He/him	2	1
Cesar	12	15	Latino, Mexican	He/him	2	3
Red	11	14	Latino, Mexican	He/him	2	3

Table 3-3. Participant demographics

Data Sources

Data sources were shaped by the ongoing, iterative nature of DBR and the desire to dig more deeply into individual youths' experiences in interaction with the design. To inform the iteration to curriculum design, the research team video recorded sessions, spoke with youth *in situ*, formally interviewed youth, and collected youth-created artifacts. Each collected data type is discussed in more detail below. Table 3-4 outlines the amount of collected data per focal youth. The differences in the amount of collected video data reflect the differences in the time youth participated in *Sensors*.

Participant	# Years in *Program*	Clearly Visible/Audible Video (hrs)	# of Focus Groups	Reflective SRI	Other Interviews
Elizabeth	2	13.3	1	1	n/a
Cassidy	2	10.2	2	1	1
Adina	1	5.2	1	1	1
Mariabella	2	13.8	1	1	1
Rodrigo	1	5.8	1	1	n/a
Cesar	3	18.6	2	1*	2
Red	3	18.6	2	1	2

Table 3-4. Data collected per focal youth

Observations and Video

Over the three years that the *Sensors* programming has run, the research team, including myself, have collected over 100 hours of video data. I also collected associated reflective field notes (Creswell & Poth, 2017; e.g., Rahm & Gonsalves, 2012). I call these field notes reflective in that they were constructed after interacting with youth, focused within the larger DBR study context (Erickson, 2006; Gutiérrez & Vossoughi, 2010). The video captures my enactment of the *Sensors* programming plan and youths' interactions and engagement. Video was captured as part of the more extensive DBR study and focused on capturing the most interaction in the frame

(McDermott & Raley, 2011). Although this is a limitation of the data source, as it does not focus specifically on focal youth, focal youths' artifacts, memos, and focal youth interviews (both in focus groups and individually) supported tracing focal youth's engagement. I sorted all video data to identify "clearly visible" video for all youth, where the focal youth was in frame with clear audio.

Semi-Structured Stimulated-Recall Interviews

Engaging in in-depth interviews seeks "…to understand the 'lived experiences' of the individual" through subjective, issue-oriented, information-rich conversation (Hesse-Biber & Leavy, 2007, p. 118). One step deeper, stimulated-recall interviewing:

> "…brings informants a step closer to the moments in which they actually produce action. It gives them the chance to listen or view themselves in action, jog memories, and give answers of 'I did,' instead of 'I might have.'" (Dempsey, 2010, p. 350)

To provide a space for youth to reflect on their *Sensors* experience, I engaged in in-depth stimulated-recall interviews with focal youth based on analytically significant moments I identified in the *Sensors* video. Sample interview questions can be found in Appendix A. The front-end of these interviews were focused on youth discussing their engineering experiences *writ large* and reflecting on what engineering means (or does not mean) to them (cf. Varelas & Martin, 2013). All focal youth participated in this section of the interview. I then showed youth at least three 5-minute clips of their most recent participation in *Sensors* to support memory (O'Brien, 1993). During these interviews, the youth had control over the video to stop at any point to discuss. After watching, I asked youth a set of questions to reflect on their experience. These interviews were semi-structured in that if youth raised another memory from their *Sensors* experience, we would also revisit that video, photo, or image together. This portion of the interview was video recorded, and both portions of the interview were fully transcribed. All youth, except Cesar, participated in this section of the interview. Due to his robotics scheduling and then the onset of the Covid-19 pandemic, Cesar declined to participate in the stimulated recall portion of the interview.

Artifacts

Over each iteration of the *Sensors* program, I have collected originals or copies of all youth-created artifacts, such as written reflections, research notebooks, or data tables, throughout the 3-year run of *Sensors*. In any iteration of *Sensors*, there was variability in the artifacts created given: (a) the curriculum's adaptation over time and (b) the nature of the project direction and subsequent research. To address this limitation, Table 3-1 audits what each iterations' project focused on, along with what programming supports were provided to youth in my analysis. Samples of youth work (scanned documents and photos) and copies of programming plans or curriculum documents used in the *Sensors* programming contextualize what it looks like for youth to engage in engineering within the *Sensors* local context.

Focus Group Interviews

At the end of each iteration of *Sensors*, we conducted a focus group with all available participating youth to explore their experiences within the program, reflect on their goals for the project, and provide feedback to shape the program for future iterations. Focus group questions can be found in Appendix B. All focal youth participated in at least one focus group.

Other Interviews

In the context of the more extensive DBR study, shorter interviews were sometimes recorded with focal youth. These interviews could focus on a particular topic (e.g., problem definition, in Adina's profile) or could be a "walking" or *in-situ* interview, such as recording talking to Red and Cesar as they were working. Given the ranging nature of these interviews, they served as secondary data sources. This type of data was useful, however, in triangulating across other interview sources. An example protocol for these other interviews can be found in Appendix C.

Data Analysis

Methodologically, I drew on both interpretivism and critical framing. Under the assumption, "meaning does not exist independent of the human interpretive process," interpretive approaches are salient as I explored youths' interaction within the program with front-end design practices, as well as our discussions of their broader engineering experiences (Hesse-Biber & Leavy, 2010, p. 17). In this, I interpreted youths' actions and discussions with me through sociocultural lenses. As I consider the exclusionary and oppressive cultures of engineering, however, it is foundational to my study to note that engineering contexts "…have been constructed and reconstructed by people in evolving power-laden environments" (Hesse-Biber & Leavy, 2010, p. 20). The research questions posed, which ask how focal youth both engage in engineering and discuss their experiences, are not overtly critical by nature. Thus, to interrogate power, I draw on critical STS theories of design in my analysis, valuing the perspective of and learning from those in a liminal position in engineering.

Building Focal Youth Profiles

To build a profile for each focal youth, I sought to create some form of "analytic order constructed from the messiness of everyday experience" amidst the transcription, coding, and interpretation process (Dyson & Genishi, p. 110). My data analysis process was interactive and iterative with continued data collection (Hesse-Biber & Leavy, 2010, p. 307). For example, I needed to watch (and re-watch) the *Sensors'* video and organize artifacts to prepare for the semi-structured stimulated recall interviews with focal youth. This process of the organization was also a process of making meaning of the data. As such, I memoed about the preparation for each interview, as well as after each interview.

At first, I worked to code data with transcribed interview data, video, and artifacts. My coding procedure began "…by reading over and becoming familiar with the data…to gain insight and understanding" (Hesse-Biber & Leavy, 2010, p. 308). Focused on focal youth individually, I read (and re-read) transcripts, memos, and field notes and re-watched the video. To connect with the data (Saldaña, 2014), my first round of coding was *in vivo* coding and process coding, creating codes from what youth were saying directly (Saldaña, 2015; Saldaña, 2014). I then engaged in process coding, creating gerund codes for what youth were doing (Saldaña, 2015). The codebook was flexible throughout the analysis. Simultaneously, throughout all coding, I wrote analytic and reflective memos on my subjectivity, but also to "…elaborate processes, assumptions and actions subsumed in [my] codes" (Charmaz, 2004, p. 511). The ongoing memos were essential to auditing across all my profiles, capturing internal validity questions, and shifting directions. Eventually, memos became a sense-making tool to think across youths' profiles. This process included three additional rounds of conceptual coding, driven by my research questions.

Analyzing Across Profiles

In my first round of conceptual coding, I focused on video data and the nature of youths' engagement. What did it look like for youth to engage? Layering on top of my *in vivo* codes, I coded focal youth's ways of doing (activity, tool use) and ways of being in design work. In doing this, I asked:What changed within the iteration? What changed across the iterations? Samples of these codes can be found in Table 3-5.

Code	Definition
Questioning design	Youth raised questions about our design process in *Sensors*
Questioning each other	Youth questioned each other about design (e.g., why proceed this way?)
Drawing on data	Youth talked about data in design to argue for a design decision.

Table 3-5. Sample engagement codes

In my second round of conceptual coding, I drew upon design science literature to examine how youth engaged in *engineering design* practice. Building on my process coding, I focused primarily on video, reflective field notes, and artifact data. I drew on traditional definitions of engineering design best practices (e.g., Crismond & Adams, 2012) to define focused categories of youth practice. In this round, I aimed to explore what happened during the front-end process compared to current conceptions of engineering best practices and how that shifted with time. Table 3-6 shows an example of design science-based codes describing focal youths' engagement.

Code	Definition
Problem Definition: Beginning	Treat design tasks as well-defined, straightforward problems that they prematurely attempt to solve.
Problem Definition: Informed	Delay making design decisions in order to better explore, comprehend, and frame the problem.
Research: Beginning	Skip doing research and instead pose or build solutions immediately.
Research: Informed	Do investigations and research to learn about the problem, how the system works, relevant cases, and prior solutions.

Table 3-6. Sample engineering “best” practice codes

In my third round of conceptual coding, I foregrounded focal youths’ interview data. This study was not a narrative inquiry, nor was this analysis entirely narrative analysis. However, I drew upon narrative analysis methods to think about youths’ discussion of engineering and discussion of self. Layered on top of initial *in vivo* and process codes, I coded for the small stories youth shared in their interviews around engineering (Bamberg & Georgakopoulou, 2008; Georgakopoulou, 2020). Drawing first on Sfard & Prusack (2005), I bracketed off youths’ first-person “reifying, endorsable, and significant” moments in the interview related to engineering experiences. For example, in an interview with Mariabella, I originally bracketed her saying, “I would never want to be in that part of engineering” (Mariabella Transcript, 02/14/2020). These moments were often captured in my *in vivo* coding and were adjusted to conceptual in this pass. I then coded for “small stories” around these moments (Table 3-7). What proceeded? What followed? As framed by Georgakopalou (2020), how did youth “do self” in narrative at any given point (p. 128)? For example, in Table 3-8, I present how Mariabella’s utterance was expanded.

Mariabella’s Engineering Work story	Codes
Um, well [at first I would... Before, like if somebody were to ask me this question I'd be like, "Oh, engineering is just like building stuff and like, computers and stuff."	Constructing engineering, early
But now I'd describe engineering as like	Changing construction
I don't know about the other views of the building, 'cause I wasn't really in that	Splitting engineering practice
but like-The like, part of it where you like, lead the team in not building, but like, the steps before building. Like, I don't know, I don't know how I would, how I would really explain it	Thinking
Like, just now I know there's just way more to engineering than just building like, the sensor or like, putting in, putting in the sensor	Constructing engineering (later), “more,” ID
Like, I would never want-To be in that part of engineering	ID, relation to self (-), splitting engineering
But I like the leader part of engineering. Like, giving out the surveys and stuff. Collecting the data and like, yeah	ID, relation to self (+), splitting engineering

Table 3-7. Example coding process

After capturing these stories, I looked throughout the interview and across interviews for similar stories and noted any tensions between stories. Upon completing profiles, I member-checked the profiles with each youth, sharing and discussing the written profiles and transcripts.

Code	Definition
Engineering Work Story	A small story describing the work of engineering. This could include what engineers do, how engineers work, what engineers know, value or neglect. (+/-) youth explicitly calling this engineering.
Engineering Pivot Story	A small story where youth narrates being driven toward or away from engineering. This is likely elicited by the nature of the interview.
Goal Story	A small story youth tells about youths’ goals for themselves, others goals for them
Gender Story	A small story youth tells about gender, experiences of being a particular gender, gender of others

Table 3-8. Example small story codes.

Moving across profiles, I was not seeking to compare to point to instances of difference. Instead, I sought to raise emerging patterns of similarity. In this analysis, I engaged in multiple rounds of data analyses, examining patterns in conceptual coding and colligating data into preliminary groupings. I then developed these groupings into a set of assertions, which I then submitted to axial and selective coding processes to develop categories (Creswell & Poth, 2017; Saldana & Omasta, 2017). I undertook this process by moving iteratively from the data itself to holistic assertions and back again repeatedly. I used category charting and theoretical memo writing to map an evidence trail throughout the process and search for disconfirming evidence within categories (Erickson, 2012; Saldana, 2014). To enhance trustworthiness, I developed and iterated a key linkage chart representing connections between assertions within categories (Erickson, 2012). Developing the key linkage chart supported my thinking between discrete bits of data to emerging, larger holistic assertions and back again. It helped ensure that my assertions were warranted by a range of data points, connecting the whole and the parts in meaningful ways. At the end of this chapter, I introduce the key linkage chart to situate the overarching argument from the analyses (Figure 3-3).

Positionality and Reflexivity

I asked my research questions from a position of science and engineering as social enterprises constructed by humans and involving a long cultural history (e.g., Harding, 2015; Sismondo, 2009). My positionality and experiences within an engineering program are salient to my perspective. As an engineer-turned-education researcher, I come to this analysis with my own experience seeing the potential good engineering can do and seeing the immediate harm it can inflict. As a white, middle-class woman, I pursued an engineering degree in the late 2000s at an R1 institution. I experienced engineering as a place where my identities were simultaneously privileged and devalued, and my perspectives were not aligned with the dominant culture in engineering, which often centers on the perspectives of upper-class, white men. I came to education hoping to understand and deconstruct an enterprise that seemed to snuff out the diverse perspectives it claimed to want. In my work, this begins even before the college engineering gauntlet, with the brilliance of youth. In this dissertation and my life in general, I aim to do research that supports all youth feeling as though they belong in engineering and imagine engineering as a more just, empathetic, and liberatory place (Benjamin, 2019).

Further, I researched across differences (McCarty et al., 2013). I, a white scholar from the suburbs, worked with Black and Latina/o/x youth from the Large Midwestern City. I worked in a predominately Latina/o/x neighborhood in the city. Thinking about my positionality, I grappled with my standpoint (cf. Harding, 1991): What was I trying to look at specifically? How? Where was my seat at the table? Where were focal youths? In this study, I centered relationships I came to develop with these seven focal youth. Through these relationships, we built trust over time. I worked with teachers at Context 1 and youth leaders at Context 2 to learn about the places and youth. The youth showed me around these spaces and told me about themselves outside of the context. I named my whiteness and my suburban-ness and laughed when youth poked fun at it. In *Sensors* and out of *Sensors*, we discussed race, class, gender, and sexuality. The seven focal youth I worked with do not need me or my research, but I am so grateful they trusted me with their work and wanted to support this research with their stories. I seek to honor that trust.

Reflexivity is an essential aspect of all qualitative research. Being reflexive in my position as a white woman engineer-turned-social science researcher within a predominately Latina/o/x community space, "…promotes continuous examination of hegemonic beliefs, assumptions, and power" that may arise, as well as how my subjective lenses developed in my experiences in engineering are influencing my research decisions (Stachowiak, 2013, p. 12). On the one hand, "[b]y its very nature, qualitative research often requires emotional engagement with those with whom we build knowledge" (Hesse-Biber & Leavy, 2010, p. 76). I acknowledge, however, that "[u]ntamed subjectivity can mute the emic voice" (Peshkin, 1988, p. 21). In this work, I hoped to strike a balance of empathy and criticality without projection. Because I am interested in youths' subjective experiences, which by nature means I am writing a "story about stories," this orientation is vital for making decisions about what perspectives to include and how they are triangulated in the analysis (Sfard & Prusak, 2005, p. 20). Further, Stachowiak (2013) comments that "…critical reflexivity promotes humanity, honesty, and constructive discomfort for me, the participants, and the readers" (p. 12), which is something I strived for in this work. As noted earlier, creating memos, bracketing off my subjective thoughts while not dismissing them, and continual and open dialogue with colleagues and participants are some of the ways I sought continual reflexivity throughout my research.

Validity and Transferability

In thinking about the validity of this study, I assume a stance that, "…values a recursive, open process in qualitative inquiry and gives us an analytic tool by which to identify a comparative, operational, methodological relationship among the research purposes, questions, and processes" (Cho & Trent, 2006, p. 333). As such, this study's validity arises from exploring my research questions in a way that thoughtfully and coherently reflects both my interpretive and critical stances, my conceptual framing, and the holistic context of the data I collect. Throughout, I interrogated my process with an eye toward consequential validity and validity for thick description (Cho & Trent, 2006; Creswell & Poth, 2017; Johnson, 2012). In my stances, these views of validity will employ what has been called transactional and transformative methods or heterogeneous approaches to validity (Cho & Trent, 2006; Freeman, deMarrais, Preissle, Roulston, & St. Pierre, 2007; St. Pierre, 2000). I aim to establish trustworthiness with my readers as situated in both interpretive and critical communities of practice.

Further, validity for thick description "…makes it clear that a one-to-one correspondence between reality and observation is never achievable and may not even be a major aim…" (Cho & Trent, 2006, p. 329). This work does not seek a single, generalizable answer to the research questions but provides in-depth descriptions of youths' subjective experiences within a design. To foster rigor and trustworthiness, I engaged in practices that increased my data's richness and made visible my subjectivity. Some examples of these practices involved ongoing member checking with focal youth and youth during data collection and analysis. Triangulating multiple data sources such as interviews and observation, along with comparing these sources for similarities and differences, also served as tools in promoting trustworthiness and "justifiability" (Auerbach & Silverstein, 2003, p. 82). Creations of memos along the way helped me reflect on my own subjectivity and positionality within this process and served as an audit record for transparency and coherence.

Taking these validity considerations as a whole, I aim for transferability and translatability in my work, "…allowing both a deep understanding of the case at hand and the use of the findings in other contexts" (Hesse-Biber & Leavy, 2010, p. 262). Given the study's nature, I aim to present this work to learning science and engineering communities. As such, I purposefully choose the language of *transferrable,* rather than using the term *generalizable,* to define the work's aspects. In the engineering literature, generalizability tends to embody a limited, positivist view, seeking one truth (Buede & Miller, 2016). To avoid mismatched comparison and in line with transformative goals of DBR, I would offer that dimensions of how focal youth engaged in engineering and storied their engineering experiences may be *translatable* to other contexts, informing inclusive engineering learning environments.

Presenting the Key Linkage Chart

From my analysis of the data, I assert that front-end design work in *Sensors* created opportunities for youth simultaneously to engage in increasingly recognizable design practice and to move design toward more liberatory directions. Within the program, focal youth drew upon their experiences and personal knowledges as assets to the work, building critical skills and imagining new meanings for design in their lives. As youth reflected on their experiences in the *Sensors* program, they discussed distinctions between the front-end design work and building-focused or technocentric activities. They shared that these practices were meaningful to them in different ways. These discussions also revealed that youth made meaning of their engineering-specific experiences using their personal experiences, knowledges, and relationships.

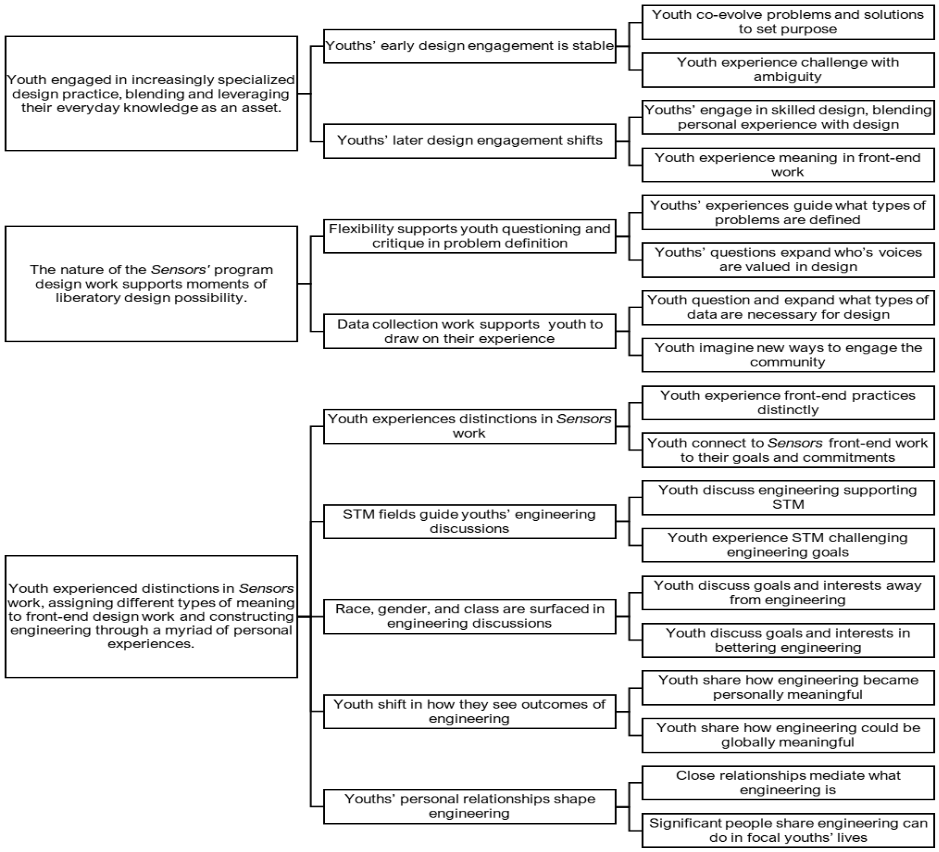


Figure 3-3. Key Linkage Chart

The presented key linkage chart graphically organizes overarching assertion from this study. In the following findings chapters, I introduce youths' profiles through their individual engagements and discussions (Chapter 4). Then, in Chapter 5, I present the specific analyses exploring Research Question 1 (RQ1) – How do youth engage in the design practices of the *Sensors* program? The left side of the key linkage chart addresses the sub-assertions I make to address RQ1. In Chapter 6, I present the specific analyses exploring Research Question 2 (RQ2) – How do youth discuss their engineering experiences? The right side of the key linkage chart addresses the assertions I make towards RQ2. In the following chapters, I will return to the key linkage chart to demonstrate connections between assertions and the data.

CHAPTER 4 Meeting Focal Youth Through Their (Engineering) Stories

For this study, I investigated the engagement and discussions of seven focal youth, who graciously worked with me over the *Sensors* program's iterations. Among other things, I came to know these young people through their engineering work and their evolving interests (or non-interest) in engineering and beyond. In the following chapter, I introduce each focal youth. As I could easily spend hundreds of pages on these young people, I tailor these introductions through examples of their engineering stories and time in *Sensors*. Thus each presented profile introduces the focal youth broadly, delves into their evolving engineering stories, and describes their participation in *Sensors* over time.

On *Sensors* Experiences

In the following profiles, the examples from focal youths' engineering stories are drawn from their experiences in *Sensors* and from aspects of our conversations that elicited the discussion of another engineering program or experience. To position each youth in the Sensors program precisely, I draw upon reflective field notes, video, and youth artifacts to overview each focal youths' participation in the *Sensors* program. Chapter 5 presents an analysis of focal youths' engineering practice and engagement in *Sensors* over time.

On Discussions of Engineering

In this chapter, I also present examples from focal youths' discussions of engineering broadly. These examples are not meant to represent all their engineering or design experiences, nor capture some truism about how youth has come definitively know engineering. Although I knew each of these young people through the *Sensors* program, their engineering stories were much larger than one experience. Further, focal youth's engineering experiences shifted with time, tumbling together like a kaleidoscope as we have talked over the years. The presented examples represent snapshots of particular moments we spoke, mediated by time, context, and goals. They illuminate consistencies and shifts in focal youths' discussions of engineering over time. Further, they provide a primer to the ways focal youth described experiencing *Sensors*. This chapter is devoted to showcasing the youth as individuals; Chapter 6 presents an analysis of engineering discussions and meaning making with focal youth.

An Introduction to Thinking Across Youths' Profiles

To launch this chapter, I offer an initial organization to think across the individual profiles I present. Having gotten to know and work with these youth over the years, I hold their input and stories in high regard. I have come to think of them as stakeholders, not just in *Sensors'* program design but in the design of engineering education experiences more broadly. Each youth holds varying experiences, interests, and goals around engineering. These focal young people each came to engage in *Sensors* work deeply, gravitating towards one or multiple aspects of the practice. I present their discussions, stories, and practice as a means to think deeply about whom we design educational experiences for, to speculate about how these youths' experiences help us (re)envision engineering design learning environments, and to honor their experiences by "imagining and crafting" engineering programs that are celebratory and liberating (Gaskins, 2019).

Introducing Focal Youth from Context 1

The *Sensors* programming ran at Context 1 for two iterations over the 2016-2017 and 2017-2018 school years. Over these iterations, I met Elizabeth, Cassidy, and Adina. These sessions took place after school at the Charter School. Some youth, like Adina, lived within walking distance of the Charter School. Others, like Elizabeth and Cassidy, lived in other neighborhoods of the Large Midwestern City. Context 1 *Sensors* youth worked on parks in a nearby neighborhood and the local River Conservancy, located in the Large Midwestern City downtown. In what follows, I present Elizabeth's, Cassidy's, and Adina's profiles, constructed through our time working together.

"…then I'm a go and get it": Meeting Elizabeth

> *My name is [Elizabeth] and I am a Freshman at the University of [Major City], majoring in Business Administration but will be joining the 5 year-accelerated BS/MBA program for the upcoming year. I love that business has many branches to choose from and will be concentrating in Finance/Accounting. The careers I am leaning towards is a financial analyst and a stockbroker. Growing up, I have a big family, which has made me very family-oriented. I was raised by a single mother that immigrated from Mexico to the United States for better opportunities. My mother ran her own catering business, while raising 6 children by herself. This has influenced me to work hard in life and never to take things for granted because I saw the hardships and successes of my mother owning her own business, while caring for my family and I. Throughout my life, I was raised speaking Spanish and English. At home I spoke Spanish and at school spoke English, so I heavily immersed with the Mexican and American culture which at times blended. This*

year, I will be getting my certification in Spanish. Overall, coming from a hard-working entrepreneurial family has taught me to work hard in life and to cherish my education because I am the first in my family to go to college. - Elizabeth, in her own words.

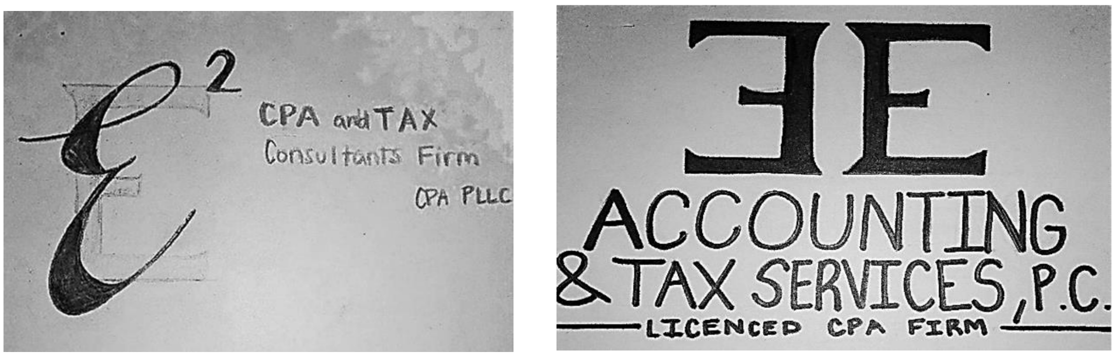


Figure 4-1. Elizabeth’s logos for the future business

In my most recent interview with Elizabeth, I asked her to describe herself. She said, “…I could say I’m smart, but I could be smarter…I say…if I set a goal, then I would say I’m very ambitious. I don’t settle for nothing less than what I should earn.” When I asked what she meant by could be smarter, she replied, “I could be challenged more….I feel like there’s more stuff to know.” (Elizabeth Transcript, 02/04/2020). Elizabeth embodied at least two first-generational identities. The second to youngest of six siblings, she is a first-generation Mexican American citizen and first-generation college attendee. Ending her high school career in the Top 10 of her class, she sought to excel at the high accountability Charter School. Over time, Elizabeth discussed liking numbers and math, seeing them as foundational to all her interests.

In *Sensors*, I was privileged to meet and work with Elizabeth’s family. Beginning her freshman year, Elizabeth joined the group with her two sisters, Sofia (12th grade) and Francesca (11th grade), and their friend Alma. Unless I asked them otherwise, the sisters would sit and work together on the *Sensors* projects. On a fieldwork trip to collect data at a local Conservancy, Elizabeth invited her mom to attend. In the following year, when Elizabeth and Francesca returned to *Sensors*, their youngest sister, Miranda (8th grade). The sisters were support systems of one another. During one *Sensors* session, Elizabeth showed me her current report card, where she got straight A's and ranked top 10 in her class. Her sisters joined the conversation to exclaim, "She's so smart. Isn't she so smart?" (Transcript, 03/16/2018). Elizabeth points to her family as emotional support in her college application process as well:

> **1** I mean my whole college application experience, which is like, asking questions, like
> **2** no one came up to me like, "Oh, you need help?" It was always like me like, "Oh, do
> **3** you need help?" And I was just like, I knew I could do it by myself. And I know with, I
> **4** know my family can't help me out, like throughout the whole college application, but
> **5** they help me out emotionally. Like, "Oh, you'll get through it. You know, you can do
> **6** it." And I'm like, "Yeah, I know I can do it." (laughter) (Elizabeth Transcript, 02/04/2020).

Elizabeth cites her family members' entrepreneurship as one inspiration for pursuing a business degree. Like other Latina first-generation college students (e.g., Leyva, 2011), she balances establishing independence while being supported by and supporting her family.

Iterating Goals: An Example from Elizabeth's Stories

At times, Elizabeth had expressed interest in engineering. Throughout her time at the Charter School, she participated sporadically in robotics class and after-school club. Along with Cassidy, she had applied for and was accepted to the Great Lakes University Engineering camp the summer after her freshman year. This came up at the end of *Sensors* focus group, when I asked if she would like to participate in summer programming:

> **1 Cassidy:** I'll be at [Great Lakes University] for two weeks, but after that I will…

2 Elizabeth: Me too, what are you talking about?

3 Cassidy: You told me you never turned in your-

4 Elizabeth: I am, I turned everything in. I'm going!

5 Jacquie: Are you going, too?

6 Cassidy: Yay, I'm not gonna be alone!

7 Jacquie: Congratulations! That's awesome!

8 Elizabeth: I'm not gonna be alone! // [cut 23:20-23:40 – side conversation]

9 Elizabeth: 47, I mean out of 470, there were 30 people.

10 Cassidy: Exactly. We're 30 out of that many people.

11 Jacquie: You guys did awesome….I'm really glad that you guys are gonna be there.

12 Cassidy: 6% of people. 6%!

13 Elizabeth: I'm excited to go (Transcript A, 06/07/2017)

Ultimately, Elizabeth could not attend because her family was moving, but she was excited to be part of the camp with Cassidy. Both girls seemed happy to have an ally at the camp (lines 6-8). She also pointed to the camp's exclusiveness (line 9), in that there were only a small number of freshman girls accepted. This exclusiveness seemed to be something both she and Cassidy were excited about and proud of for accomplishing.

When I originally asked Elizabeth to be a part of my study, she told me she had "fallen out of engineering" and was predominately interested in pursuing business. In a later interview, I asked her to elaborate after she mentioned engineering "used to be" one of her goals:

1 Elizabeth: I looked into engineering. I looked into industrial like, the environment. I'd

2 have to stay in an office space, but I'm, but I don't like the pay. Like the pay is good.

3 Like, you could like, rise up and- and get to a certain amount, but it's just like I don't

4 like being demanded from like, all type of people. Like, I like being my own boss…I

5 prefer being my own boss than just working for somebody my whole life.

6 Jacquie: Is that why you feel like you've fallen out of that track?

7 Elizabeth: Yeah. Also because I feel like if I own my own business, I'm my own boss.

8 And there's not many like, women that are like, CEOs and- and I want to be that.

(Elizabeth Transcript, 02/04/2020).

Later on, in the same interview, her previous interest in engineering came up again, storied slightly differently. As I started to ask Elizabeth to define engineering, she offered:

9 Elizabeth: Yeah, I wanted to be industrial engineer….it was like, I didn't really know

10 what it was until like, I was like, "Oh, I think I like industrial engineer." And then I

11 heard of a software engineer, but like, I don't really like the-Technology behind it

12 (laughs)…And I was like, "Industrial is like, just finding the issue and like, in the

13 environment and making it better." But I was like, I didn't like the science I was in, I

14 mean I didn't like science. I just, I wasn't just good at it. I was like, why would I go

15 into something that I know I could like, get better at, but I wouldn't be happy with?

(Elizabeth Transcript, 02/04/2020).

Elizabeth is someone who has explored a variety of options for her future. These snapshots from her discussions reveal how she negotiated multiple types of experiences and knowledge to refine and pursue her goals (lines 1-2). Elizabeth's stories had moments of steadiness and moments of shift. Both in both conversations, Elizabeth discussed a goal of excelling and achieving, despite exclusivity. Early on, this was reflected in engineering, being one of few selected for the engineering camp, and later shifted to be reflected in business, being one few women CEOs (lines 7-8). At the same time, Elizabeth's later statement points to how her experiences with science were also implicated in her future goals shifting away from engineering (lines 13-15). As I followed up with Elizabeth about her science experiences, she discussed high-rates of teacher turn over as one reason she struggled to achieve the grades she wanted. In an amalgam, she notes how her experience learning science ("I didn't like it") constituted identity shifts around science ("I wasn't good at it"), and thus shifting interests and goals around engineering. Like her other goals, Elizabeth's negotiations around engineering were multi-faceted, connecting across several areas of her life.

Delving into "Thinking Work": Elizabeth in Sensors

In *Sensors,* Elizabeth seemed most drawn to collecting and analyzing data. In her first year, Elizabeth worked predominantly with surveys. She developed the scales for the survey questions and often offered critiques to her peers to develop their research questions more deeply. She handed out surveys during a field visit and preferred analyzing the surveys during data analysis. In her first year, she deemed this "thinking work," saying:

> **Elizabeth:** Yeah, there wasn't a lot of hard work.//[Inaudible Cut] A lot of thinking….A lot of thinking (Transcript A, 06/07/2017).

In her second year of *Sensors*, she continued to delve deeper into "thinking work." Taking lessons forward from the previous year, she thought deeply about what types of information she needed to make sense of the problem space and how she might ask questions to get this information. Upon collecting data, Elizabeth was vital in establishing analysis methods for the survey data. She developed analysis tables that allowed for qualitative and quantitative data to be explored in one space and developed data storage structures for the group. Over time, she became a leader in the group, training and supporting her peers in data analysis. When I asked Elizabeth in our most recent interview why she thought she was good at engineering, she pointed to this work:

> **Elizabeth**: Probably the critical thinking and the problem solving that we always use. Like, you always made us think like, we spent like, almost 10 minutes thinking like, "Oh, we need to make these questions." And then it's just like, how people react to them. Some people like, would get…get offended if you wrote this. And it was just like, finding a, like getting a judgment and making like, … and figuring out the scenario after that. (Elizabeth Transcript, 02/04/2020).

Elizabeth seemed to like the thinking work and analytics necessary in flexible design work. She took "problem solving" and "critical thinking" as skills that she gained in *Sensors* and as processes where she excelled.

Alternatively, there were also aspects of *Sensors* Elizabeth openly enjoyed less. Reflecting on being introduced to sensing technologies, Elizabeth offered:

> **1 Elizabeth**: Oh, yeah we went to like, um look at the sensors. I was like, I was like, I
> **2** never knew they put that in the sensors. Like, the wiring and when my friends told me
> **3** like what they, the robotics did, the intakes that they do. And- and I was like, that's
> **4** cool. But like, I don't want to know that, but It's- it's really cool. Like they program
> **5** code. And I'm like, I don't think I could know that. I mean, I know I could do it if I put
> **6** my mind to it, but I'm like, I don't think I'm up for it.
> **7 Jacquie:** What, so what about it were you not up for?

8 Elizabeth: I feel like, I mean I feel like I could do anything, but I'm like- I don't feel
9 like the interest in it. Like-You know when you have like, a passion (Elizabeth Transcript, 02/04/2020).

Sensors' sensing technology portion was less interesting to Elizabeth than gathering and analyzing data from the community. For Elizabeth, *Sensors* was not as much about sensors as it was about analysis. Notably, she pointed to the skills she gained in analyzing and connected those to her future goals in business, saying, "business is a lot of things to do with like, analysis and-finding like, oh what people need." Elizabeth's *Sensors* experience seems to support her goals in financial analysis.

"…you have to just make sure like, everything like, flows together": Meeting Cassidy

In her sophomore year of high school, Cassidy described herself as "I am smart, unique, artistic…but not drawing artistic…but everything else in the arts…" (Cassidy Transcript, 03/03/2018). When I asked her to say more, she shared that she does not struggle once she understands something. In later interviews, she added, although she can be quiet, she sees herself as a leader, saying, "I think my sense of leadership comes from like, I'm the oldest of all the, all of my siblings. So, probably that's where it comes from" (Cassidy Transcript, 02/17/2020). Cassidy is a Black girl. Before college, she lived in the Large Midwestern City with her mom and four younger siblings. She attended the high-accountability Charter School, where her hard-work and GPA consistently ranked her top in her class over her four years there.

Currently, Cassidy is in her first year at State University, pursuing a degree in hospitality management, and plans to attend culinary school. In our most recent interview, she told me stories about making lemon curd and whipped cream. At *Whole Foods*, she showed me granola bars she had made as part of a culinary training academy. She joined this program during her sophomore year of high school and remained connected with them in college. Cassidy also worked in the kitchen of a local Vietnamese restaurant in the summers and after school. Cassidy showed apparent interest in food and culinary work early on in high school, and it might seem like her pathway to pursuing a hospitality degree was clear-cut.

However, when I learned she was seeking to pursue a degree in a culinary space, I was surprised. I worked with Cassidy over her freshmen and sophomore years, and we often spoke about her goals and interests around engineering. Besides participating in *Sensors*, Cassidy also participated in her school robotics club from her freshman year on. Starting the summer after her freshman year, she attended engineering camps each summer at major universities, both in and out of state. All of these camps were invite-only and hosted explicitly by engineering departments and programs. In our final interview, I asked Cassidy about her college decisions:

Jacquie: Could you say a little bit about the decisions that you’re making for school?

Cassidy: Because I like, all this time I thought like, “Oh, I want to go to school to be an engineer.” And then it’s like, all of a sudden my brain just went, “No.” (laughs) So …we, a lot of people are like, thinking like, “Oh, you’re about to go to school to be an engineer. You’re gonna bring in a lot of money,” and…that’s not what I want to do anymore (laughs). It’s just like, something…clicked in my brain and was like, “You gotta like...” I’ve been trying to go along with…a lot of my interests that I have. ’Cause…I did have a lot of interests with engineering before, but now it’s just like, I’m more leaning towards…the culinary aspects of everything. And…I know that…I can pair that pretty well with business (02/17/2020 Cassidy Interview).

For Cassidy, two paths seemed to be unfolding at once as she learned about culinary work and engineering work. These paths were not necessarily dissimilar, either. In the titular quote, Cassidy was describing the connections she makes between engineering work and culinary work. For Cassidy, both types of work involved “making it flow” and “testing.”

Fun and Frustration: An Example from Cassidy’s Stories

Over time, Cassidy seemed to experience slight shifts in the ways she described her engineering experiences. During an interview in her sophomore year, I asked her to share about her engineering camp over the previous summer:

> **Cassidy**: …I enjoyed what I did over the summer, at [Great Lakes University]. But I was confused then too (laughs). We had put together a little robot, and we had to direct it on this course to do certain things…and it was like, I didn’t know how to code…so that was a hard thing my group had to get used to…my partner, she knew how to code… And like, I would always try to help, but… (laughter) I…I’m not very good at coding. (03/03/2018 Cassidy Interview).

Cassidy shared a tension she experienced in wanting to help her partner but not feeling like she fully could without the specific skill of coding. She hedged this language (“not very good”) and also emphasized her want to help. Cassidy shared a hope to improve her coding skills. Although participating in significant engineering programming, she expressed she did not necessarily feel like an engineering person in the same interview:

> **Cassidy**: I don’t know yet…yeah, I don’t know. I think I’m still figuring that out. I just need to learn more about it…I know there are a lot of different types of engineering. I want to learn more about each individual one before I’d be able to figure out if I’m an

> engineering person…I'm definitely a math person though" (03/03/2018 Cassidy Interview).

Cassidy voiced how she was figuring out her alignment with engineering or not. She seemed to discuss this as mediated by her understanding of the topic ("I want to learn more about each individual one"). Cassidy separated "being a math person" from engineering, even though engineering skills often rely on mathematics (like linear algebra in coding). In our most recent interview, Cassidy brought up Great Lakes University again when I asked her about coding and computers:

> **1 Jacquie:** Um, so two things I want to follow up on. One is that…heard you say that you
> **2** didn't feel like you're good at stuff on computers. Can you say a little bit more about
> **3** that?
> **4 Cassidy:** Okay, so one, I'm not good with coding. Like, I know that. Coding and
> **5** programming, I know I'm not good with that. And that was even from just being at like,
> **6** the [summer program at Great Lakes University] (laughs). Like, I tried to help. It's…I
> **7** understand... I understand like, what you have to do- But it's just I don't understand
> **8** what it is that they're doing 'cause there's like a whole bunch of different like, coding
> **9** and programming sites and some…they're all like, different (Cassidy Transcript, 02/17/2020).

Although two years have passed at this point, Cassidy repeats that she did not feel "good at" coding, or understand the coding, tying it back to that experience at Great Lakes University. At this point, she seems to more definitively state that she feels "not good" at coding (lines 4-5). In this interview, I remembered her discussing this experience with me previously. We dug in to this together:

1 Jacquie: Do you like coding?

2 Cassidy:…yeah 'cause it's just like we had, when we did [the Great Lakes University
3 Camp] it was just like, a little robot. And it was just like, I, that's what I really enjoyed,
4 though, like having the little robot and just like, coding it to just do different things…So
5 like, when we had to like, code it to just go for a minute and just stop at a certain point,
6 it was just like, "Okay…if we have it going for too long and it doesn't stop where we
7 need it to, or it doesn't turn where we need it to, it's just like we gotta like, go back
8 and…just tweak it." So, like I like that part, everything.

9 Jacquie: And did you think that that part was... Like, you liked it. Did you think it
10 was…fun?

11 Cassidy: Yeah.

12 Jacquie: Did you think it was useful?

13 Cassidy: It was fun. It was fun, and was it useful? Hmm... I mean, I don't remember
14 what we used 'cause I think it was like, connected to like, whatever company we got
15 the robot from, so I don't know (Cassidy Transcript, 02/17/2020).

While reflecting on the fun she had in the testing part of the robotics work, she did not describe the work as useful. Cassidy shared the robot experience was structured as a challenge to make the robot do several tasks, like traversing an obstacle course. Structured as a set of building and coding tasks, this experience may have lacked a larger purpose for Cassidy, beyond a fun experience (lines 13-15). Cassidy's engineering stories illustrate how "fun" activities are laden with significant dimensions of meaning-making. Cassidy came to know herself as "not understanding" and "not good at" coding through this outreach experience meant to attract her to the field. The experience also did not seem to connect Cassidy's love of mathematics to the work of coding. Would this experience have felt different for Cassidy had the camp connected to her love of math? Regardless, as her goals shifted to culinary, this experience might no longer have seemed particularly useful to Cassidy's life beyond having fun with a robot.

Building Community and Skills: Cassidy in **Sensors**

Upon working with Cassidy, I was struck by her thoughtfulness in research work and to others in the group. Cassidy joined *Sensors* in her freshman year. Although she was in her freshman year, she worked with the seventh- and eighth-grade students without hesitation, often opting to switch the group she was working with each week. In the first Iteration, she engaged significantly with the data collection planning at the local Conservancy. She partnered with younger group members, supporting them in their data collection efforts. She seemed to enjoy collecting data, analyzing data, and turning them into design recommendations. During a focus group she offered she wanted to see more data work, to keep people engaged:

> **Cassidy:** Yeah, [data collection] could, that could do it…Yeah, more but that…that kept us busy. That kept us going…It was interesting to see what the differences were in everything (Transcript A, 06/07/2017).

Cassidy seemed invested in the fieldwork we did in *Sensors*. Over her two years participating, she attended four different data collection trips to local greenspaces in the Large Midwestern City. When Cassidy's younger brother started kindergarten at the same school, he became a constant fixture at our *Sensors* meetings and fieldwork. Cassidy supported him in handing out surveys on these data collection trips. On one of these trips in her sophomore year, she was one of two youth participating. Following that trip, she asked if she could invite her close friends to join the group, so that we had more support in collecting data. Reflecting with me most recently, I asked her about her favorite moments in Sensors:

> **Jacquie:** What aspect of [*Sensors*] was your favorite?
>
> **Cassidy:** The data analysis. (laughter) I really liked the data analysis.
>
> **Jacquie:** Yeah.
>
> **Cassidy:** Like, really not even just the analysis part. Just the whole **data area** of it (points to surveys and data tables), I really liked (Cassidy Transcript, 02/17/2020).

Cassidy was also quick to help others in analysis during her second year participating, sharing data tables across the group and leading a discussion on qualitative coding. On a snowy winter evening near finals, Cassidy supported her freshman and eighth-grade peers in analyzing the quantitative and qualitative responses on a recently collected survey. She explained how she did this type of analysis the previous year and outlined data tables for her peers to follow. In subsequent data collections, she continued to provide this support to younger members. Reflecting with her later, I asked her what she thought about guiding her peers in data analysis:

> **1 Cassidy:** It was like, that’s like just where it comes in. Like, if I have to take on a
> **2** leadership role, then like, I will…Because it’s like…that’s why there are people
> **3** who...teach the new people. (laughter) Like, that’s why they’re there. ’Cause…if
> **4** you…have all this information and like, somebody doesn’t, then…you can’t just like,
> **5** leave them to fail…Or … to not do things right. So, you gotta help ’em.

6 Jacquie: (laughs) Was this meaningful to you? Was this portion meaningful to you? Or

7 what did you get out of it?

8 Cassidy: Yeah, I just like, I really like looking at the different data and seeing

9 everyone's different information and just everything like that (02/17/2020 Cassidy Interview).

Cassidy worked to build community, both with her peers and in the local spaces we worked in. She liked taking the lead on this data analysis to design recommendations space. As much as she wanted to help her peers, Cassidy cared deeply about seeing the work we did out in the community. She shared that she looked for benches we helped design in her community. During the community presentation, she prepared and discussed community data collection and analysis, the most intricate parts of the presentation. On presenting her work, she shared:

> **Cassidy:** …on certain projects like this…you're kinda doing it for a reason. So, it's kinda just like, if nobody's…here to…take the information and do something with it. Or like, you aren't like, going through and showing…everything you did to get up to your solution or your final point-Then like, what's the point? (02/17/2020 Cassidy Interview).

Here, Cassidy pointed to the importance of purpose in her work. To her, the community presentation was a way to get information to others so that change might continue. As she moves into her new chapter of life, Cassidy continues to seek purpose When I asked her to share if and how *Sensors* work connected to her current goals, she said:

> **Cassidy:** Um... yeah. It's just like…a lot of my skills that I took on with *Sensors,* I just try to use [and] to put forth like, it just comes so naturally to me now…Like my leadership skills, my problem-solving skills, having to sit down for long periods of time

and go through things. Just like, that stuff, it just comes naturally now (02/17/2020 Cassidy Interview).

Although now in a different disciplinary space, Cassidy connects her work in *Sensors* to her culinary work through the skills she feels she has gained. She says these skills come with her as she moves into a new space and is essential across her life. For Cassidy, her *Sensors* experience was about connecting with those around her, through the group and data. It was also about transferrable skills that will support her in her emerging career.

"Nah. I'm doing what I want to do." Meeting Adina

In my most recent interview with Adina, I asked where she saw herself in the next few years. She replied, starting college and getting a car. Adina is a senior at the high accountability Charter School with a strong interest in STEM. Her current goal is to pursue a degree in astronomy and astrophysics or aerospace engineering, saying:

1 Adina: It's between those two, actually. So um, aerospace engineer because I want to
2 be able to be... I really wanted to be able to say, "I'm a rocket scientist," (laughter) but
3 like, I also want to actually help bring people into outer space so we can travel and see
4 if we can actually preserve the Earth or make new life on a different planet because this
5 one's kind of going downhill…And aero- um, astrophysics is because I want to do the
6 same thing. Like, see if I can help with the like, atmosphere and stuff like that while
7 being on Earth because I am not going up there (laughs).

In early interviews, Adina described herself as "logical" and, jokingly, "socially-awkward" (Adina Transcript, 06/27/2017). Later on, she would add that she is artistic and likes to create. Adina speaks candidly about being at the intersection of several identity groups. She is a queer

Afro-Latina, born to a Puerto Rican mother and an African American father. When asked why she wanted to get better in engineering during an interview, she offered:

> **Adina:** Um, because I am part of the LGBTQ and I'm African American and a couple different other nationalities. And so, me being like, "Oh, if I can do it then everybody else that's just like me, or anybody else that's different from the norm can do it" (Adina Transcript, 02/27/2020).

Adina is aware that STEM "norms" often do not reach to liminal intersections of someone like her and that STEM fields are often exclusionary spaces, but she remains undeterred in her goals to pursue an engineering degree.

Support Structures: Examples from Adina's Stories.

Reflecting with me recently, Adina stated she had loved STEM since the 7th grade, science, and engineering to this day. Even though she has had people in her life question her interests in STEM, she says:

> **Adina:…**over time I've been told that's reaching way too far for me. And I was just like, "Well, I'm gonna do it anyways." So, it was kinda…for a second I was like, "Uh, I could probably do something else," but then I was like, "Nah. I'm doing what I want to do" (Adina Transcript, 02/27/2020).

This goal, she said, was highly influenced by her older sister, who is currently pursuing a degree in biology. Her sister's goals and actions were an inspiration to Adina:

> **1 Adina:**…Because my sister wanted to go into biology, I wanted to go into the
> **2** aerospace, and like, those two, if they go together, would be very nice because you

need to be, you need to know the world to save it. And so her theme of a biology made me want to do… aerospace because I was like, well, she was reading a book about like, nerves and stuff. And I'm just like, "Well, the world is just one really big person." So if we could figure out what's killing those cells for the ozone layer, we can figure out how to prevent it and…undo everything it's done. (Adina Transcript, 02/27/2020).

In 7th grade, she began participating in robotics because of her older sister joining the Charter School's team. She has stayed with robotics, saying that she realized in that first year:

Adina: I was like, "Oh, I think I'm kinda good at this, so I guess I'll keep trying it out." And the more that I did it, the better I got at it (Adina Transcript, 02/27/2020).

Adina's robotics experiences are overwhelmingly positive. She enjoys figuring out how to make the robot work, working with her team and mentor, and "[t]he fact that we fail a lot" (Adina Transcript, 02/27/2020). These examples from Adina's stories provides the inverse of Cassidy's examples above. Feeling good at robotics ("I'm kind of good at this") brought Adina back to robotics and supported her goals in engineering. Adina's examples also raise the importance of people and relationships in engineering goals, and goals in general ("Her theme of biology made me want to…"). Like Elizabeth, Adina cites her family member in shaping her future trajectory.

***Building Beyond the Program: Adina in* Sensors**

I met Adina in the first Iteration of *Sensors*, where she worked with me once before moving to a different high school. Having had the group recommended by her 8th grade science teacher, she joined the group with several of her friends. Participating in *Sensors* with her friends, Adina was positioned as a "smart" group member. She was often asked questions by her friends to clarify work and seemed to trust her guidance. For example, while discussing challenges in *Sensors*, Adina's friends Lianna and Marie described how they looked to her for support in the work:

1 Lianna: …I would be like…what does this mean? So, I would just go to [Adina] and

2 go, hey, [Adina] what does this mean? Like, I don't know. OK, OK, OK, [Adina],

3 you're no help and you're supposed to be the smart one.

4 Adina: I'm supposed to be the smart one?

5 Lianna: Yeah

6 Adina: You trust me with that title?

7 Lianna: Yeah, at least you're not the dumb blonde…like Tamera is.

8 Marie: Yeah (nods) (Transcript B, 06/07/2017)

Adina brought much ingenuity to the work in *Sensors,* going beyond the suggested plans. For example, the youth decided to develop a survey to collect data about a Conservancy in their city. While developing questions for the survey, Adina suggested that the group ask about the Trump Administration's 2017 proposal to cut the Environmental Protection Agency's budget drastically. She saw connections between the local Conservancy's work and more extensive conversations about the environment and wanted to explore them. Later, I asked the youth to pilot the surveys in their sciences classes, with their teachers' permission. Adina asked her teacher to give the survey in other classes to collect more data and pass from her study hall to hand out surveys to other study halls. Although she described challenges in the data collection, like Conservancy visitors not wanting to talk to her, Adina liked learning about peoples' lives at the Conservancy data collection, offering:

1 Adina: Yeah, it was really fun when people did speak to us because they would have the best stories about [the Large Midwestern City]. Like, um, in the ground you can put somebody’s name. You can buy a brick and you can put somebody’s name in the ground, and I never knew that about [the Large Midwestern City].//

Jacquie: What do you remember liking about this experience?

Adina: [T]he people. Used to terrify me that I had to speak to them, but their stories were always like, different (Adina Transcript, 02/27/2020).

Taking to analyzing data, Adina met with me over the summer twice to finish analyzing data and offer recommendations to the Conservancy. On her own time, she interviewed people in her neighborhood about elements they might like to see in the Conservancy’s redesign (Figure 4-2).

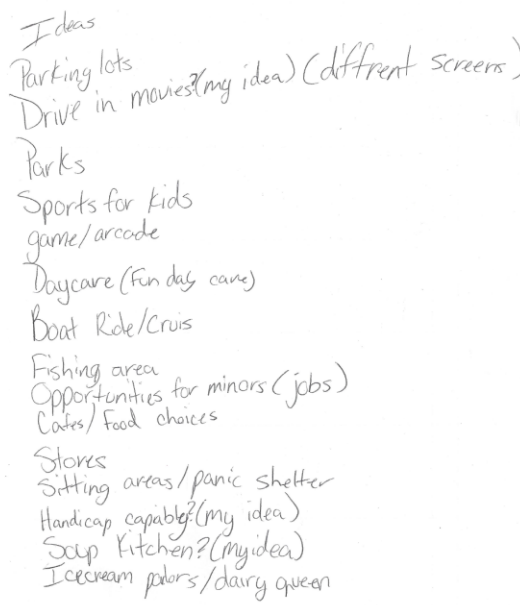


Figure 4-2. Adina’s self-researched recommendations

Adina’s love of STEM seemed to support her work in *Sensors*, leading her to expand outside the program. In turn, the data work in *Sensors* seemed to support her love of STEM and reinforce an understanding of broad and expansive engineering. Beyond the work itself, relationships within the program seemed critical to shaping Adina’s experiences. Although

Adina only participated for one Iteration due to changing schools, she reflected that her experiences with *Sensors* were positive. She discussed how content and relationship entertained and sustained her interest:

> **Jacquie**: [H]ad you stayed at [the charter School], do you think you would've stayed in *Sensors*?
>
> **Adina**: 100%, I would've came back. Yeah, as long as you were the mentor because I-wouldn't had like, trusted anybody else with *Sensors* because-You were, you were never monotone. And if somebody else was monotone and they ruined *Sensors* for me, it would've just been horrible. Like, (laughter) because this was an engineering program that's…if you hear an engineering program and you're in the 7th grade or in the 8th grade, you're gonna be like, "Mm, that's just a bunch of math and hitting stuff. I don't want to do that." But, **then once you actually get into engineering, you're like, it's not just about math. It's mainly about math and science and stuff like that, but it's also a social as- aspect of engineering as well. So you don't always have to just be very smart about things.** Like you can be like... There's not always going to be things as easy for you, but you're going to have to learn to do them anyways. So like, **you're going to learn in engineering that you can do things that you never thought you could** (Adina Transcript, 02/27/2020).

Mirroring the importance of her relationship with her peers and the data, Adina points to the importance of relationships with mentors in shaping engineering experiences (lines 3-6). She notes how engineering programs, especially when she was younger, could feel different by how and by whom she was engaged. Adina also pointed to how program structures can mediate if she feels she needs to perform in specific ways (lines 10-12). Although framing this as a positive thing, it is notable that Adina points to the "social aspects" of engineering where she may not need to be as "smart" as the science or mathematics aspects. Although potentially helpful to Adina to feel relaxed or that she belonged, her comment also suggests that she did not see the social aspects of engineering as challenging or skill-laden. *Sensors,* for Adina, seemed to be both a space doing engineering differently from a math-heavy norm and developing connections between group mates and mentors.

Introducing Focal Youth from Context 2

The *Sensors* programming ran at Context 2 over the summers of 2017, 2018, and 2019. Over these iterations, I met Mariabella, Rodrigo, Cesar, and Red. Each of these focal youth had been coming to the Community Center for multiple summers. During the Community Center's summer camp programming, the *Sensors* youth met daily for two hours. Bookended by other camp programming, the group sought project spaces that were near to the Community Center. As a result, Context 2 *Sensors* youth worked on a Neighborhood Park located near the Community Center in the Large Midwestern City. Below I present Mariabella's, Rodrigo's, Cesar's, and Red's profiles, constructed through our time working together.

"I just know that I want to…help people": Meeting Mariabella

> *My name is [Mariabella]. I am 16 years old, in the 11th grade, and I attend [Private Highschool in the Large Midwestern City]. I'm very outgoing, passionate, and [an] intelligent young woman. I take the utmost advantage of my education because I vow to learn for young women across the world who do not have access to education. I've always had a passion for helping others, especially those who are unable to help*

themselves. Working at [the Community Center] during the summer is an amazing opportunity for me. It helped me grow as a person and become a stronger leader. It's great to have a hobby of helping my community, and learning about technology while doing it. – Mariabella, in her own words.

When I first met Mariabella, I knew she would be a commanding force in the *Sensors* program. On day one, she was questioning the process. Although she barely knew me, she expressed her opinions, drawing clear distinctions between what she considered right and wrong. When I asked Mariabella to describe herself in our most recent interview, she offered she is smart, well-spoken and:

> **Mariabella:** …if I see something that I don't like, or see something like, happening to another person and they don't say anything, but I can tell they don't like it, I'm not afraid to stick up for them or stick up for myself if I feel disrespected or I don't like something (Mariabella Transcript, 02/13/2020).

Mariabella consistently shared concern for justice, both for individuals and her community. At the time of our interviews, her goals included going to college and attending grad school to become a lawyer, a teacher abroad, or working with a nonprofit organization.

Over time, Mariabella discussed how different school experiences (both positive and negative) shaped her sense of self. Mariabella is Mexican American, living with her mom and sisters on the border of the Large Midwestern City and a Nearby City. She currently attends a Private Highschool in the Large Midwestern City that "that really cares about me" (Mariabella Transcript, 08/14/2019). She has spent three summers at the Community Center, which she said "help[ed] me learn how to use my voice and use my voice for good" (Mariabella Transcript, 08/14/2019). In these contexts, Mariabella felt supported. Conversely, she attended middle school in the Nearby City and described often being the only Latina in her classes. On being from the Large Midwestern City while attending school in the Nearby City, Mariabella shared:

> **Mariabella: …**I feel like it…allows me…to understand like, the different perspectives as to how people live ’cause I also went to school in [the Nearby City], like which is like, a wealthy part. And like, yeah, I wanted to be from [the Nearby City] when I was little ’cause like, it made me feel crappy that they had more than me. And… they would like, not knowingly front to what they had, but like they would and it would make me feel crappy ’cause my mom couldn’t get that for me. But, now I go to [Large Midwestern City] schools. Like, it makes me feel good being from [the Large Midwestern City] because… I’m not materialistic and I understand that like...And like I understand…how I need to take advantage of school and how I need to take advantage of these opportunities because that’s how like, that is how I’m going to succeed in life. And so I feel like being from [the Large Midwestern City] makes me work harder- And like, be more empathetic to people….but at the same time, I feel like uh, being from [the Large Midwestern City] makes me feel judgy to like…other people who are…who come from like, a better life. Like not necessarily like a better…life, but like more, a more wealthy life (Mariabella Transcript, 02/13/2020).

Mariabella discusses feeling aware of and “othered” by her socioeconomic status at an early age and how that influenced her perspectives and goals. She points to how she gained criticality from these experiences, supporting her to pivot towards goals and careers pursuing social justice in her community and beyond.

Cracked Foundations: Examples from Mariabella's Stories

On the first day I met Mariabella in *Sensors*, she shared with me how she disliked engineering. As we walked back to the Community Center from a community walk, she told me about a time in her middle school STEM class where she had to build a marshmallow launcher. "Why would I want to do that?" she rhetorically asked (Field Notes, 07/17/2018). At first glance, Mariabella's engineering stories appear to have one consistency – that she does not like engineering. On her second day working with *Sensors*, she offered, "I love people, but I hate technology" (Transcript, 07/18/2018). This sentiment seemed to stay with her, even as she discussed challenges she faced in *Sensors* a year later:

> **Mariabella:** I couldn't just have…everything that I wanted. I have to listen, I had to listen to other people in the group. And personally, I don't like…I don't like technology and stuff-In any like, technology, but…I had to also like, collect data for that, too. I remember last year we worked a lot with the sensors, and I personally did not like working with the sensors (Mariabella Transcript, 08/14/2019)

I asked Mariabella about her dislike of technology in our most recent interview. She offered:

> **Mariabella:** Like, obviously I like my phone. But I don't like computers…I feel like looking at them is just like, so boring and…just sitting there like, trying to program something is so boring. Like, I used to have a coding class and I know that's part of engineering. I hate coding so much. It's just like, so... What is it called? I'm trying to think of the word. So tedious (Mariabella Transcript, 02/13/2020).

Ongoingly, Mariabella verbalized disinterest in technology-focused work. Yet, fascinatingly, she participated in the *Sensors* program for two summers. Through her school, she had an internship at a plastics engineering company. Mariabella participated in engineering and even sought out engineering experiences.

Within the same experiences and interviews that Mariabella shared a distaste for technology, she also shared evolving understandings of engineering that included more facets beyond technology. These ideas shifted within one interview but related to leading, collecting data, and working with the community. For example, early in an interview after her second summer in *Sensors*, Mariabella said, “this group is basically an environmental justice group where we’re going to help” (Mariabella Transcript, 08/14/2019). Later on, in that same interview, I asked her how she thought people described or talked about engineering:

> **Mariabella:** I feel like they emphasize the technology part more of engineering-Instead of…being the face and collecting all the data….Like I used to think about engineering, I used to think about like, machines and building them and like... But now like, I’m in an engineering group and like, I realize that I put it together. I’m not a techie, an actual like, I’m not like a mechanical engineer. I’m the data person…leading the technicians person (Mariabella Transcript, 08/14/2019).

Similarly, in our most recent interview, I asked Mariabella where she first learned about engineering. She shared:

> **Mariabella**: Um, like in school. Yeah, when they would say “engineering” like, we would just always be building stuff and I wouldn’t like that. So like, I just feel like school gave me that perception of engineering. And showed like and showed that engineering is just like-we’re always like, building something and I don’t…like building stuff (laughs) (Mariabella Transcript, 02/13/2020).

Later in interview, I asked if and how engineering was important for her life. She shared:

1 Mariabella: It allows me to help the community, like, in a way.

2 Jacquie: Can you say more?

3 Mariabella: Like, us building the bench... Well, we saw homeless people…laying on,
4 laying on the floor and stuff ’cause there wasn’t any benches. So like, I hope that
5 like…instead of laying on the floor I hope they go and sit on the bench ’cause they
6 shouldn’t be laying…where like, all those bugs are and stuff (Mariabella Transcript, 02/13/2020).

Mariabella’s engineering stories provide examples of small but critical shifts youth may have in understanding engineering and how these understandings might involve reconciling conflicting experiences. Initially, for Mariabella, engineering was informed by her several engineering experiences that were technology-focused. These felt misaligned with her interests and goals. By engaging at the Community Center and in *Sensors*, Mariabella shared ways that parts of engineering were purposeful (e.g., building a bench *for* community members) and aligned with her leading and helping goals. Nevertheless, Mariabella's connections in *Sensors* were at odds with her other tech-focused engineering experiences, which remained salient in her discussions.

***Becoming (Data) Driven: Mariabella in* Sensors**

Mariabella participated in *Sensors* for two iterations over the summers of 2018 and 2019. To her first summer, Mariabella brought critique and questioning. She was skeptical of working with sensors, skeptical of front-end processes, and skeptical of the *Sensors’* leadership team. In the first two weeks, she often paused the group to ask “why?” – why we were doing something the way we were or why weren’t we doing something else. That summer, Mariabella also brought a strong drive to help the community. While planning for data collection, she insisted on collecting data from Community Center staff, youth, and parents. She went to local businesses and to people staying in the park to collect their opinions. She worked with the group to analyze community data and provide recommendations, suggesting that bench concepts include planters and books in English and Spanish. Although she left the *Sensors* program early for summer school, she wrote a project summary that the youth used on their posters in the final presentations.

The following year, the *Sensors* program might not have happened without Mariabella. Participating in another of the Community Centers program, she told the Youth Leader that she wanted to do the *Sensors* program again and "continue research in the community" (Field Notes, 07/08/2019). Further, she wanted to work with me to observe the other programs to learn more research skills (Figure 4-3).

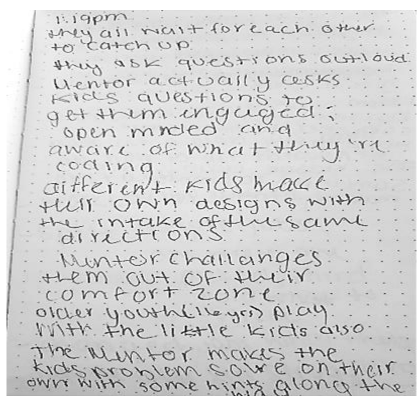

1:19pm
they all wait for each other
to catch up
they ask questions outloud
Mentor actually asks
kids questions to
get them engaged;
open minded and
aware of what they're
coding
different kids make
their own designs with
the intake of the same
directions
Mentor challanges
them out of their
comfort zone
older youth(16yrs) play
with the little kids also
The Mentor makes the
kids problem solve on their
own with some hints along the

Figure 4-3. Sample of Mariabella's field notes

That summer, Mariabella helped bring the *Sensors* group together and led the program. She brought ideas for pilot data collection, worked with the group to develop two surveys to better understand the problem space, and stayed late on two sessions to analyze the data. Collecting data and using data seemed to be essential for Mariabella. Reflecting, she calls it the most significant part of engineering:

> **Mariabella:** …working with your team to collect the data because like, the data is the most important because...Well, you're not gonna really know how to go about fixing it, or like if it's really worth fixing, if like the data isn't like... Like for example, in order to figure out what we wanted to do, we had to collect the data because we wouldn't have known what to do if we didn't know what the people wanted. So we- needed to figure out well, what was most important? Not just in our opinion, but in other people's opinions…Yeah…if we didn't like, if we didn't work as a team to collect the data we would've … never even went about that project. So, I just feel like collecting the data's the most important step (Mariabella Transcript, 02/13/2020).

Ending the summer, Mariabella helped design a new style of bench with the team and created painted stones with inspirational quotes to put near it. She drew upon data showing the community wanted more seating and wanted the park to feel more welcoming. Reflecting on her experiences most recently, Mariabella shared of her time in *Sensors*:

> **Mariabella:** Yeah, I feel like what was really impactful was… like well getting to meet you and getting to meet like, the other kids that like, are also outspoken. And like, I feel like I wasn't the only one. And like, you made me feel like…it was okay for me to have my opinions (Mariabella Transcript, 02/13/2020).

For Mariabella, *Sensors* was a place where her drive was recognized. She was also in community with others like her, who were engaged and cared about their community. Although not fully invested in the sensor technology, she could connect to engineering work through collecting community data in front-end design. Ultimately, *Sensors*, for Mariabella, was about being a leader and helping her community.

"Well, to be honest, if I'm on the phone I'm only seeing construction": Meeting Rodrigo

One of the first things I learned about Rodrigo was that he loved construction work. While we were out on a community walk together, he saw construction workers fixing a large pothole in the street and commented how he wanted to join their work. Reflecting with me in his most recent interview, Rodrigo shared:

> **1 Rodrigo:** And I go see…anywhere that I pass by, like if there's construction there I just
> **2** look at 'em.
> **3 Jacquie:** (laughs) What do you like about doing construction?
> **4 Rodrigo:** I don't know. It's just, it has, it- I don't know. I liked it ever since I was
> **5** five. 'Cause my mom saw when I was five... I still had them tapes that you like, you
> 6 know them boxes of tapes?... What was it called again? It was like, a box-And inside
> **7** that box, it had movies of the uh, like VH tape, I think. Something like that.
> **8 Jacquie:** Oh, a VHS?
> **9 Rodrigo:** Yeah…I used to play with those. Build like, houses with them
> (Rodrigo Transcript, 3/10/2020).

Rodrigo is a Mexican American youth living in the Large Midwestern City with his mother and siblings. Laughing during an interview, he describes himself as chill and social. From an early age, Rodrigo remembers liking to build and construct things. Whether using VHS tape boxes, mud, or sticks, Rodrigo sought to transform these into a structure of some sort. Now a sophomore in high school, Rodrigo has a goal of eventually pursuing work he enjoys, which he named as:

> **Rodrigo**: Anything with engineering, like architectural engineering. Civil engineer, mechanical engineer, or electric-, like electrician engineer//I'm trying to get to my goals by basically getting like, if I have a, if there's any possibility of being in a program-I will be in it. Any opportunities I get, I'll take 'em (Rodrigo Transcript, 3/10/2020).

Driven by his early interests and goal in engineering, Rodrigo sought engineering programming around him, participating in robotics in school and the Community Center's Computer Automated Design (CAD) program, which supported youth in 3D printing.

Building Identities: An Example from Rodrigo's Stories

Rodrigo's engineering stories capture an early interest in working with his hands. During our most recent interview together, he shared three different instances of being younger and building. In Rodrigo's stories, building, construction, and engineering are inextricably linked. He shared:

> **1 Rodrigo:** …explaining to you what it had to do with…what that construction thing had
> **2** to do with engineering. Well basically, like, it's a lot of things. You just can't put
> **3** cement on the road without seeing if it works or not, right?...So you gotta put some type
> **4** of structure around it, right? So you gotta engineer like... Let's say if it was a circle, a
> **5** circle. Like-It's not just like with wood or anything. You gotta do like, a special
> **6** material too, to see if it'll work or not and how much weight you can put on it. Like,
> **7** some streets, you cannot put over like, two tons or some like- like a car (Rodrigo Transcript, 3/10/2020).

For Rodrigo, laying concrete is a natural extension of engineering (developing and testing) road materials building materials. He describes them as part of a more extensive, conjoined process.

Rodrigo's family and history are essential characters in many of Rodrigo's engineering stories. For example, beyond videotaping him building, Rodrigo was with his mom at work when he most recently heard the term "prototype":

> **Rodrigo:** Like last time, it was like, way off this right now, but it was like-I was working… cleaning up a [mechanical] factory with my mom. And then I hear some guys around like,…saying, "Oh, do a prototype for this," and like that. Then I go to school and then I went to a science fair-Like in a field trip and they said, "Oh, this is the prototype." And like, you know, anywhere I go it's the prototype, prototype. (Rodrigo Transcript, 3/10/2020).

For Rodrigo, construction and engineering often happened with his family as an out-of-school activity. While describing wanting to pursue architecture, he also mentioned how his dad taught him carpentry by taking him on jobs. In our most recent interview, I asked to describe a recent engineering experience, and he discussed building a house addition with his uncles:

> **1 Rodrigo**: It was like, two years ago. Three, maybe 'cause now it's 2020. I think it was
> **2** three years ago, two. I don't remember. I was in Mexico. We were supposed to, you
> **3** know, chill over there with my grandma and everything, but instead I went to work
> **4** with my uncles, which my mom didn't let me. So I'm like, "Shh." But yeah, we were
> **5** construction, we were constructing a house-//And... (laughs) instead of you know,
> **6** cranes and everything that pick up the things for you, we had to do it by hand. We had
> **7** like, buckets and me, or my uncle, would like pick it up with the rope and I burnt like, I

8 burnt my hands. It was only like that. Sometimes it was three or four, five buckets and

9 we had to like-[pull them up] (Rodrigo Transcript, 3/10/2020).

Rodrigo's engineering stories exemplify how engineering learning happens for youth, in and out of engineering-specific programs. Rodrigo connected the skills he learned from his family experiences to engineering work and his engineering goals in the future. Rodrigo's stories also raise questions about what (currently) counts as "engineering." He describes the experiences with his family as rich in engineering building work and reflective of a historical or manual approach to engineering ("We had to do it by hand"). This lower-tech approach might stand in opposition to tech-heavy approaches to engineering. While expressing love for building and making, Rodrigo shared a more tepid reaction to technology. Although participating in a CAD course, he repeated, "I hate programming" four separate times in a focus group (Transcript, 08/14/2019). When I asked him about his thoughts about using technology in engineering, he shared a story about a show he watched where a man re-built an old Volkswagen Bus:

1 Rodrigo: And so they had to make a new chassis and everything, and he had to use his

2 own measurements. He like, he had a measuring tape, too-But like, his own

3 measurements and everything, and you know, he was just using his instincts. And well,

4 when like, our ancestors' ancestors way back in the day, they didn't have measuring

5 tapes or anything- So, they even had to go by their instincts. So that I kinda respect and

6 try to do the same thing as them, you know? Instead of doing high tech…I prefer low

7 tech than high tech, but sometimes if it's like, a big job, I prefer both (Rodrigo Transcript, 3/10/2020).

Rodrigo's engineering stories implicate history in the work of doing engineering. For Rodrigo, part of doing engineering is acknowledging and respecting these histories of building and making (e.g., Barajas-López & Bang, 2018).

***Building Up to Taking the Lead: Rodrigo in* Sensors**

I met Rodrigo in the last Iteration of *Sensors* over the Summer of 2019. He joined the group at the Community Center's leaders' recommendation, joining with one new member, John. Rodrigo was among four returning members who had worked with *Sensors* previously. In early sessions, he was more likely to listen to his peers than to share. When he first saw some of the parks' improvements, he

> **Jacquie:** I agree with that…[Rodrigo], what do you think? 'Cause this is your first time seeing it. How is it to like, see the new stuff?
>
> **Rodrigo:** Actually, I was kinda surprised…Yeah.
>
> **Jacquie:** Why were you surprised?
>
> **Rodrigo:** 'Cause really I haven't seen those uh, things in parks in a while. They're always like, probably broken down or already taken, torn apart. (Transcript, 07/16/2019).

Rodrigo was excited to see the positive impact on the park from *Sensors*' work during previous years. He supported expanding that work by thinking deeply about stakeholders and taking up a significant role in data collection. On his own, he asked if he could take some surveys to the nearby neighborhood to broaden the potential stakeholders reached. While out on a community data collection, Rodrigo was unphased in approaching local business owners and local construction workers about their opinions. That summer, Rodrigo and his peer, Mariabella, were responsible for most surveys and interviews collected from the community.

Potentially becoming more comfortable in the program, Rodrigo took on a leadership role in the back-end design. He was the "doer" of the group. While designing a new type of seating arrangement for the park, Rodrigo worked to integrate the research findings with his peers' input. He sketched potential options for a pallet-based bench and got feedback from the other team members (Figure 4-4). Reflecting on this, he offered that during this sketching work:

Rodrigo: What I remember was just I felt, I felt like a little engineer.

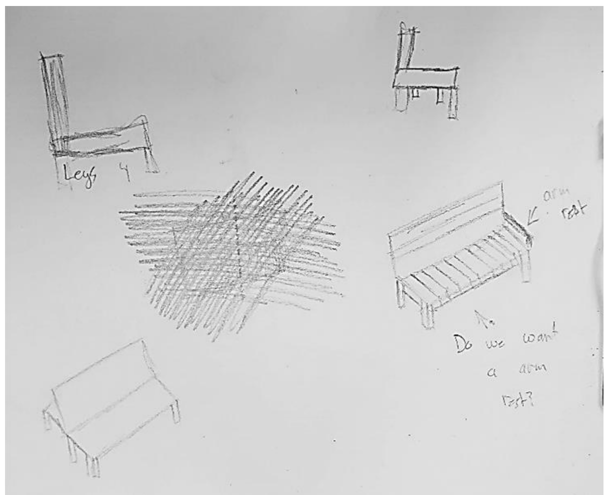


Figure 4-4. Rodrigo's data-driven sketches for benches with questions for the team

Later on, Rodrigo worked to re-paint and re-position a previously built *Sensors* bench. He asked to stay out with me to plant herbs around the park. Reflecting with him in our most recent interview, he offered:

> **Rodrigo:** On the record, well, everything was meaningful. Especially helping out people, the community…I hope we actually put more benches in (Rodrigo Transcript, 3/10/2020).

For Rodrigo, *Sensors* appeared to be a space where he could work with his hands and do the building work he enjoyed. Like other Community Center programming, where he could use CAD to 3D print, *Sensors* supported him in his goals of pursuing engineer and architecture. For

Rodrigo, all aspects of *Sensors* were generally equal, and he appreciated the opportunity to see his work in the community.

"I do better when I'm doing it – that's how I learn": Meeting Cesar

Cesar is a tinkerer. At any given moment while hanging out at the Community Center, he could be found playing virtual video games, timing himself completing a Rubik's cube (Cesar is a competitive speedcuber), or modifying an online blueprint he found to 3D print a Pokeball. He goes and does - building, sometimes failing, and trying again. In our most recent interview, Cesar described himself as a "relaxed" type of person and offered:

> **Cesar:** … I find things interesting and if- if I do, I like, want to learn more about it (Cesar Transcript, 08/14/2019).

Over our years working together, Cesar sought out several opportunities to learn more about his interests. These interests were often STEM-related, ranging from robotics to CAD to the *Sensors* program. If there were no specific formal opportunities available, Cesar turned to YouTube. In our last summer working together, seeing the cracked screen on my computer, Cesar offered to fit my computer with a new screen. He had recently bought component parts and fixed his smartphone screen after watching three YouTube tutorials. On his interests, he shared:

> **Cesar**: I enjoy working with technology. And I also like building things (Cesar Transcript, 08/14/2019).

Cesar named technology, particularly the hands-on construction of technology, as an interest but never named any specific goals around this interest in our conversations. Other than a specific goal of going to college, Cesar has more regularly shared emerging interests with me, like video game animation and programming. Currently, Cesar is a sophomore in the Large Midwestern City and has competed on his school's robotics team since his freshman year.

Cesar is a Mexican American and the second oldest of four brothers. Although quiet, he quickly brought a critical perspective to conversations, pushing back on his fellow group members. For example, during a conversation on the Trump Administration's immigration policy, he reminded the group that the Obama administration deported more people than the Trump Administration. Working at the Community Center, he felt supported by his peers and mentors to explore his interests and think about his community.

Seeking Sensors: Examples from Cesar's Stories

Cesar's engineering stories predominantly feature technology. He points to his CAD experiences at the Community Center and his ongoing robotics experiences when thinking about his engineering experiences. Over our time working together in *Sensors*, Cesar's interest in working with technology has remained consistent. After his first summer in the program, he said the program could be improved by "[w]orking a little more with sensors" (Transcript B, 08/09/2017).

The next summer, Cesar worked more closely with the engineering team to collect data and install a sensor into a community bench. He, and his friend Red, took on extra responsibility to set out the sensors in the Local Park before our meeting times. That summer, when I asked in a focus group how I could improve the program, Cesar offered:

> **1 Cesar:** Um, I feel like we could... It's something that would be easy and not too much,
> **2** would be like, have the participants like, actually build the sensor and stuff…Like
> make-

3 Red: Yeah, like more interaction to, with the sensors.

4 Cesar: Like it can all be, it can already be coded. Just like, building them.

5 Daniel: Oh, putting the parts in.

6 Cesar: Yeah, putting the parts in.

7 Daniel: Like Legos.

8 Cesar: Like Legos, exactly (Transcript, 08/14/2018).

Although having worked more with the sensor technology broadly, Cesar shared a particular desire to build the sensors, putting them together like he might a robot or Legos. In our final summer working together, I asked both him and Red what they were taking away from *Sensors*. Cesar shared:

1 Cesar: … It's like, learning how the sensors, it was learning how the sensors work.
2 One of the things that kept me like, going to [*Sensors*] is mostly like, um, knowing that
3 we were gonna be able to use sensors and-… Using like, using technology like, really...
4 It, I really enjoy it and that's how when I heard we were gonna like, we would be using
5 sensors, that we were gonna be using sensors, I was like, interested in the
6 program…And I feel like that's one of the reasons why I kept coming over to the
7 program.

8 Jacquie: Why'd you stay?

9 Cesar: Um, I just ended up liking like, helping out the community problems. And
10 there's not much, not much more. I just really enjoy helping out (Transcript, 07/23/2019).

These examples from Cesar's engineering stories capture a steadiness in Cesar's technological interests. Working with and building sensor technology drew Cesar to the group and something he consistently wanted to see more. These examples also capture how goals might shift in engineering outreach experiences. Cesar might have reorganized his goals as he returned to *Sensors*. Although not meeting his expectations for building sensor technology, Cesar shared that he stayed with the program because it supported another interest – helping his community.

***Deciding and Doing: Cesar in* Sensors**

Cesar participated in *Sensors* for three years, returning each summer with his friend Red. Each summer, he seemed most interested in tailoring the problem space and tangibly creating solutions. A shy group member, Cesar preferred using collected data to plan the design rather than interviewing or surveying people himself. In his first year, he shared that he felt challenged by presenting his work to a large group. Focused on outcomes, Cesar also looked toward how the group might continue improving a local park past that first summer:

> **1 Cesar**: Well, my idea was like uh, I don't know if it was my idea, but like, if you guys
> **2** come next year and they do all the improvements at the park, or like the differences
> **3** between this year and last year.
> **4 Jacquie**: //(Cut– reminding group of norms) Sorry, [Cesar]. I interrupted you.
> **5 Cesar**: That's okay.
> **6 Jacquie**: So, what were you saying about the park?
> **7 Cesar**: No, it was like, if you guys do come next year…we could come back here and
> **8** like, check the differences between the like, this year and then you know, next year
> (Transcript B, 08/09/2017).

Over the next two years, Cesar seemed to grow more analytical, balancing time constraints and data to suggest directions to the group. He provided reality checks, posing logistical "how" and "can we?" questions to the group. Cesar continued to prefer planning the data collection, as opposed to collecting it. During the summer of 2018, he and Red suggested new ways to collect data using suggestion boxes, and he worked with the engineering team to collect data with the sensors beyond our meeting time. That summer, Cesar and Red presented the groups' data collection efforts to local community members.

In our last summer working together, Cesar emerged as a leader in the group. Drawing on his past summers' experiences, he helped shape the groups' research plan and design plan by citing findings from the data and constraints. For example, upon seeing the improvements made to a Local Park he worked on in previous summers, he suggested that the group work to further that project:

> **Cesar:** [Continue] what we already have on. 'Cause we already have research, we already know a lot about the park. We already know. We just would, we would just need to ask people like, what's better right now that wasn't there before? (Transcript, 07/16/2019)

Thinking about timing constraints, Cesar seemed to pull on both experience and previous data to suggest a potential design direction. Throughout all our work in *Sensors*, making and executing design decisions was how Cesar consistently engaged. In our most recent interview, I asked him what was most important to engineering work in *Sensors*. Cesar offered:

> **Cesar:** Deciding…You can't really start something and then change it halfway through, and then when you're almost done with that, change it again. 'Cause it wastes time and

> there's not... It's not convenient. Maybe you can do like, little changes here and there, but like, if you want to like, restart the whole thing, it's not very convenient (Cesar Transcript, 08/14/2019).

For Cesar, *Sensors'* work seemed to be about getting the work done and seeing the results. To do this, he supported the group in finalizing directions. Although not a place where he felt he exercised technical skills, working in the *Sensors* was a way Cesar could support his community.

"What I'm saying is…ideas shouldn't just be kept in your mind": Meeting Red

Red often surprised me with the directions he took our conversations. In our most recent interview, the topics ranged from our work in *Sensors*, to *Dungeons and Dragons*, to extraterrestrial life. I asked him to describe himself, and he said honest, lighthearted, and:

> **Red:** …I am honest. 'Cause when someone asks me a question, I fully intend of getting, giving them the answer that is the truth and not something that would make them like, feel sad or feel happy, but what they really need to listen to. And I am very weird 'cause I believe (laughs) there is no such thing as normal…So I would guess I would clarify myself as weird (Red Transcript, 03/04/2020).

Red has a lot of interests and ideas. Over time, he described interests in engineering, writing, astronomy, and philosophy. During our last interview, he shared the fantasy quest book he is writing and developed new characters on the spot. Beyond his work in *Sensors* in the summer, he participated in the Community Center's CAD group. In addition, he joined a board games club, robotics, and weekend martial arts classes during the school year. At the time of our last interview, Red was also in the process of applying for high school in the Large Midwestern City. I asked him where he saw himself in the future:

> **Red:** Still doing philosophy or even astronomy, because…I always like, question... Or not question, but like think about outside of our view in space because there has to be something out there… That's not normal to us, or that we've never discovered…but, not something as harmful as like, new diseases. But something that can revolutionize human society (Red Transcript, 03/04/2020).

The youngest of my participants at 14, Red connects between his interests through questioning and discovering. In his titular quote, he was discussing why engineering is an essential part of his life. For Red, engineering is one way his ideas can leave his head to "either run free or come to life" (Red Transcript, 03/04/2020).

Red points to family and friends when thinking about how he got interested in questioning and discovery. Red is Mexican American, living in the Large Midwestern City with his family. During some summers we worked together, he visited his grandparents in Mexico. He and his family speak both English and Spanish at home, and he has been attending the Community Center's programming for seven years. The youngest of four siblings, he started coming to the Community Center with his sisters. When I asked Red if engineering happened in his neighborhood, he shared this of his siblings:

> **Red:** Okay. I would say not really in my neighborhood. Well, not even my family, I would say. I don't know how I developed like, the mindset of like, thinking of all these different ideas or just like, having this creative mind because my family is…I would say pretty normal. But I feel like what really inspired it is…my brother, he is I believe uh, 30 now. And he like, showed me... Well, no. Actually, all my siblings, not just my

> brother. All my siblings would show me all these cartoons and mainly my sister would show me cartoons and my brother, he was a very- very nerdy person ’cause he was a toy collector, gamer. He got into anime and then like, later into the years he started showing me all these things and I’m like, “Wow. This is cool, but I want to make my own spin off.” Not spin off, but own idea off of it (Red Transcript, 03/04/2020).

For Red, creativity and having ideas is a significant part of engineering. Supported by family and friends, he continues to develop his creativity. Now finishing his freshman year of high school, Red still sees the world with significant breadth.

Evolving Ideas, Coming to Life: An Example from Red’s Stories

Overwhelmingly, Red discusses engineering and his engineering experiences positively. For example, in our most recent interview, he described his engineering experiences as instilling confidence to pursue other interests he had, like hydro-dip art:

> **Red:** And then after doing like, robotics and [*Sensors*], that gave me…how do I say this? That gave me not hope, but courage to actually do it and to see either if it comes out good or bad, I can definitely do this. Which engineering helps with because you can actually think of ways to either make your ideas better-Or to see how you can improve it (Red Transcript, 03/04/2020).

Red described engineering as a process of creating, building, and fulfilling ideas. He positions it as a means to achieve particular goals and as a place where failure is accepted. Red identified his formal engineering experiences as robotics, *Sensors*, and CAD, and all of these experiences were a part of the Community Center’s programming.

Over time, Red's relationship with engineering seems to have evolved. Using examples from the Sensors programming, Red's connection to engineering seemed to morph from being *a goal to achieve* to a *process supportive of other goals*. In this, Red pointed to different things he has taken away from *Sensors* over the years. Early working together in *Sensors*, Red pointed to particular aspects of the *Sensors* programming, like the sensors themselves:

> **Red**: I feel like this will like, improve like…my dream to be more like an engineer. To like, helping us…telling me like how to use a sensor and what types of different sensors and there's an … engineer you guys know that's my name. (laughs, referencing [Red], part of the *Sensors* engineering team) (Transcript A, 08/09/2017).

Two years later, he repeated the interacting with the sensors themselves, but also noted that *Sensors* made him feel more in tune with work in his community:

> **Red:** I feel like what I've taken away from *Sensors* is like, get a more grasp on like, how sensors actually work and the different types. And also, how to like, help out with like, community issues or just to realize community issues. 'Cause many people don't realize things that are happening in the world, or they just don't do action to it (Transcript, 07/16/2019).

In our most recent interview, Red offered that he has a goal to eventually "…make a separate power source that does not hurt the environment, or humans, or animals." When I asked him where he started thinking of this idea, he said:

> **Red**: When I thought about it was actually here in [*Sensors*]. (laughs) How you like showed us many different kinds of sensors of how, of what they can track. Which made me think of like, how all the bad things in like the, either the air or the environment can

> be tracked by…sensors. And made me realize, why doesn't anyone do anything about it if they can see how bad it is? And that's how I thought… just these random ideas…(Red Transcript, 03/04/2020).

Red's engineering stories provide examples of how youth might come to connect to engineering work differently over time. At first, Red appeared to want to be an engineer ("my dream to be more like an engineering"). Over time, it appears Red moves toward wanting to use engineering to accomplish the goals he has ("why doesn't anyone do anything about it…?). Red's engineering stories show shifts towards an understanding of engineering as a personal tool. In this, engineering aligns with his goals for himself – creatively addressing the world's problems.

Building Satisfaction: Red in **Sensors**

Red was the youngest member of the *Sensors* group, joining when he was 11 years old. He has also participated in *Sensors* for three iterations, one of the focal youth's longest tenures. From early on in *Sensors*, Red seemed interested in the work. While reading a case study of a previous park in Large Midwestern City, he offered:

> **Red**: Can…I want to know more about the entire neighborhood. How could we tinker with it? (Transcript, 07/19/2017).

Red had two instances where his partner for activities was absent in his first year, positioning him to work alone to prep a presentation and survey data analysis. Although admittedly nervous due to a time constraint and that the presentation was to members of the local Neighborhood Board, Red faced the challenge head-on. He put in earbuds to play music and worked uninterrupted for 90 minutes tabulating survey data (Figure 4-5) and discussing potential findings with me. Looking back on the experience with me, he offered he liked:

Red: I guess just figuring out everything-and, I guess like I was saying, I'd be in the zone and like, feeling confident of just like, "you did all this work-In this amount of time" (Red Transcript, 03/04/2020).

From his analysis, he and his peers offered concise recommendations for improving the local neighborhood park.

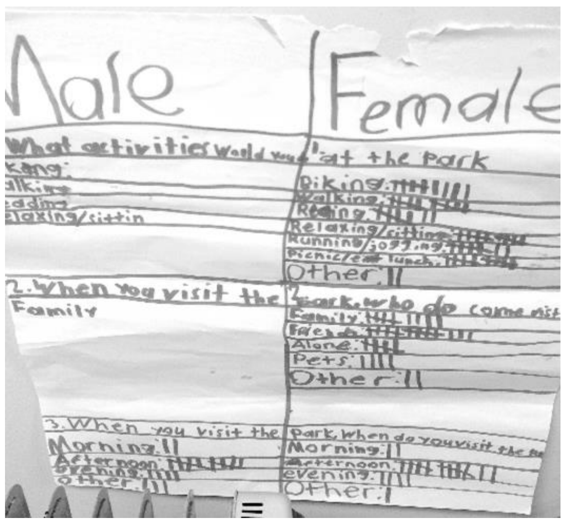


Figure 4-5. Red's early data analysis

Over the next two Summers, Red returned to *Sensors* with his friend, Cesar. In all its forms, Red expressed an interest in taking on leadership roles in data collection. During his second year, he took the lead on revising some of the groups' survey questions. He and Cesar offered to turn on a PIR sensor during the morning camp sessions so the group could have more data. Red also proposed a new way to collect data after installing the prototype bench by leaving surveys at the bench. For the final presentation that summer, he and Cesar volunteered to present data collection and analysis to community members. Collecting more data was challenging that summer, with a quicker analysis needed to create the prototype bench. Reflecting on the analysis, he shared:

Red: …I guess it's- it's just really satisfying to know all your hard work that we've put so much time into is actually just being used, I guess.

Cesar: It's actually going somewhere (Transcript, 08/14/2018).

Although challenging, Red connected the data planning, collection, and analysis he did to something purposeful – designing and installing their prototype bench. This year, Red appeared satisfied that his work had paid off with an actual installation in the community.

In the most recent Iteration of *Sensors*, we learned that the Neighborhood Board had petitioned the city to improve the Local Park. During a community walk, we saw significant changes to the park, many of which reflected recommendations from *Sensors* youth over the previous two summers. Balancing analytics and creativity, Red suggested ways the group might build upon the park improvements' success while also incorporating some new ideas. He worked to edit and analyze multiple surveys to bring together several different perspectives in the group. At the end of our most recent interview, I asked him what it was like to think back through all his work in the program. He shared:

1 Red: I guess seeing how it evolved from a **little presentation, to actually getting a**
2 bench, and then actually making changes all throughout the park and not just a
3 little piece or just like... 'Cause I understand how in the beginning we had to create the
4 presentation-…To actually get permission and to **actually prove that the changes we**
5 were gonna make are definitely gonna make a benefit to this park and to this
6 community. And then when we got the- the next year when you guys came in and you
7 told us we del-, we had permission to make some changes, uh, it was just like **I felt so**
8 satisfied. Like, just amazed of how we, it actually worked. And then when we put

9 this bench in I was like, "**This is gonna be a start to- to the greatest um, just to the**
10 greatest benefit to this park and to the community." And then how last year, or
11 We- we saw all the changes and we still did analysis on it, but just seeing all the
12 changes really like**, felt so satisfying to see all of our work actually built up to the**
13 moment that we wished to…Other than being like, "Oh yeah, we gotta wait another
14 year to do all this." But instead, we actually saw everything we hoped for.
15 Jacquie: Yeah. Is there anything else that you want to say about…this work and all of
16 your time that you've been doing it?
17 Red: Well, I would just say like, it is a great experience to see either old, like old
18 people coming back to the same program…like seeing new faces being involved with
19 it. And it's just how, the satisfaction of our work being like, **considered serious.**
20 'Cause I know like, some places of how they try to accomplish something with their
21 program, but then nothing really ends up happening other than just like, the teach-, or
22 the [teachings] to the actual participants. So, all in all is what I'm saying is how it's so
23 satisfying and **so rewarding to see all of our hard work being like, introduced into**
24 the park. And not even just the park, but just the experience of over all of it-Was
25 just so much fun, in my opinion (Red Transcript, 03/04/2020, emphasis added).

Having worked with *Sensors* for so many years, Red experienced a significant arc in the project (lines 1-3; 7-9). He saw the park change both within iterations (over a single summer) and across iterations (over the years). As the changes progressed, he named the satisfaction of seeing his work make a difference, and he expressed surprise and amazement at times that it did (lines 11-13; 23-25). Where I added emphasis in the excerpt above, Red points to the fulfillment he sees in doing the work (lines 4-5), being taken seriously in work (line 19), and seeing the work transform his community (lines 23-24). Red's *Sensors'* experiences were about the hard work paying off and the change he helped make.

Summarizing Across Youths' Profiles

Looking within and across youths' profiles, there is incredible complexity to ways focal youth come to know and do engineering work. Driven by evolving goals, shaped through new learnings, filtered through stable and emerging identities, how each focal youth engaged in engineering and narrated their engineering shifted over time. Their relationships with the designed world and emerging engineering pathways were complicated, heterogeneous, and full of twists and turns. They reflected several types of experiences, relationships, and contexts. Nothing about these youths' experiences suggests some uniform pipeline carrying youth to engineering (Pawley & Hoegh, 2011). Yet, by analyzing individual focal youths' stories and their engagement in *Sensors* design practice, commonalities emerge that speak to how we might better understand how youth engage in engineering and how we might support them. Further, it illuminates crucial patterns of meaning focal youth make of their engineering design experiences, raising questions about how we genuinely seek to support all youth in coming to know the designed world and do engineering work. In the following chapters, I present analyses about how youth engaged in *Sensors* work and discuss their engineering design experiences.

CHAPTER 5 Exploring Focal Youths' Engineering Design Practice in *Sensors*

In the following chapter, I present analyses that explore Research Question 1, moving across youth profiles to examine how youth engaged *Sensors* design work, particularly in the front-end of design work. Specifically, I explored shifts over time in youths' practice, emerging tensions within practice, and how engaging in *Sensors'* front-end design created opportunities for youth to expand and humanize design work.

Through the *Sensors* program, focal youth engaged in different dimensions of design across iterations. Each iteration, however, began with front-end design work to define, explore, and address a community problem space of relevance to the group. From the analysis of my data, I assert that front-end design practices – as particularly constructed in *Sensors* – created opportunities for youth simultaneously to engage in increasingly recognizable design practice, explore personal relevance of design, and participate in humanizing design towards more liberatory ends. Further, focal youth drew upon their experiences and personal knowledges as assets to the work and imagined new meanings for design in their lives.

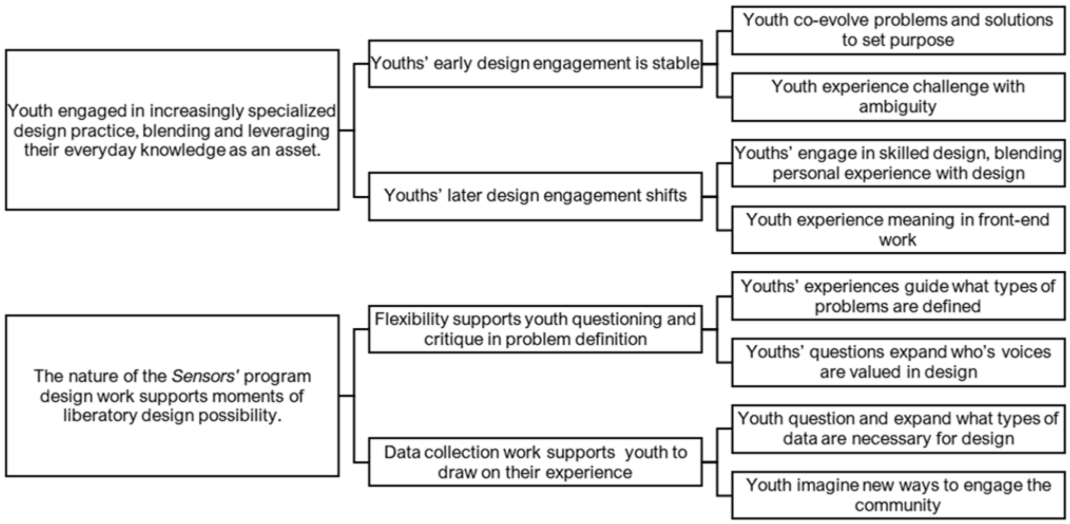


Figure 5-1. First section of key linkage chart

Making the Abstract Tangible: Focal Youths' Design Engagement

For some time, engineers and designers have described front-end design work as challenging. Deemed the "fuzzy front-end" or "the design squiggle," design science scholars have long detailed how the work of front-end design is to manage ill-defined, "wicked" design problems (Borgianni et al., 2018; Buchanan, 1992; Murray et al., 2019). Understanding, defining, and exploring engineering problems in context is often ambiguous and tedious, and early designers may minimize this work or skip it all together (Adams et al., 2003). Yet, front-end design work is purposeful and supportive of ultimately high-quality design (Crismond & Adams, 2012; Daly et al., 2012; Murray et al., 2019). Design science scholars have noted informed ways of being in front-end design work include pausing to interrogate how the problem is defined and treating it as surprising (Bruer, 1994; Crismond & Adams, 2012).

In this first section, I looked at focal youths' design work in *Sensors*, paying particular attention to the ways *Sensors* constructed and engaged front-end design work. The *Sensors* curriculum spent 40% of its time, on average, in front-end design work. For example, if focal youth and our *Sensors* team worked together for five weeks in the summer, two of those weeks would be spent defining the problem, root-cause analysis, mapping stakeholders, and exploring the problem. As described in Chapter 3, front-end design work in the *Sensors* program was not a lockstep process. Including front-end design practices in the curriculum was not meant to be a set of tasks for youth to complete; rather, these practices were intended to embrace the "fuzziness" and engage youth in framing, exploring, and addressing relevant, real-world problems. In the curriculum, the front-end design work asked the youth, as a group, to:

- Ideate potential problems spaces
- Map who might be affected by or interested in those problems
- Come to some consensus on a project focus
- Begin problem exploration through community data collection.
- Ideate potential solution spaces.

As youth raised and explored problems meaningful to them, there was no set solution space or outcome. I and others supporting the *Sensors* enactments sought to support youth engagement in a *process* driven by their ideas from early as problem definition instead of guiding them to complete a particular engineering or design *product*. As I explore my first research question, I take on these aspects of *Sensors* design work not as a generic list of tasks but as practices purposefully constructed in the program to support open-ended design.

Across their time participating, focal youths' engagement in front-end design in *Sensors* seemed to shift with time. This shift seemed to happen from participating in one iteration of *Sensors* to another (or across programming cycles). The nature of the shift focal youth exhibited was both in their practice and discussions of the work. Over time, youth engaged more directly with complex problem spaces and shared more appreciation for, or at least less struggle with, the ambiguity and openness of *Sensors* design work. In the next sections, I explore youths' "early" and "later" front-end design work. I use "early" to describe how focal youth engaged during their first time in *Sensors* and "later" to describe how they engaged during subsequent returns to the program.

Early Front-end Design Work: Establishing Purpose and Evolving Problem-Solutions

At the beginning of their participation in front-end design work, the *Sensors* team asked the youth to imagine what community problem spaces, issues, or concerns they might like to work on for our time together. We went on community walks in this process, where youth jotted open notes about their school or community center's surrounding physical areas. The group would begin an ideating discussion upon returning, generating a "living" list of problem spaces we would update for the remainder of front-end work. In this early problem space generation, focal youth engaged in the work to establish a purpose for the design, using solution-posing as an entry point. For Elizabeth, Adina, and Mariabella, this involved sharing specific projects they thought we could complete as a group. Seeking to establish a group goal, these focal youth described what they, as a group, "should" or "could" do to remedy a problem space. Early on in their engagement, these focal youth co-evolved the problem space with a potential solution space, negotiating how they might solve the problems they were posing (Dorst & Cross, 2001). For example, on her first day in *Sensors*, Mariabella engaged in problem framing by solution posing. On this day, the youth and I were building a list of problem spaces to explore after participating in a community walk:

1 Jacquie: So, we only have a few minutes left and I want to respect your time. Is there

2 anything that is not on our current [problem space] list that we want to add? I know I

3 was having some conversations with you all about…

4 Ava: The trashcans

5 Jacquie: Yeah, the trashcan situation. Do you want to say a little bit more about that?

6 Ava: Yeah, so like the trashcans are all on the curb, and all the trash is in the middle of

7 the park. So, we were wondering if we **could** move the bins.

8 Mariabella: They **should** put more trashcans in the park. And there **should** be a

9 recycling bin, instead of just trashbins.

10 Jacquie: So, this has to do with the litter and cleanliness...so I wonder if the problem

11 behind this is the location of the trashcan.

12 Mariabella: **I think the biggest problem is the litter**.

13 Jacquie: So, I think Ava was saying that the relationship between the location of the

14 trashcans might contribute to where there's trash.

15 Ava: Yeah

16 Mariabella: Ok

16 Jacquie: Ok, so what else. Just to come back to this idea of more information or

17 signage, there was no…even if those blue cans were recycling cans, they were not

18 being used as such and they were not marked.

19 Mariabella: They **should** be green and have a recycling thing on it to make sure it's

20 clear that it's recycling

21 Jacquie: Ok, so in their current state, the recycling bins are not clear (Transcript, 07/16/2018).

In this excerpt, Mariabella and her colleague Ava engaged in front-end design work through solution suggestion, co-evolving a problem space about community litter and trashcan location, and labeling. By offering examples of what the *Sensors* group or the city might do to improve the park, Mariabella and Ava began to shape a problem space, driven by their observation and shaped by the community. In line 5, I prompted Ava to share her conversation about the local parks' trash bins, inviting both the problems and solutions she and her partner discussed. In lines 6-7, Ava shared a wondering that contains both a problem and solution – the inconvenient location of the trashcans and the moving those, so they were easier to reach. In lines 8 and 9, Mariabella built upon Ava's wondering with a solution of more trashcans and adding a recycling bin. In lines 10-12, I posed that the problem space has something to do with litter, general park cleanliness, and trashcan location. Mariabella confirmed and added specificity in line 12, sharing that she thinks the biggest problem is litter. The overall effect is ongoing jumps between what the *problem* might be and how it might be *bettered*.

Ava and Mariabella also used "could" and "should" to enter their ideas into this conversation. This way of participating in early front-end design work suggests that these youth were thinking about the goals and purposes of the work. For example, Mariabella's use of "should" in this exemplar speaks to emerging commitments and needs – what does the park need to be improved? From a problem solution co-evolution perspective, this *is* the work of front-end design, and Mariabella and Ava were actively beginning to engage in its' messiness. Ava and Mariabella moved toward potential problem spaces they might take ownership of in the design future. Ava and Mariabella began to engage in practices aligned with how person-focused designers see design – an amalgamation of ideas from different sources shaping the design direction. They also participated with the designed world, noting the designed aspects of the park. In thinking about developing engineering experiences for youth, imagining ways to make visible that the solution and the problem may co-evolve together may support youths' engagement in this type of work.

A tension emerging here is whether conversations like Mariabella and Ava had with me above would be considered recognized *engineering* design work. Compared to some framings of engineering design work, their engagement may look and sound misaligned from recognized engineering behavior: it does not appear to be systematized, jumps around, and their opinions are forefronted. Further, the problems they were raising – park cleanliness and trashcan locations – may or may not be considered engineering problems. Depending on how (or who) you ask, Mariabella, Ava, and I's conversation could be considered civil *engineering* or urban *design* (Abd Elrahman & Asaad, 2021; Pinson, 2004; Strickland, 2017). However, Mariabella and Ava started developing problem spaces that had meaning to them (line 12), were designable, and could be engineerable (Costanza-Chock, 2020). That is to say, the early design work Mariabella and Ava engaged in was necessary for future work – even if it was in tension with certain images of engineering.

Beyond setting up a larger goal for the project, early front-end design conversations seemed to create opportunities for multiple types of knowledge to evolve the problem space. Because we developed *Sensors* as team-based work, much of the front-end design funneled through group discussion. That meant, as youth began participating in front-end design work, they also negotiated several perspectives as a group. For example, Cesar engaged in this discussion after a stakeholder meeting with community elders, where a conversation had taken place about bike safety in the city:

1 Angela: We should do the bike thing…

2 Jackie: No, but most times people drive their cars…

3 Rosa: But there's a lot of people that it would help

4 Jacquie: (Writing on "Community Problems" list) Yeah…so what else. Safe biking
5 and what else?

6 Cesar: **One day, me and my cousin we were riding our bikes and we were in the**
7 bike lane but this car… it came and took the bike place and then we had to go into
8 the street and then the sidewalk…

9 Angela: And **they should have**…if they had bike rails to put your bikes in…they
10 should have a lock…but **they should have a machine to tell you what the lock**
11 numbers are…

12 Matteo: No, because then that might reveal them and if they do it again then
13 somebody might steal them

14 Cesar: **You should use the type of locks where you type in your own code then**
15 you close them, then you can use it to open them again…

16 Jacquie: Ok, so [Cesar] I'm hearing you say there is a problem around safe biking
17 routes…(Transcript, 07/18/2017, emphasis added).

Like the above exemplar, youth co-evolved the problem and solution space, moving quickly between potential problem and solution spaces. This exemplar begins with youth debating a potential direction for their project – bike safety (lines 1-3). The initial conversation reflects youth thinking through their ideas and the community elder conversations while establishing a goal for the work. In lines 6-8, Cesar shared a personal experience with bike safety in the city, grappling with how he and others interact with the designed world. Amid the co-evolution of potential problems and solutions, Cesar's contribution added detail and specificity around the ways biking might be unsafe from interactions with cars in bike lanes. He began to position himself and his cousin as stakeholders in the bike safety problem (or, as Rosa says, someone who would be helped by work on this problem). At the same time, his contribution revealed how addressing bike safety might be personally relevant to him. In this problem definition discussion, Cesar's story reveals how youth may move between different roles early in the design – both as designers and stakeholders. For Cesar, engaging in front-end design created an opportunity to establish purpose and personal relevance to our *Sensors'* work.

Thinking through the exemplar from the perspective of program development raises some interesting considerations. From Cesar's contribution, Angela suggested another type of bike safety problem and solution: how to store bikes safely (lines 9-11). As opposed to returning to his initial problem, Cesar and Matteo began to build on the potential solution space of safe bike storage, digging into this hypothetical design's specific details. Although we eventually returned to Cesar's story later on in the conversation and framed a problem from it (line 16-17), engaging in this conversation as a group meant his story became one of many conversation threads. In participating in this front-end design conversation, Cesar balanced the story a community elder had shared about bike safety, his own experience with bike safety, and his peers' perspectives on bike safety. As youth began to engage in *Sensors* design work, drawing on all these perspectives seemed to support creative, expansive discussions. However, the sheer breadth of ideas in the group may have made connections between ideas less clear. This situation raises the question: What might personal relevance look like in group design work? As was modeled in the particular design approaches *Sensors* adopted, design work is often collaborative, necessitating group work and decision making (Pattison, Gontan, Ramos-Montañez, et al., 2018; Rosner, 2018). Formal classroom settings may seek to mirror this disciplinary feature and/or require group design work due to time, resources, or class size constraints (Radloff & Capobianco, 2019). As previous scholarship has interrogated the tensions between school-based curriculums, disciplinary authenticity, and personal relevance (e.g., Kapon et al., 2018), understanding how young people's interests and goals are supported and integrated into larger group design settings is an important area for continued study.

Experiencing Front-end Design Work as Challenging

After *Sensors* groups wrapped up the research and design work, culminating in some sort of public communication, we would reflect on the process together. In these reflections, youth would point to successes and challenges they felt in the process, revealing how they were initially making meaning of the front-end design practices. Initially, reflective conversations surfaced the ways youth saw *Sensors* design practices, particularly around the autonomy of problem definition, as challenging. For example, after their first *Sensors'* experiences, Elizabeth, Cassidy, Red, and Rodrigo named problem framing and maintaining a connection to "thinking work" as challenging. In the following exemplar, Elizabeth and Cassidy reflected together on their challenges:

1 Jacquie: …So getting back to, so what were some of the, more of the challenges, in
2 doing the work itself? So like, going to the riverfront. You guys had mentioned like,

talking to people… figuring out what you guys were wanting to study…

Cassidy: Oh, yeah. **That was really hard, that was really hard in the beginning**. **Trying to find out what we were trying to study**…Topics and everything.

Elizabeth: Oh yeah, **I don't know how we got to the Riverfront**. I don't know how we got to the riverfront (laughs).

Cassidy: Yeah, **I'm like, "EW, okay."** (laughs)

Elizabeth: Oh yeah, it was like…**we just needed a topic quickly** 'cause the time was about up. It was almost time for with the program not to end, but like, **it was too much time we were wasting on giving out studies**…And **finding a topic, that was challenging**. Making up a topic.

Cassidy: Yeah.

Jacquie: Okay. What made it challenging?

Cassidy: Trying to understand it. Like, I don't know how to explain it. **Trying to understand what we're trying to study, basically**. 'Cause I was kinda confused at first…And then once we started going over everything like, more than once and we worked through it, it made it easier.

Brandon: See, with me I didn't really have a challenge. You know, you know, I came like I- I wasn't here all the time. I picked up on the things I thought was still important that you were talking about. So, it wasn't really challenging 'cause I understand what you all was talking about.

Jacquie: Ok, so you felt like it was okay…figuring out our problem was okay. What do you guys think?

25 Elizabeth: I mean, it was challenging, but nothing was really challenging. **It was just**
26 a lot of thinking (Transcript A, 06/07/2017, emphasis added)

In this exemplar, Elizabeth and Cassidy grapple with experiences related to the initial ambiguity they experienced in *Sensors'* work. Both named how intangible and ambiguous front-end design work, explicitly problem definition, felt. Both noted that they were unsure how the group arrived at their final problem focus (lines 4-9). Their reflection suggests that the process felt at least muddled with the amount of information available and that defining their own problem (as opposed to engaging in a pre-defined problem) was a new space. As Cassidy suggests in line 5, the autonomy to develop the space may have felt originally challenging because it required new types of practices. The youth had to manage their own time, experiencing and reflecting on the constraint of designing within limits (lines 9-12). They had to explore and delimit something ill-defined instead of pre-constructed (lines 15-17). Yet, I do not interpret "challenging" here to mean insurmountable. Both Cassidy and Elizabeth share that these new practices were doable, that they could manage the difficulties (lines 17-18, 25-26). Having joined the group more consistently in the final months of work, Brandon experienced the problem space as more defined and benefited from the significant "thinking" work Elizabeth, Cassidy, and their peers, had done (lines 19-22). Although experiencing the newness of front-end design work, Cassidy and Elizabeth ultimately expressed more comfort with ambiguity, a necessary perspective when engaging in real-world design. Importantly, Elizabeth explains she did not feel overly challenged as much as she felt like she had to *think* (line 26). Her statement suggests that, perhaps, this experience engaged her thinking in ways she had not been previously asked to in engineering or

STEM contexts. It also raises interesting considerations around how experiences might better engage and value youths' thinking.

Similarly, Adina, Mariabella, and Cesar named challenges of negotiating stakeholder and group interests. For example, reflecting on her first design, Adina stated that her biggest challenge was:

> **1 Adina**: Finding somewhere to actually put our ideas. That was the biggest challenge for
>
> **2** me cause I was like, **I didn't know what to do**.
>
> **3 Jacquie**: What do you mean places to put your ideas, so like…
>
> **4 Adina**: **So like when we were, when the people were coming here, and I was like**
>
> **5 they all have great things wherever they are**. It's just like what do…
>
> **6 Jacquie**: Where do we want to partner?
>
> **7 Adina**: Yes (Transcript B, 06/07/2017, emphasis added).

Like Cassidy and Elizabeth, defining the problem space as situated within community spaces and stakeholders was a new experience for Adina. In this reflection, Adina shared the challenge she experienced sorting through the multiple perspectives on potential problem spaces. In this instance, she felt she juggled her own interests, the groups' interests, and two community organization interests brought in for a stakeholder meeting (lines 6-7). She locates the defining process of focusing a data collection and design effort, or "somewhere to actually put our ideas," as a place of unknowing. Like Cassidy and Elizabeth, Adina had participated in other types of design and engineering experiences before, like robotics. However, to this point, it seemed she had not been asked to make meaningful decisions about the direction of the design, like evaluating how and where to partner with community stakeholders in ways that shaped the design outcome (lines 4-5). In this sense, Adina's reflection animated her emerging experience as a designer with an ill-defined, real-world problem space.

Despite many having prior engineering experiences, focal youth seemed unfamiliar with defining and delimiting the ill-defined types of problems they might experience in local, real-world contexts. This suggests that these focal youth had not been invited into front-end design work up to this point. Taking focal youths' practices and reflections together raise interesting complications for curriculum designers that seek not to overdetermine youths' experience. As youth engage in front-end design practices for the first time, paradoxes might emerge. At once, youth could actively participate in establishing the purpose for a design, seeing their interests or commitments as invited in that space *and* struggle with the work's ambiguity.

Further, how we enacted front-end design work in *Sensors* likely contributed to discomfort: the work *was* undefined, ambiguous, discussion-heavy, and done as a group. However, these experiences were not necessarily negative for focal youth. On the contrary, they described these aspects of their *Sensors'* engagement as thought-provoking, requiring them to contemplate their problem space deeply. In this, youth experienced challenges similar to those of practicing designers (Dunne & Raby, 2013; Rosner, 2018). Creating room for youth to wrestle with this unfamiliar, ill-defined space invited opportunity for discovery and new thinking.

Later Front-end Design Work: Developing New Design Skills and Seeing Purpose

When focal youth returned in later iterations of *Sensors* and engaged in subsequent designs, their engagement looked different from their practice in early engagement. Continuing to co-evolve problems and solutions, focal youths' engagement in the "fuzzy" *Sensors* front-end began to align more with the recognized practices of informed designers than it had in earlier iterations. Reflecting new design skills, focal youths' subsequent participation in *Sensors* demonstrated increased engagement with tools to explore and define problems and a greater tolerance for the ambiguity and struggle of problem definition work. For example, when Red and Cesar engaged in their second design cycle with *Sensors,* they offered a sophisticated focus on and expansions of exploring their problem using data. The following exemplar comes from a discussion where I asked both youths to dig into the problem space of "Safety" at a local park (Figure 5-2.a). As a pair, they added "welcoming" as a problem space to this exploration.

> **Jacquie**: Alright, so talk to us about what problem you were working on…
>
> **Cesar**: So what were doing was welcoming and safety [of the park]. And the first "why" we said was the **quality of benches in the park**. **They don't seem safe or they don't seem welcoming.**
>
> **Red**: Like the benches seem like a hazard…with the spikes…
>
> **Cesar**: **You don't feel like you should stay there because there is nowhere to sit**.
>
> **Red**: It doesn't feel welcoming because **if you saw a lot of broken benches nearby, you wouldn't feel welcome**.
>
> **Cesar**: And now the questions (laughs)
>
> **Red**: And while we were thinking of questions for the survey and the interview, one question for both of them would be, do you feel welcome, or do you feel safe at the…[park]
>
> **Cesar**: **Actually, a question after that would be, why don't you feel welcome? Or why do you feel welcome? Why? To, like, check ourselves.**
>
> (Transcript, 07/22/2018).

Red and Cesar had been tasked with thinking about a problem space and thinking about what they would want to know about their problem. Although the original problem space the group (specifically Mariabella and Ava) brainstormed was “park safety,” Cesar and Red added “welcoming” in their discussion and began to ask questions about “why” the park felt both unsafe and unwelcoming. By pairing these two concepts together, Red and Cesar defined a more complex problem space. In the same breath, this new problem space also reflected their own experiences and understandings of designed spaces – there was some sort of interconnection between feeling “safe” and feeling “welcome” in a space. Tasked with exploring root cause, Cesar shared early thinking about a root cause of why the park might feel both unsafe and not welcoming – the benches at the park were ripped apart, leaving exposed metal spikes (Figure 5-2.b, lines 3-4). Moving away from exploring root cause, Red and Cesar begin to postulate about how a park-goer may experience or feel about the park's current state. This postulation was important – by empathizing with a park-goer and drawing on their own experiences in the community, Red and Cesar forged a path into a tricky problem space. Yet, this hypothesizing was an extrapolation of their own experiences. In a move to powerfully connect data with design, the youth drew on this empathizing work to define what information was necessary to explore their problem space (lines 9-12). Notably, Cesar suggested ways their research instruments might collect disconfirming evidence to “check” their hypothesizing (line 14). Looking across this interaction, Cesar and Red are engaging in important design skills. By framing the problem space as welcoming and safety, they defined a more complex problem and created an opportunity for a diverse range of solutions that addressed the criteria of a “safe” and “welcoming” space. Beyond helping shape the project’s goal through their framing and questioning, Cesar and Red were engaging in sophisticated, socially engaged design practices that envisioned a park that better welcomed and protected its visitors (Buchanan, 2001; Costanza-Chock, 2020).

Further, they engaged in merging data with their personal experience, positioning community data as a way they might confirm or expand on their own experiences at the park (Purzer et al., 2015). A recognizable engineering design skill, Red and Cesar balanced drawing on their personal experiences to meaningfully frame and explore the design problem in ways a community outsider might not, while not making their experience the ultimate design authority. Through defining and exploring a community problem in *Sensors*, these youth demonstrate growing design skills, which in turn has the potential to lead to engagement as both designers *of* and participants *in* the designed world. It also illustrates how drawing multiplicity of experiences can frame and develop problem spaces that better serve all communities.

Figure 5-2. Cesar and Red's working paper for exploring and framing a potential problem space (a) around bench quality (b, photo taken by Red)

Part of the way youth seemed to shift their practice in later *Sensors'* participation was by bringing more data into the problem-solution co-evolution. In doing so, youth demonstrated a growing understanding of how community research can serve as a tool for community-engaged design and engineering work. Coming back to the *Sensors* program and perhaps knowing what to expect, focal youth seemed apt to pause in problem framing and exploration because of an impending community data collection phase. Connecting with community stakeholders through data was another way the *Sensors* project took on meaning for youth. It also seemed to support initial connections between front-end design work and back-end solution implementation. For example, Mariabella returned to *Sensors* in her second year because she was interested in "exploring the community more and collecting more data" (Field Notes, 07/08/2019). During an initial problem ideation discussion, she suggested a problem space of "community stress" because of the current political situation in which the city was hosting a primary debate and suggested a solution might be to use inspirational quotes in some way (Field Notes, 07/10/2019). In this suggestion, Mariabella drew on her own experiences and knowledge of her community to co-evolve and humanize—a problem and solution space. In fact, her imagining of how a large-scale political event in her community opened up a sophisticated problem space for designing in a restorative and just manner (Costanza-Chock,2020; Gaskins, 2019).

Mariabella and her team members (Cesar, Red, and Rodrigo) decided to do a short pilot survey to see if that problem space was supported by data (Figure 5-3). This decision was markedly different behavior than her first year participating, where she often sought to "get to work" addressing potential problems the group brainstormed (Field Notes, 07/18/2018). Mariabella missed the programming day during which we had planned to do the pilot data collection, so her team decided to wait for her to return. Upon returning, she said:

Mariabella: You only got one survey back? Why? You should have been handing them out to the people around [our community organization] so we could get that data back (Transcript, 7/17/2019).

After expressing her frustration that we had not collected the data, she and the group collected 52 surveys for the pilot. During the next programming session, as the youth were beginning to analyze, Cesar joked about skipping analysis:

1 **Cesar**: I'm just saying…like, if they ask anything, why don't you just give them the

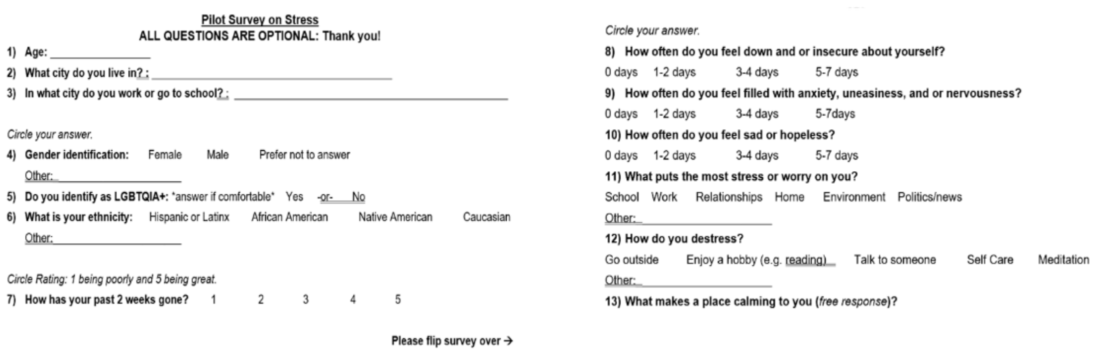
2 surveys that are already filled out? Like we could do that that instead of these analyses

3 (laughs)

4 **Red**: Ohh…no. **Analysis is more professional**…

5 **Mariabella**: Yeah, no. **Analysis is more for us, so we know what to do**.

6 **Red**: And it's more professional presenting, if you really think about it (laughs) (Transcript, 7/22/2019).



Pilot Survey on Stress
ALL QUESTIONS ARE OPTIONAL: Thank you!

1) **Age:** ______________
2) **What city do you live in? :** ______________
3) **In what city do you work or go to school? :** ______________

Circle your answer.

4) **Gender identification:** Female Male Prefer not to answer
Other: ______________
5) **Do you identify as LGBTQIA+:** *answer if comfortable* Yes -or- No
6) **What is your ethnicity:** Hispanic or Latinx African American Native American Caucasian
Other: ______________

Circle Rating: 1 being poorly and 5 being great.

7) **How has your past 2 weeks gone?** 1 2 3 4 5

Please flip survey over →

Circle your answer.

8) **How often do you feel down and or insecure about yourself?**
0 days 1-2 days 3-4 days 5-7 days
9) **How often do you feel filled with anxiety, uneasiness, and or nervousness?**
0 days 1-2 days 3-4 days 5-7days
10) **How often do you feel sad or hopeless?**
0 days 1-2 days 3-4 days 5-7 days
11) **What puts the most stress or worry on you?**
School Work Relationships Home Environment Politics/news
Other: ______________
12) **How do you destress?**
Go outside Enjoy a hobby (e.g. reading) Talk to someone Self Care Meditation
Other: ______________
13) **What makes a place calming to you (*free response*)?**

Figure 5-3. The front and back of the focal youths' survey to understand community stress

Like Cesar and Red, Mariabella shifted how she engaged in *Sensors*' design work, seeking data to support her problem space and potential solution. She demonstrated emerging design skills, suggesting a larger, less tangible problem space and using data collection to refine it (Crismond & Adams, 2012; Murray et al., 2019). Beginning to engage in an informed front-end practice of "building knowledge through research" (Crismond & Adams, 2012, p. 752), analyzing the data was how Mariabella informed what came next and how Red saw what was "professional." Importantly, the youths' engagement in these sophisticated design practices stemmed from Mariabella's experiences, with Red, Cesar, and Rodrigo building on her ideas. Front-end design work created opportunity for youth to explore meaningful potential projects, and voice their concerns, in ways that were also recognizable by the design discipline.

After analyzing the data, the focal youth learned that community stress was less common than anticipated but was reported by some community members. Reflecting on this process and his time in *Sensors*, Red shared how he saw the changes in the projects over the years:

> **1 Red:** I feel like…like we definitely upgraded of where, how we did the year before
> **2** that. How…our initial ideas were like, they could've been better. **And then when it**
> **3 came to this year, we definitely like, found out the errors, found out what was**
> **4 wrong, and even found like a little bit more newer problems. [L]ike how we**
> **5 were talking about the survey, how we put [a question about] stress [on] it and**
> **6 we found out someone said, "No stress" is how we figured out a new, not a new**
> **7 problem, but a new concept.** And then actually organizing everything and
> **8** knowing what to do next, or just how to figure out those topics that we have found
> (Red Transcript, 03/06/2020).

Red's reflection animates the potential power of youth engaging in front-end design work over multiple iterations. Red saw the change in his and his colleagues' practice by exploring community problems over three years – framing "better" and "newer" problems using community research (lines 2-4). He, and other returning focal youth, experienced the ways problem spaces and designed solutions can continually be iterated and improved and the means through which to do so. Having participated in multiple *Sensors* iterations, returning youth experienced true scaffolding into design work – scaffolding that could be removed with time. As opposed to being a process that I was facilitating for or requiring of the youth, as might have been common in their first time in *Sensors*, framing the problem and collecting data became a meaningful way youth understood the problem space and shaped the project direction (lines 5-7). In turn, over multiple iterations with youth, my suggestions became less about the practices we might use to frame and explore a problem and more about how we might expand our ideas.

Findings from youth-guided data collection did not necessarily jettison their initial thinking or personal experiences. Instead, in later participation, it seemed to offer "not a new problem, but a new concept," or a new way of thinking about the problem that blended personal and community perspectives together. For example, in the park project, the group combined the dimension of support for a stressful time for some community members into continuous improvement of a nearby park. As a result, the group pursued "community support" as a dimension of broader park improvement. They developed another survey to collect more data to support their design work. Taking all the data together, the group developed a new type of chair to allow for more relaxation in the park, planted herbs for community use, and designed colorful landscape rocks with supportive phrases that were incorporated into existing park structures. Youth compiled their process into a poster for their community center, an artifact that captures youths' analysis and subsequent design decisions (Figure 5-4). In this, multiple opportunities to engage in the *Sensors* program – iterating and expanding the adaptable, relevant front-end design work it evinced – seemed to support youth in *seeing* the designed world and *designing* within it. Returning focal youths' experiences and reflections suggest an important role for time and iteration in developing engineering design experiences.

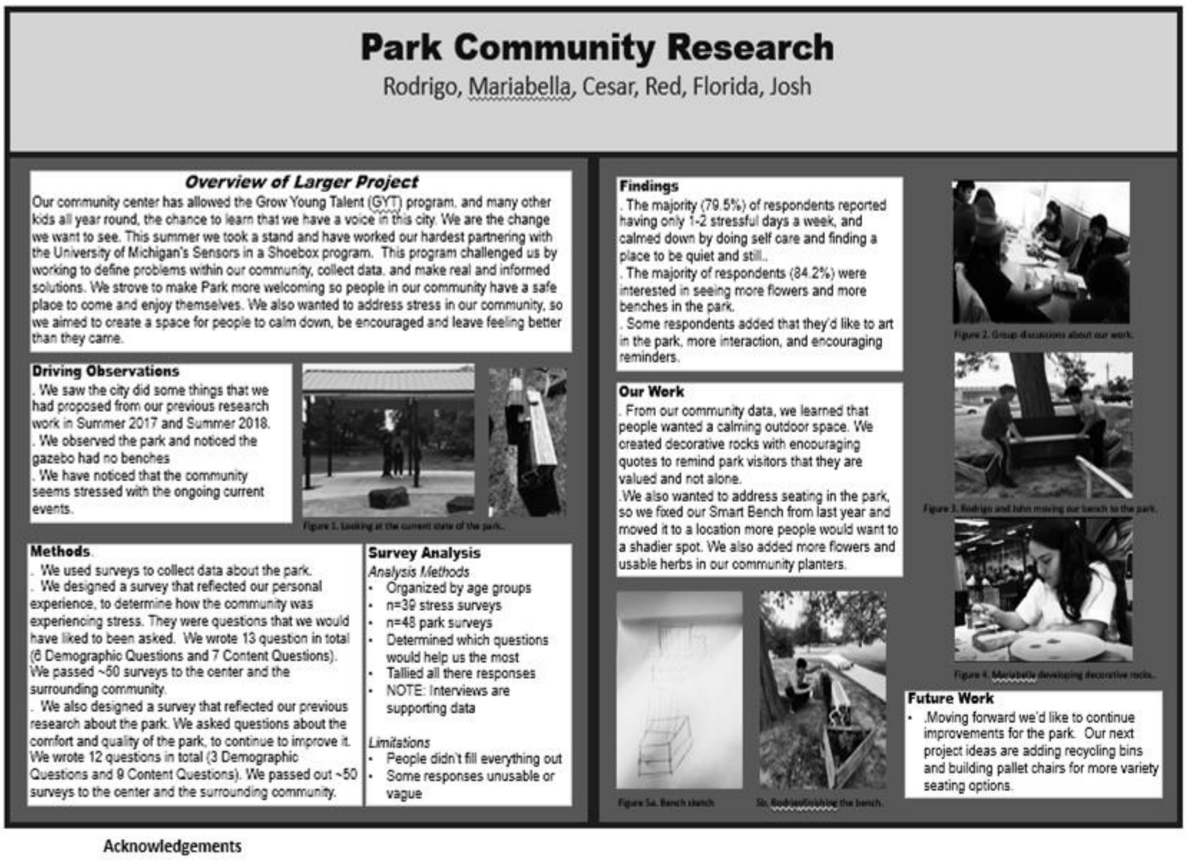


Figure 5-4. Focal youths' final design poster *Note. Names and places have been de-identified.*

Experiencing front-end design work as meaningful

Perhaps establishing more comfort in the *Sensors* design process and also possibly a function of their individual development, Elizabeth, Cassidy, Mariabella, Cesar, and Red (those returning to *Sensors* for a second or third time) also seemed to experience less challenge and more interest in *Sensors'* front-end design. Beyond participating with more autonomy, these focal youth discussed moments where they were more comfortable in ambiguity (without explicit project direction) and used tools on their own to decrease ambiguity. For example, in Red's and Cesar's second summer, they reflected on an argument they had had in the group about the bus stop location and whether they considered it part of their problem space and physical context. There was a consequence to this argument: including the bus stop meant more data collection, different types of questions asked, and (potentially) a different type of design. Another team member, Daniel, who was a first-time *Sensors* participant, offered that he found the arguments challenging (line 2), but Red and Cesar disagreed (lines 5-6, 14):

1 Jacquie: Yes? Um, so um... why do you think that that was a challenge…//

2 Daniel: Um, we were wasting a lot of time instead of just working on the task at hand.

3 Jacquie: Okay, so you felt it was taking you kind of off task, maybe?

4 Daniel: Yeah.

5 Cesar: I disagree. . .**Because we were discussing on where places would be good to**

6 place the actual bench that we made.

7 Jacquie: Okay, so [Daniel] what I'm hearing you say is that it, you felt like it took

8 you offtask, but [Cesar] you're saying that's kind of part of the process. Like, maybe it

9 was like, a ton of argument, but it was helping you guys kind of get to where you

10 needed to be for placement? Is that about right?

11 Cesar: Yeah.

12 Jacquie: Okay. Red, what do you feel?

13 Red: Hmm. I feel like it was taking off-…track a little bit and it was a little bit

14 pointless-**But like, At the same time, we had to know if like, the... We had to know**

15 (laughter) if…we were actually gonna work on the bus stop...For like, the project. I

16 still vote we should vote uh, promote- promote some of our time to the bus stop (Transcript, 8/17/2018, emphasis added).

In this interaction, Cesar disagreed with his colleague about the purposefulness of the heated discussion about the bus stop. His and Reds' contradictions suggested an acknowledgment of a different "task at hand." Instead of taking away from their engineering solution building, Cesar and Red seemed to view the arguments as a productive struggle, adding purpose to the design. Paraphrasing what Red says in lines 14-15, the discussion helped them figure out if "they were actually going to work on the bus stop" or the limits of their design context. Of course, Daniel's discomfort with the protracted conversation could have been legitimate: Perhaps the youth did go off track "a little bit," as Red acknowledged. Alternatively, Daniel could have felt some hesitation with the conversation because he did not have the same insider experience with Sensors as Red and Cesar had. For that matter, Daniel's discomfort could have been as much about a social interaction from which he felt excluded as it was about "wasting time." All of these explanations are possible, but it remains the case that Red and Cesar not only engaged in a sophisticated design skill of delaying making premature decisions (Crismond, 2001; Crismond & Adams, 2012) but also saw how this practice was purposeful to their work. They "read" the designed world (seeing the park and bus top as constructed spaces) through their own design work (V. C. McGowan & Bell, 2020). In this, Red and Cesar engaged in ways that supported their informed participation in the designed world and also demonstrated ways that they were beginning to engage in recognized engineering design practices.

Returning focal youth also discussed *Sensors'* front-end design work in ways that demonstrated greater personal investment. Some of these young people spoke explicitly about the importance of problem definition, mirroring the value informed designers place on this practice. For example, when asked in her final interview what was most important in engineering, Elizabeth replied, “I mean the surveys were very important ’cause I was like, if we’re trying to solve an issue, **what is the issue, first of all**?” (Elizabeth Transcript, 02/04/2020, emphasis added). Shifting from her earlier questioning of studying the problem, she went on to say:

> **1 Elizabeth:** Yeah, I feel like people- people are like…**people know the problem, but**
> **2 they don’t like know what caused the problem**. Like, they like, “Oh … there’s like
> **3** water drop-, dripping down the roof.” Well, what is that causing that? Like, how did it
> **4** cause it and how can we- Fix it? People just think like, “Oh, we’re gonna patch it up.” I
> **5** mean, you can’t just patch it up, but like you gotta-See where the water’s coming from
> **6** and- See if like, you can stop it on top instead of just like, “Oh, I gotta patch it up.” If
> **7** you just patch it up, it’s just like putting a Band-Aid to a bullet wound (Elizabeth Transcript, 02/04/2020, emphasis added).

Elizabeth suggested the need to “know the issue” before getting starting solution development and acknowledged that people might not always seek to explore or define a problem in depth. In her leaking roof example, she suggested the need to understand a root cause, an important practice to all design work, if engineers hope to come up with an effective solution. Without this problem definition work, she notes, the solution developed might be like “putting a Band-Aid on a bullet wound.” Taken together, I see this example from Elizabeth as (a) an assessment of the value of analytical designerly work, another specialized designerly process (Crismond & Adams, 2012; Dym et al., 2005); and (b) evidence of increased alignment with the practices of the larger engineering design community. Similarly, as Cassidy reflected on doing front-end work, she offered:

> **1 Cassidy:** So it's like, **if one of us had one idea, but we had to like, we just had to**
> **2 make it flow and make sure everything made sense.** So it was like, if we had this one
> **3** idea, it would just be like, "Okay, like yeah. We could do that, but what if this
> **4** happened? Or like, what if like..." We always had like, two different ideas and we had
> **5** to like, bring them together. It was just like they would like, bump heads in some way.
> **6** So we had to like, **make them flow to make sure everybody's ideas like, came**
> **7 together**.
> **8 Jacquie**: Gotcha. At that, and- and that's, and you're talking about like, kind of at this
> **9** beginning part of design?
> **10 Cassidy**: Yeah, at the... Yeah, at the beginning- part, yeah.
> **11 Jacquie**: I gotcha. Um, what did you like about doing this activity, or like this
> **12** beginning part of the design?
> **13 Cassidy**: The beginning part? It was like, it was, it was chill. **I liked it, it was chill**. I
> **14** was just like, so ready to like, **do the surveys again, though, and go through the**
> **15 data**. **So it's just like,** (laughter) **like I was just so ready for it**. (laughs) (Cassidy Transcript, 02/13/2020).

Making meaning of her experience in front-end work, Cassidy describes the front-end of design as something she was interested in and excited about. In line 2, Cassidy introduces the idea of "making it flow," how she describes bringing together multiple perspectives into a problem space. As she elaborates, Cassidy describes the "feel" of designing, the process of bringing multiple ideas, perspectives, and possibilities into the fold (Bach et al., 2018; Hubka & Eder, 2012). At once, she described design like a designer and reflected on her enjoyment of community data collection (lines 13-15). Whether a function of Cassidy's multiple experiences with *Sensors*, her development, or her learning about *Sensors*-related practices, Cassidy demonstrated a growing appreciation for the work of design. No longer a space of challenge or confusion, Cassidy and Elizabeth's reflections showcased how flexible and real-world front-end design, like that developed in the *Sensors* program, work might support personal connection with the design and the development of skills that support youth as people who live in and might contribute to the designed world.

Learning from Youths' Engagement: Multiple Opportunities to Engage in Messiness

To summarize, focal youth appeared to shift in their design work as they participated in multiple iterations of Sensors. Youth demonstrated important emerging problem-solution co-evolution design behaviors in their first time in the *Sensors* program, as well as brought their experiences to the fore. Returning to the program in subsequent iterations, youth demonstrated more advanced engagement in and comfort with recognizable design practice, that they cleverly blended with their personal knowledges, experiences, and commitments. These shifts are important in thinking about the development of inclusive engineering experiences – they began to position youth as both participants *in* and designers *of* the designed world in ways that incorporated (as opposed to invisibilized) their personal experiences. Learning from youths' shifts begs the question: What about the nature of *Sensors* work might have facilitated them?

Moving particularly from a sociocultural perspective in this section, I locate two dimensions of the *Sensors* context that may be different from other engineering design contexts for youth and that are valuable in the ongoing conversations about developing these spaces: *Complexity* and *multiple, iterative engagement*. In complexity, I am referring to the complexity and ambiguity of defining, exploring, and addressing a relevant problem of interest from scratch. As I described at the beginning of this chapter, *Sensors* tried to adopt front-end design work in a way that was flexible, driven by youths' interests, and located in local place. *Sensors* invited youth into the very beginning of design to the problem ideating conversations, the power-laden space of imagining what a design might be. *Sensors'* developers and facilitators did not attempt to simplify these practices (e.g., proposing projects for youth to pick from). Instead, the intricacy of problematizing in design was engaged in real-time through our design discussions (cf., Goessling & Wager, 2020). The openness and flexibility of this figurative space seemed to allow for youths' perspectives to be meaningfully developed into the design. In this, youth experiences and knowledges were fundamental to the work of problem framing, as opposed to being absent or non-consequential (Nazar et al., 2019; Rodriguez & Berryman, 2002).

Further, formally trained designers note that front-end design work looks and feels "fuzzy" due to its constant adapting and iterating nature (Borgianni et al., 2018). Youths' engagement in *Sensors* work mirrors these significant conversations within design literature. Work in the design thinking field has engaged with the idea that problems and solutions inform each other, or co-evolve:

> Creative design seems more to be a matter of developing and refining together both the formulation of a problem and ideas for a solution, with constant iteration of analysis, synthesis, and evaluation processes between the two notional design "spaces"—problem space and solution space (Dorst, 2006, p. 10).

Dorst refers to this definition as a “design paradox,” noting that not having a set problem space or considering solutions early in the process is very different from traditional engineering design notions but is closer to the reality of the work (Dorst, 2006; Dorst & Cross, 2001). I argue that making visible this paradox for youth – as opposed to blackboxing it – created an opportunity for youth to grapple with design closer to the ways formal designers do. In this way, the messiness, fuzziness, and ambiguity of *Sensors* front-end could at once support youths’ experiences and interests meaningfully guiding design and the development of increasingly sophisticated design skills.

The opportunity for multiple iterative engagement also emerged as a feature supporting youths’ engagement, as evidenced by the shifts across time. Simply, because the *Sensors* program was iterated and offered multiple times, youth could return and think about similar types of problems again. Focusing on *process* and *practice*, as opposed to particular design outcomes or engineering solutions, the tools and scaffolding structures were similar, whereas the specific problems, goals, and information about design varied. Having somewhat emerged from the ambiguity of their first design, returning youth could potentially engage in front-end design work with more trust of these processes. It is across this successive *Sensors’* front-end design work that youth’s practice began to blend personal meaning and recognizable design skills that might be translatable to engineering spaces or informed citizenship in an increasingly technologically focused world. As valuable as this blending may be for re-envisioning inclusive engineering spaces, it is important to note that these shifts emerged as youth returned and continue to engage with design. It was not necessarily a hallmark of youths’ early practice.

This analysis supports and extends the idea that, ideally, inclusive design work with youth might allow for multiple opportunities to engage with and iterate ideas over significant time (e.g., years, not weeks). Yet, engineering experiences in other types of K-12 contexts may not be able to support or sustain work over that long of time frame. What then can we learn from youths' early engagement in *Sensors* work to inform those programs? One explanation for focal youths' early front-end design challenges might be that the problems raised were too concrete for new designers to dig into deeply. On the surface, Mariabella noting that the trash was the issue without any reframing left little room for creative solutions – one could arguably say the solution is to pick up the trash. Understanding what makes a designable problem space is a skill engineers develop over time. American Society for Engineering Education asserted the importance of systematically framing an engineering problem space, locating it as an Engineering Practice and Habit of Mind (*Framework for P-12 Engineering Learning*, 2020). Although not all problems are solved with engineering design, some of the work in potentially using front-end design practices to support engineering learning might be helping youth reframe problems raised from their observations, interests, or experiences in ways that allow for generative design processes. To borrow words from Buchanan (1992), the educational design work might make the youths' suggestions more "wicked," or complex, to allow for more creativity. Such a task might be counterintuitive for curriculum designers, who typically seek to introduce new design skills with low cognitive load tasks so that learners can focus their energy on learning the new skill rather than on a complex task. Inadvertently, a curriculum designer could make front-end design practices harder to understand if the richness of the problem is removed for initial learning purposes. This raises an important question: What does it mean to develop developmentally appropriate experiences if the goal is to help youth learn to frame, ideate, and iterate around complex problems? Regardless of the answer, continuing to examine the ways youth engage in front-end practices raises these types of conversations, frames new educational design problems, and helps the field think more deeply about what it considers engineering knowledge, practice, and ways of being.

Towards Liberatory Design: Moments of Possibility in *Sensors* Design Work

Developing inclusive engineering experiences for youth requires inviting youth into the work as themselves, but it also being critical of what they are being invited to. This means that who youth are and how they experience the experience matters. Further, it means that it is important to ask questions about *how* and *from what perspectives* are experiences supporting youth. To frame the second part of this chapter, I offer the following call from sociocultural scholars, which is also discussed in critical STS theories of design:

> …in order to see robust, authentic connections between the everyday knowledges and practices of youth from nondominant groups and those of the academic disciplines, we must look beyond the typical connections made in school curricula and identify important continuities of practice (Nasir, et al., 2014, p. 695).

From this perspective, it is necessary to think about other ways youth engaged in design that might be less obvious or recognizable as "engineering" design (e.g., Pleasants & Olson, 2019); but, in fact, is critical or liberatory design work or might move design towards more just ends (Benjamin, 2019; Costanza-Chock, 2020.; *Liberatory Design*, n.d.; Moganakrishnann et al., 2018). Through these lenses, the field might better understand broader types of experiences that support authentic connections. Further, we might imagine new directions for engineering and design for and from youths' practice. Taking on a call posed by sociocultural and critical STS design scholars alike, I explore how and in what ways youths' engagement in *Sensors'* design work opened opportunities to think critically about design practice.

Throughout focal youths' front-end design work in *Sensors*, I argue that there were ways youth engaged in *Sensors'* design work through their questions and critiques that created moments of liberatory design possibility (Benjamin, 2019a; Goessling & Wager, 2020). I use the term "moments of possibility" to signal that these were short fragments of conversation that could – or could not – introduce change in the design work. Inviting youth into ambiguity and the ill-defined nature of design work in *Sensors* also seemed to create an opportunity to organically humanize design work, moving it toward more generative or liberatory ends (Eglash, 2019). Here, I use the term "move toward" to indicate that liberatory design is not necessarily achieved but is an ongoing process (*Liberatory Design*, n.d.; Moganakrishnann et al., 2018). I argue that these conversations with youth during the front-end design spaces in *Sensors* were certainly forward steps within this process. Particularly, the openness of this structure was an outlet for youths' voices, everyday knowledges, and commitments meaningfully shaping design in liberatory ways.

In the second part of this chapter, I examine how *Sensors* design work supported youth used their personal knowledges and experiences in humanized design. Elizabeth, Mariabella, Cesar, and Red drew on personal knowledges to question "why" we were proceeding in a particular design direction at different points. Cassidy, Adina, and Rodrigo drew on personal relationships to expand who the design is for. Another characterization of youths' engagement in front-end practice was to leverage personal knowledges, relationships, and experiences as supports for design work not only to establish meaning for the design, but also to establish greater purpose in their lives. In the next sections, I look across profiles of youth in Context 2 to illustrate the nature of how critical engagement in front-end design work created meaning for design in youths' lives. Particularly, I argue this takes form through identifying what is problematized, naming who design is for, and shaping the process through which a problem is explored. I assert that focal youths' everyday experiences and knowledge were significant assets to engaging in front-end design and supported youth in developing new meanings for design in their lives.

What is Problematized and for Whom?

Adina once described that the information she considered most pertinent in problem solving was understanding, "**[w]hat the problem really was**…." (Adina Transcript, 06/29/2017). With consistency over time, focal youths' personal knowledge and experiences emerged in defining an engineering problem of interest in *Sensors*. In defining "what the problem really was," as Adina would say, youth raised personal experiences, connected observations to personal opinions and/or and questioned from their own knowledge. Echoing Elizabeth's point above, youths' personal perspectives were most on display when considering the questions: "what is the issue, after all?" Defining what was actually being problematized was shaped through youths' understandings of themselves and their community (Table 5-1).

Sensors Programming Iteration	Suggested problem space	Reason for raising (from video data and artifact).
Iteration 1, 2, & 3	Bus station comfortability	Raised by Cassidy and Red, motivated by experience taking city buses across the Large Midwestern City (supported by a Community Bench Maker)
Iteration 1 & 3	River walk comfortability	Originally raised by Adina, drawing on family members' experiences in fishing (supported by the Local River Conservancy)
Iteration 2	Bike safety	Raised by Cesar and Red, guided by experiences biking in the Large, Midwest City
Iteration 2, 4, & 5	Park usage and comfortability	Raised by Cesar, Red, Mariabella, and Rodrigo, drawing on experiences at the Community Center and community walking (supported by seeing work done at the park)
Iteration 3	Air quality near an industrial island and bridge	Raised by Elizabeth, drawing on friends and family members playing soccer at site
Iteration 5	Park design to relieve stress	Raised by Mariabella, guided by friends, family members, and personal experiences with a stressful political time

Table 5-1. Sample problem spaces raised by youth

These initial problem spaces developed through discussion with community stakeholders, each other, and mentors take on a particular point of reference from youths' own experiences. As such, the problems pursued in *Sensors* indexed youths' perspectives and were located in local place. Considering the design of engineering programs for young people, problems youth raised looked different than problem spaces found in common pre-college engineering experiences (like robotics) or in current engineering curricula, which often adopt a more "global perspective" to engineering (e.g., building a bridge in another country, Bottoms & Anthony, 2005). Yet, all these local problem spaces, rooted in youths' knowledge, are designable and engineerable with support. They can be explored and designed toward. Although focal youth needed support at first to develop these spaces, holding space for them to define a problem from their own perspectives, to *engage with problem definition critically*, ultimately led to guiding problems - just as workable as any other - for a design project.

What is particularly interesting was how youth arrived at these problem spaces. It is not a novel concept that youth might leverage their personal experiences and identities to shape a problem space, as these are lenses through which their world has been shaped and is shaped (Varelas, 2012). Rather, I offer that as they engaged in *Sensors* design work, focal young peoples' perspectives on *what are design problems* and *who is engaged in the design problem* may index different concerns than what is traditionally seen in pre-planned, building-heavy engineering experiences. This created moments of opportunity and liberatory imagination, leading to consequently different outcomes in the project design space. To make this point, I draw on a specific moment during the third iteration of the program. In this exemplar, Mariabella and Ava questioned and critiqued our potential design directions during a problem space brainstorming session. The group was ideating local problems spaces, particularly around a nearby park:

1 Jacquie: Ok, what other problems are you all raising?

2 Ava: So, there's a lot of homeless peoples that hang around there. And someone asked

3[on my sheet] how could we reduce this problem. But at the same time, **I don't want to**

4 look at homeless people as a problem…

5 Mariabella: Yeah, that's not a problem…like if anything, we should make it for

6 them…

7 Ava: …more like, we should make it welcoming for them, not like, "Oh they're fixing

8 it, so now we have to go somewhere else."

9 Jacquie: So, I'm wondering there if there is any issue of safety…

10 Mariabella: That's basically, **no that's basically who we are fixing it for**…the

11 homeless people there…making it more welcoming so that they will like want to come

12 there to like meditate, or whatever. Like why would you want to get rid of them, it's

13 their community too.

14 Jacquie: Ok, for sure.

15 Mariabella: They're basically the ones who go visit there and they take their naps

16 there…why would they want to lay down in litter?

17 Jacquie: Ok, for sure. So… I'm hearing you say is welcoming for those there [in the

18 park], and I'm also thinking there's a safety question or concern there in terms of the

19 trash if there's glass or…

20 Mariabella: Yeah, I saw shattered glass, yeah.

21 Jacquie: Ok, so things of that nature, like glass or sharp trash, that are making it

22 unwelcoming and unsafe…so that, to me, is raising a safety issue for those who might

23 be in the park for longer periods of time (Transcript, 07/16/2018).

In this conversation, Mariabella and Ava came to the discussion with questions, seemingly to reconcile their personal knowledges and experiences (displaced persons are a part of the community) and what they perceived to be the potential (discriminatory) expectations of the space (designing for the park does not include displaced persons). Critically, they offered a challenge to the group: Are displaced persons in the park a *safety problem to be solved* or *stakeholders in developing a welcoming and inclusive space* (lines 3-8). In lines 10-13, Mariabella asserted that not only were these people stakeholders, but they were our end users – whom we were designing *for*. Bigger than this, they were a part of the community. In this way, Mariabella and Ava's questioning and critique created a moment of opportunity to pause and reassess out *Sensors*' design work.

Responding to Mariabella and Ava in the moment, I initially tried to frame her and Ava's conversation as one about safety (broadly) for all park goers, including displaced persons (line 9). Frankly, my lack of specificity was wrong and stemmed from my often neoliberal engineering training around who designs are for (Benjamin, 2019; Costanza-Chock, 2020). Instead, Mariabella and Ava urged me (and the group) to consider the displaced persons in the park as particular stakeholders in the design, with distinct needs and requirements. In this design process, they were humans to be consulted and designed for (McGowan & Bell, 2020). Contrary to corporate or civil design initiatives that problematize urban homelessness (Kinder, 2014), they problematized the lack of safe conditions for unsheltered persons within the park space. Through sharing their perspectives and commitments, focal youth arrived at a distinctly different problem space than community outsiders, myself included, may have arrived at historically and might arrive at in the future. Instead, their short moment of questioning and critique began to shape a new design narrative, one based in community understanding and inclusion. This was a moment of liberatory design possibility.

Notably, something about the particular nature of *Sensors'* front-end design practices allowed this important conversation to occur. Given the social, flexible, and local nature of *Sensors'* front-end design work, Mariabella and Ava's issues of care, dignity, and humanity were able to enter these conversations naturally. Occurring during earlier design conversations also created opportunities for them to carry through the rest of design (Rosner, 2018). For example, during the discussion, we documented Ava and Mariabella's idea on the brainstorming paper

(Figure 5-5a). Drawing on this conversation in the following programming weeks, Red and Cesar expanded the “safety” problem space to include “welcoming” (Figure 5-2). The group later took up Ava and Mariabella’s discussion critique by including the displaced persons in the park amongst the different populations we surveyed and interviewed for the design (Figure 5-5b), which led us to focus our design efforts on seating in the park (Figure 5-5c). This short moment with Mariabella and Ava allowed our Sensors group to imagine and design into a different space. It also raises how Mariabella’s and Ava’s peers could have constrained this suggestion through disagreement or challenge. As the people enacting the curriculum, the group leaders and I could have constrained Mariabella’s suggestion, either by not engaging Mariabella’s suggestion or locating it beyond the project’s scope. My own biases and blindness to the distinct needs of displaced persons in the park could have diminished Mariabella’s nuance in her suggestion. Although this conversation was a short snapshot in time, it represents a moment where a connection might be forged or lost. Inclusively and authentically inviting youth into design work also means inviting their critique, concern, or disagreement and creating space for these types of moments to occur.

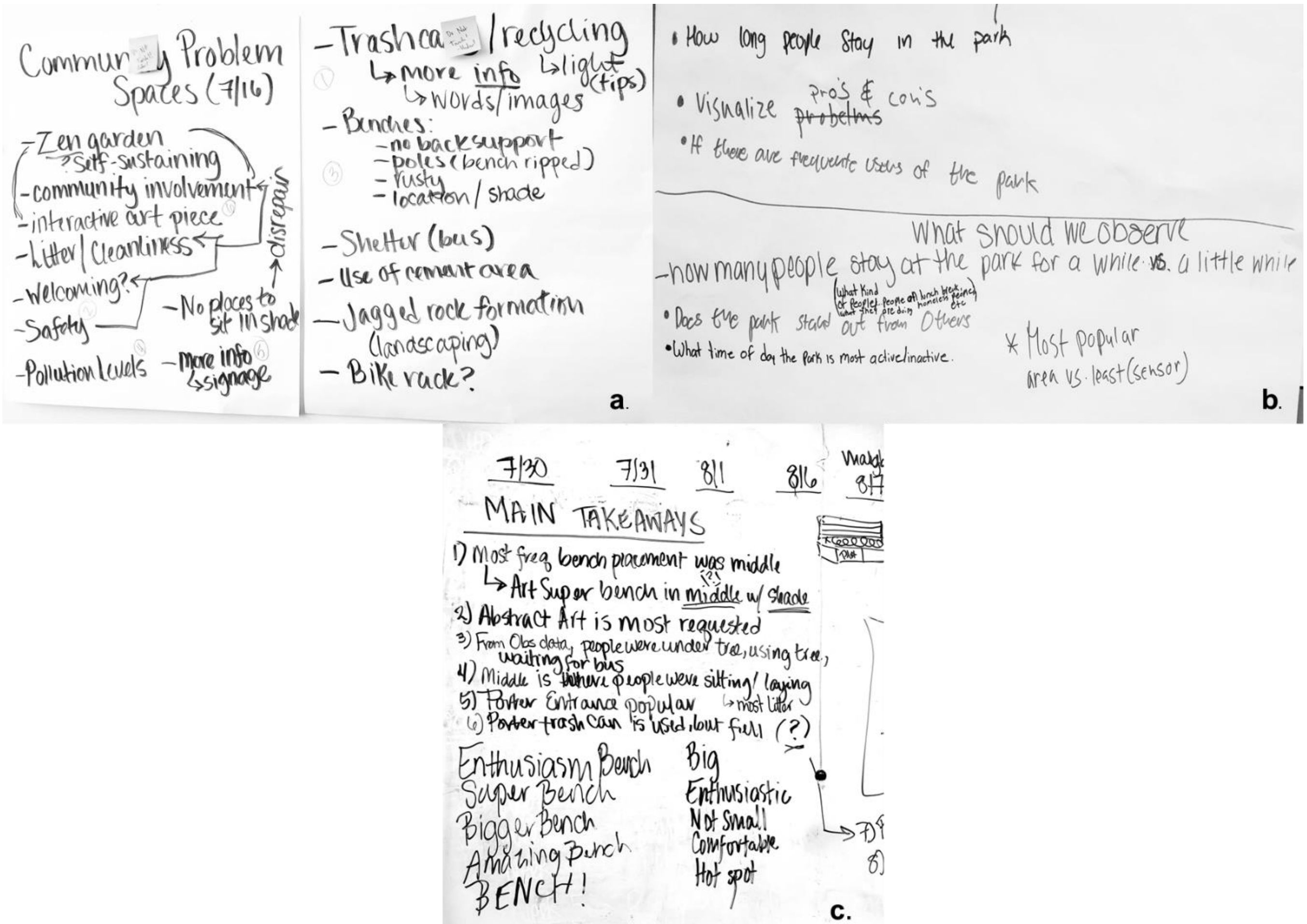


Figure 5-5. Examples of the ideated problem spaces (a), data collection ideas (b) and findings (c) that emanated from Ava and Mariabella's questioning

Although a small part of a larger conversation, this exemplar illustrates the potential power of these moments of liberatory design potential and the potential for flexible, real-world front-end design work to support them in engineering experiences for youth. There was enough flexibility in the *Sensors* program and their peers' and mentors' perspectives that Mariabella and Ava's critical ideas could be incorporated in the design practice of understanding the stakeholders. Years later, Mariabella pointed to reframing displaced persons as design stakeholders as meaningful. When I asked her why engineering was important to her life, she shared this experience and how she connected engineering to helping her community:

> **1 Mariabella:** [Engineering] allows me to help the community, like, in a way.
>
> **2 Jacquie:** Can you say more?
>
> **3 Mariabella:** Like, us building the bench... Well, we saw homeless people…laying on,
> **4** laying on the floor and stuff ’cause there wasn’t any benches. So like, I hope that
> **5** like…instead of laying on the floor I hope they go and sit on the bench ’cause they
> **6** shouldn’t be laying…where like, all those bugs are and stuff (Mariabella Transcript, 02/13/2020).

As part of the way she engaged in *Sensors’* front-end practice, Mariabella brought her concerns to design. In this, she opened a space for considering those who are often made invisible in design and engineering, moving the design in liberatory directions. This moment of potential, understanding who design was for, became an important dimension of her experience in the *Sensors* program. Her experience raises the question for inclusive program development: What ways can we better design for and engage with moments of liberatory design potential? How do we develop curricula for the moments youth critically offer up personal knowledges and experiences in ways that purposefully shape the design practice? How do we see and value these moments? How might they take root throughout the remainder of project, design, or engineering experiences?

How Do We Explore Our Problem?

Moments of youth questioning, imagination, and critique also emerged in *Sensors’* data collection work. As part of the *Sensors* program, youth explored problem spaces through several data collection techniques. Developing a data collection plan and the content of the data collection instruments also saw moments of liberatory design possibility, as youth expanded design work through their questioning. Leveraging their personal experiences and identities as evidence, focal youth shaped the direction of data collection plans and content of instruments towards directions that attended to their knowledge and concern of their community. In this, youth not only actively intervened on the problem space and stakeholders but also on the approaches to building an understanding of the problem. For example, in the most recent iteration of *Sensors*, Mariabella, Red, Cesar, Rodrigo, and Florida built a survey to explore community stress. During the following exemplar, the group was discussing what demographic questions to ask. After discussing gender identity, the following exchange occurred:

1 Red: Wouldn't it be better to ask about people's sexuality?

2 Mariabella: Why would we need to know that?

3 Red: Well, because it depends…because quotes might depend…

4 Cesar: Can you pull that off your eyes…[to Red, who put a band-aid on his eyes]

5 Mariabella: Oh yeah, like "Love is love…"

6 Red: Exactly

7 Rodrigo/Florida/Mariabella: [Crosstalk-affirmative]

8 Cesar: (taps pen) He's right because people…some people deal with stress because of

9 their sexuality, because of…what people talk about and how they react to that.

10 Mariabella: Yeah, like, **I remember one time, like they (the Community Center)**

11 were like…setting up norms, or group rules, and someone said like respect

12 others' sexuality…so I feel like it is a thing that people think about (Transcript 07/19/2019).

In line 1, Red questioned what was considered pertinent information in design. Red drew on personal knowledges and experiences to offer a new data collection option to the group to make sense of community stress as a problem space. In line 2, Mariabella prompted Red to expand why this might be necessary. In line 3, Red revealed that the information could impact the design work, expanding it toward more caring and just ends (Gunckel & Tolbert, 2018). Cesar and Mariabella supported this addition to their design practice, reasoning (from their own experiences) that how one has experienced their sexuality and others' reactions to their sexuality might be stressful (lines 5, 8-9). The youths' assertion about LGBTQ+ identities potentially equating stress may or may not be true for all who identify as LGBTQ+ and asking about these identities on surveys can be problematic (Stachowiak, 2013). However, Red's early thinking, and Cesar and Mariabella's response to him, created a moment of liberatory design possibility, expanding the types of information valuable to design. Instead of exploring a design problem in a way that is identity-blind (Bower, 1998; Harding, 2015), youth instead opted to interrogate participants' social identities as potential foundations for design. Further, this interrogation emerged from youths' own experience, both as identifying as LGBTQ+ or in other spaces where this was discussed and valued. This moment in *Sensors'* front-end work created opportunities for youths' own identities and experiences, importantly shaping data collection processes in design. Further, the fact that *Sensors* design work invited youth into these dimensions of design – the messiness of asking questions about questions – allowed for this moment to occur.

In the greater scheme of engineering, this example may raise a tension. Academic or corporate engineering cultures may operate in identity-blindness, obscuring LGBTQ+ identities (Bilimoria & Stewart, 2009). It is likely that an engineering design program developed from these perspectives, perhaps focused on a set task, would not see these youths' questions as pertinent (Benjamin, 2019a; Costanza-Chock, 2020; Hacker, 2017). Yet, Red's questioning actually engaged a sophisticated design skill – moving between the present and the future of design through data (Dunne & Raby, 2013). These youths' questioning moved the design space towards a more socially engaged end, setting a meaningful purpose for the group. In this short moment of possibility, youths' engagement troubles traditional notions of engineering design work by engaging in nuanced, just problem exploration (Costanza-Chock, 2020).

Dimensions of *Sensors* work, like "questions about questions" discussions, seemed to support moments of possibility. The process of seeking several types of information to understand the problem space was a hallmark practice in *Sensors* and practice where focal youth continued to bring their personal knowledges and experiences. Further, their personal experiences and identities were assets to figuring developing survey questions, observation protocols, interview protocol, or figuring out how and where to place sensor technology. Mariabella and I had the following exchange while developing a survey about community stress:

1 Jacquie: I think we might want to ask about where people live, **so we know if they'd**

2 use the park often…//(cross talk).

3 Red: Yeah, that makes sense.

4 Mariabella: **Or where they live might stress them out because I remember…I lived**

5 in [the Large Midwestern City], but I went to a [Nearby City] school that had all

6 these rich kids and stuff…and they would have so much better school supplies than me

7 and better clothes and always had all these new clothes for the new year. And it used to

8 stress me out as a little kid and it made me feel like I was less than them because their

9 stuff was better…

10 Jacquie: So that environment was stressful.

11 Mariabella: Yeah, but now I go to [the Large Midwestern City] so I feel more

12 comfortable (Transcript, 07/19/2019 emphasis added).

Although I originally framed the purpose of the survey question around space usage (line 1), Mariabella offered a different perspective: this information could be emotional (line 4). She asserts that where someone lives or the contradicting spaces they occupy could be a source of stress. She supports this with her own experience, negotiating stress due to class and status across place (lines 4-9). Her reasoning for including this question was very different from mine, meaning the interpretation for design could be very different. From my perspective, even if someone noted they came to the park daily, I might make decisions not to consider them as primary stakeholders and to devalue their survey responses because they did not live in the area. Whereas through her perspective, Mariabella might decide to follow up on those visiting the Large Midwest City-based park to see if the space was causing stress or mitigating stress from another place. Leveraging her own experience in the design world as evidence, Mariabella engaged skillfully as a designer to reframe the problem (Costanza-Chock, 2020; Crismond & Adams, 2012).

These examples from Mariabella, Red, and Cesar show that *how* we collect information about a problem space ultimately influences how we understand and make decisions about a problem space (Benjamin, 2019a; Goessling & Wager, 2020; Nazar et al., 2019) and what we know, believe, and value has implications for how we collect information (Costanza-Chock, 2020; Eglash, 2019; Rosner, 2018). Thus, like Red, Cesar, Mariabella, and the other youth illustrated, design is always socially and culturally mediated, whether for engineering or other purposes. It is always shaped by the identities of the designers and should consider the identities, beliefs, values, and interests of those for whom one designs (Costanza-Chock, 2020; Riley, 2008; Rosner, 2018). This has implications for design but also has implications for youth. Reflecting on her experiences in *Sensors*, Mariabella shared:

> **Mariabella:** Basically, this [*Sensors*] program like, made me more confident as a person like, to use... To like…**be me** and like not be like, "Oh my gosh. They're gonna think that I'm lame for like, things like, speaking about this." Or like, "Oh my God. They're gonna judge me because I have a different opinion than them, or they're gonna call me like... mean,"…for like not agreeing with you (Mariabella Transcript, 08/14/2019).

For Mariabella, part of the way the program was meaningful for her was that it supported her bringing opinions, formed through her experiences and identities, to bear in design. In short, she felt like she could be herself. These moments of possibility, where she provided questions, challenges, or assertions driven from her everyday understandings, helped support engagement that was meaningful to her and helped her feel like she belonged in *Sensors*. These moments were very short moments in the group but appear to make a difference in how Mariabella came to see herself in relation to her *Sensors'* experience. Learning from focal youths' examples suggests that in developing engineering experiences, the field needs to actively look for how youth bring themselves to design so that these instances might be merged into the work instead of being shut down. Further, these moments in *Sensors'* programming appeared to support new ways youth may "see" design in their life. Thinking about developing inclusive pre-college engineering experiences, this also raises questions about the ongoing demarcation conversations in the field of engineering (e.g., Pleasants & Olson, 2019) – what might be lost or foreclosed if we restrict what is considered true "engineering" for youth, both in knowledge and practice? How might expansive, generative, and liberatory perspectives of technological design help us think more inclusively about engineering pre-college? How do they help us think about good engineering and design?

Summary of Other Focal Youth Experiences

Other youths' profiles mirrored examples provided from Context 2. Each focal youth, in some way, brought question, imagination, and/or critique as we defined, explored, and began to address a problem of interest. Some youth took smaller actions, like when Rodrigo and Adina asked to take home surveys to their family and neighbors. It was a simple request that also located these focal youths' families and neighbors as stakeholders in design work. In other instances, youth suggested we try out bigger process changes. For example, while we were trying to narrow down our problem space during Iteration 4, Cesar and Red suggested new potential ways to think about the design and collecting data:

> **Jacquie**: So maybe this isn't the problem we work on solutions for, but may we can collect the data and we can say we know this is what we want to do.
>
> **Cesar**: I know with the [Community Center store] we were working at, we bought a couple of stuff and see if they sold. And if they sold, we were going to get more of them. I don't know if we could do that with the park…

6 Jacquie: Like pilot?

7 Cesar: Yeah, like pilot. Like start a little bit of it and if it works out, we can work on it

8 for the rest of the time.

9 Jacquie: Maybe we could see if we could just move the trash bins around in the park,

10 or get our own?

11 Red: And adding on to his pilot suggestion…can't we add like a board full of

12 recommendations, like we could have pen and paper…we could just stick the paper on

13 the board…

14 Cesar: Yeah

15 Jacquie: At the park?

16 Cesar: Yeah, you know like those little box things where you write something and

17 then put it in the box?

18 Jacquie: Like suggestion boxes?

19 Red: Yeah, I'm thinking like a board though, so people can see it.

20 Cesar: That would be a good thing to like, leave in the park and "ask what do you

21 recommend?" It'd be a like a survey, but a smaller one (Transcript, 07/22/2018).

Drawing on their experiences at the Community Center, Cesar and Red expanded our *Sensors'* data collection process, suggesting the group pilot a few design ideas in the community and establish a passive way to collect data (lines 11-13). At this point, this was their second time in *Sensors,* and they had experienced the space before. In this moment of possibility, Red and Cesar imagined shifts to our design process that were beneficial and generative. Based in their personal experience at the community center (lines 3-8), Red and Cesar were also beginning to "[c]onduct valid experiments to learn about materials, key design variables and the system work" through these suggestions (Crismond & Adams, 2012, p. 749). By shifting our *Sensors* design system, trying out suggestions for our design, Red and Cesar engaged recognizable, skilled design practice, "reading" the designed world was a place that could be experimented within (V. C. McGowan & Bell, 2020). Simultaneously, their suggestions invited liberatory possibility – a feedback system that would allow the community park-goers to continue input into the designed space. Starting from the place of youths' own ideas and experiences seemed to support eventual engagement in more recognizable engineering work and liberatory design possibility.

Similarly, Cassidy and Elizabeth played with our design while suggesting a prototype from data. To make more sense of the problem of seating at the Local Riverfront Conservancy, Elizabeth suggested we set up two seating models (Figure 5-6a) and collect data about if people liked it. Building on her idea, Cassidy suggested have a data collection method that allowed us not to be there since it was challenging to get to the Conservancy.

Figure 5-6. Images of Cassidy and Elizabeth's planning for prototyping

This example exemplifies how youths' suggestions merged into important design decisions. Elizabeth and Cassidy's suggestions imagined a version of designing where we could try out a few ideas, as opposed to settling on a final design. Like Red and Cesar, they sought to learn more about the design system and how people would interact with it, creating bottom-up systems where community input was the ongoing basis of design. Cassidy and Elizabeth's suggestions were, at once, demonstrations of informed design behavior, driven from personal experiences and shifts toward liberatory design. In Elizabeth's case, she was drawing on navigating all the opinions in her large family. Reflecting on this experience, she remembered:

> **Elizabeth:** We were argu-, I mean we were debating. I won't say "arguing," but we were just debating like, "No." And then we like, I had my sisters there so like, us fighting was like, normal and then- I mean it was also a bonding experience, but it was just like, it was just like fighting, but debating and finding out a way to solve it …

She went on to say that she saw this process as learning about how to bring ideas together:

> **Elizabeth**: What I got? Um, kinda learned how people think. How people like find, how people learn, how people solve a situation- And how people like- like try to solve it. And like I had different ideas, [Cassidy] had different ideas. My sister had different ideas, but we all like, we all saw each other's…perspectives and it made everything feel like, oh like, people all, all people have different perspectives than just mine (Elizabeth Transcript, 02/04/2020, emphasis added).

In this, Elizabeth got to shape the direction the design went meaningfully. Her suggestion for two designs was a way to negotiate all of the multiple perspectives around the design work and moved her toward informed design behavior. From her perspective, it helped her learn how problem solve. Elizabeth's and Cassidy's example, as well as other focal youths', raise a challenge for design pre-college engineering experiences. Having space for youth to shape design – to question, explore, or imagine within it – seems to support youth in making personally relevant meaning of the experience *and* shifting toward informed design practice. In this, youth might feel more ownership in the design work, as they have shaped not only the design outcome (a product) but the practice itself. Yet, these moments are often short, small exchanges with youth – where they pose a question or suggestion that might easily be missed. How, then, do we better 'see' these moments of possibility with young people in design? How can we better leverage them to impact design directions? Making visible the connections between youths' suggestions, their play, and canonical design practice might create more opportunities for youth to engage in design and feel as though they belong. Further, they support extending "what counts" as engineering in K-12 contexts and beyond to invite these personal connections and develop these emerging design skills.

Learning From Youths' Engagement: Real-World Messiness and Real-World Possibilities

Concluding the chapter, I offer that youths' engagement in the *Sensors* program's flexible, real-world front-end design practices revealed potentials and tensions when considering inclusive engineering experiences. From the perspective of youths' engagement and practice, youth developed meaning, and purpose for our *Sensors* project in our front-end project work. Over time, youth developed recognizable design skills that merged with their personal ideas and experiences. Engaging their ideas and experiences in Sensors design work creating moments of liberatory design potential, pushing on narrow (though recognizable, Gaskins, 2019; Pawley, 2009) understandings of engineering design work. The messy, local, real-world nature of

Sensors' front-end design work seemed to support these moments of possibility finding some outlet in design. It supported considering humanized answers to the questions: Who are the stakeholders? What is the problem? Translating design principles from *Sensors* to existing engineering programs might present challenges. The approaches we employed in the *Sensors* program were heavily mediated by the ongoing relationships in the space and reflect the goals to center youths' voices and ideas through the whole process. As such, front-end design work in *Sensors* moved from these perspectives and a critical understanding of design work broadly (Rosner, 2018). However, this analysis of youths' work in *Sensors* supports the idea that, to move toward liberatory educational design, engaging youth in front-end end design cannot be lock stepped or universalized. To invite and center youths' voice, it needs to evolve from youths' experiences, local place, and socially-engaged or critical perspectives on design and engineering (Benjamin, 2019; Costanza-Chock, 2020; Riley, 2003, 2008; Rosner, 2018). Pairing these concepts in program development and enactment may better invite the whole of youths' experiences – the good and bad, the relevant or (seemingly) irrelevant – into design work. In this way, developing and designing ways for youth to engage in the complicated messiness of a relevant problem space – as we attempted in the design of the *Sensors* program – might support inclusivity within engineering spaces that both prepare youth for participating in and/or designing, the designed world.

CHAPTER 6 Stability and Shifts in Focal Youths' Engineering Discussions

Centering youth as stakeholders in their engineering education and examining their engagement in front-end design practices is only part of the story. Indeed, studying how youth engaged in front-end design revealed a potential for supporting meaningful, skilled, and liberatory engineering work. Front-end design practices seemed to invite youths' personal experiences and support emerging skills to participate in the designed world knowledgeably. Further, how these young people brought everyday knowledge and commitments to design work revealed new design directions and increased opportunities to take ownership within the design. Still, exploring how youth discussed their experiences in design work is vital in developing programs *for* youth. Drawing on sociocultural perspectives:

> Indeed, the importance of imagination in this process offers evidence that becoming is more than just what one does as a participant. It also includes the meanings one makes of that participation. Children's ability to imagine (and the affordances for such imagination in practices) their own learning trajectories and their place in relation to others is critical to the development of new goals and access to new identities (Nasir, 2002, p. 241).

Analyzing the ways focal youth engaged in front-end design practices opened a vital opportunity to investigate how they discussed design and engineering in reflective contexts.

Looking across youths' profiles, I posed the question, "how do focal youth discuss their engineering experiences?" In our conversations, focal youth and I discussed their work in *Sensors* and the other engineering experiences they had engaged in, and their evolving understandings of engineering as a discipline. In this chapter, I explore a second analysis (modeled in Figure 6-1) and look at the different ways focal youth discussed design and engineering in total, referencing the *Sensors* program and beyond. Specifically, I demonstrate how youth experienced front-end design work as different from other engineering experiences and how they made meaning of their experience connected to personal goals. Drawing upon sociocultural understandings of learning, I examine how youth constructed[5] what "engineering" was in their current lives. I detail aspects of youths' discussions that seemed stable with time, those that changed, and variations across focal youth. I am not assigning value judgments to youths' constructions of engineering. Instead, by making visible how these youth position themselves regarding engineering, I offer that we might better understand how to design engineering experiences for all youth, not just those already interested in the field.

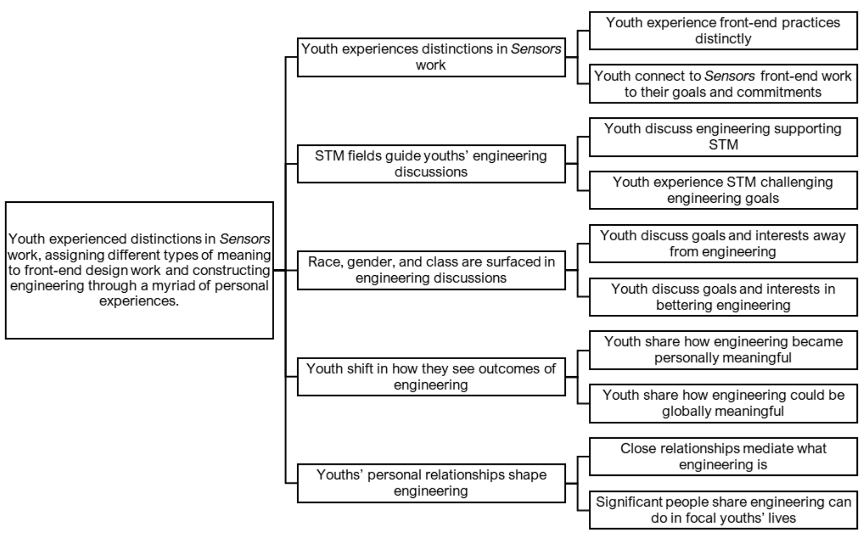


Figure 6-1. Second section of key linkage chart

[5] I use the term "constructed" here for two purposes: (a) It signals that the design and building work part and parcel to engineering is also happening for youth as design and construct what engineering is within the greater context of their lives; (b) The work these focal youth do to construct engineering for themselves is part of a is part of a larger process through which they are constructing their relationship to engineering. Youth build personal engineering "constructs," multidimensional and changeable, while ultimately designing and constructing their relationship with these constructs (cf. Varelas, 2012; Varelas et al., 2015).

Stable with Time: Experiencing Distinctions in *Sensors* work

From early on in my work with *Sensors* youth, I began to note something curious (to me, at least) in focus groups. Although the program was generally well-received by youth in Iteration 1 and 2 Focus Groups, at least one or two youth would question how the program related to engineering work. Although the program was not developed as an engineering program, aspects of it were engineering design work. Tracking on this after Iterations 1 and 2, my colleagues and I engaged in more significant efforts to explicitly name connections to real-world engineering design processes and bring other types of experiences to the program. For example, we invited the engineers on our team to attend sessions more regularly, and I began a particularly active effort to explain when engineers would engage in certain practices, naming problem exploration, design research, solution development, and public communication as work engineers do during design (Memo, 10/17/18). Paired with my attempts to better frame our work together as engineering design work, I also wanted to understand better what youth thought the work was, particularly in front-end design work. How would youth describe these experiences? Did our front-end design work feel like "engineering"? If our design work in *Sensors* was not engineering design, then what was it? How did youth discuss these experiences and the meaning they made of them? In what ways were they meaningful?

What I learned from focal youth is that all of them, in some way, experienced front-end design practices as distinct from other ways they had experienced engineering. In *Sensors*, each of these seven youth made some sort of distinction between front-end design practices and building and implementing solutions (or back-end work). As such, youth seemed to ascribe a different meaning to front-end practices and building work. The distinctions youth made emerged more in reflective conversations, like the Focus Groups and Interviews, not visible in the design work itself. Probing the distinctions youth felt between front-end and back-end work invited conversations about other ways youth had experienced engineering more generally. Each focal youth described how they experienced these distinctions differently, which surfaced opportunities and challenges for youth engineering programs.

Experiencing Front-end Design Differently

In this section, I explore the ways youth discussed and/or experienced front-end design practices as different from other experiences in *Sensors*. Making distinctions between front-end design and back-end design or working with technology is not necessarily surprising on its own: Front-end design practices require different modes of engagement than in the back-end of design. Drawing on the NGSS practices, for example, one might liken it to how “planning” and “carrying out” investigations might feel different (Ford, 2015). However, perhaps unlike science practices, which youth experience more fluently within “the scientific method” (Rudolph, 2005), how focal youth discussed experience front-end design work suggested that youth were experiencing distinctions at the practice level, rather than the project or design *process* level.

Elizabeth, Mariabella, and Cassidy discussed ways that front-end design work distinctly did not feel like engineering, whereas the other aspects of *Sensors’* seemed more aligned with how they had experience engineering in the past. For these youth, the front-end design practices were important for their engagement. For example, Elizabeth shared that looking at the sensor technology felt like engineering, whereas survey data collection (her favorite part) did not:

1 Jacquie: When you were in *Sensors*, what in *Sensors* felt like engineering work to you?

2 Elizabeth: Probably when we like, **first started and we saw like the sensors**. I was like…I never knew this was like, out. I mean I feel like I'm pretty like, nah I wouldn't say like, slow. But like, I didn't think of it. Like I didn't know like, until a while... Not until a while ago, but like, when I was little I was like, "I never knew they put wire in concrete-To make it stable." I was like…until I learned that I was like, 'cause you know there's always like damaged properties and like, concrete always falling off the walls. Like I didn't know they had wiring in it to make it stable and it was like- **like who invented it**. Like, it was like, a whole bunch of tests around it and just things like a whole, like what happens if it was just concrete? It would just fall and crumble //

Jacquie: So what of the work that we did in *Sensors* didn't feel like engineering to you, if any?

Elizabeth: Probably the, I mean probably the surveys, but like um-… I mean I feel like the surveys were- were a big, like important factor. People like, I mean I feel like it was like, not the least. But it was just like, there was, I mean the surveys were very important 'cause I was like, if- **if we're trying to solve an issue, what is the issue, first of all?** And we're trying to improve it. And some people will- will... People don't take the surveys seriously. **I mean, I feel like no one takes the surveys seriously-** When it comes to everything, but I wouldn't say, **I wouldn't say it was the least important,** but it was just like, people don't take them in consideration of the surveys**. Or like, the problem, like finding the problem. They just think, "Oh, you know, you know the problem." Like, I'm like, "You don't know the problem"** (Elizabeth Transcript, 02/04/2020, emphasis added).

When asked particularly about engineering work, Elizabeth shared that seeing how sensors technology worked and what it was used for felt like engineering work (line 2). In lines 3-10, she compares learning about the sensors to learning about rebar in concrete: a particular type of technological solution that she had not previously been aware of, though it operated in her life. In this, what Elizabeth shared felt like engineering was also demonstrated more awareness of the designed world. In line 13, Elizabeth originally names surveying the community, an aspect of front-end design work, as something that felt the least like engineering. Despite connecting to and valuing this work as part of understanding design (lines 14-17), Elizabeth struggled to place how she saw front-end work, precisely problem definition and community research, as part of a larger engineering scheme. For her, these practices were important to design but were distinct from learning about the technology. Not only did they feel different, but she believed others devalued these practices by assuming they knew where to start design work (lines 18-19, 21-22). Fascinatingly, throughout this discussion, Elizabeth demonstrates design skills as she discusses the importance of understanding a problem before beginning physical design (line 16-17, 22, Crismond & Adams, 2012). In this conversation, Elizabeth (unknowingly) indexes a larger conversation in engineering and design, one that grapples with the power and purpose of front-end design work (Riley, 2008; Rosner, 2018).

Similarly, Mariabella initially did not consider community-focused activities in front-end design to be engineering work, nor did she think that what she called "leadership" or "helping" activities constituted traditional engineering work. When I asked Mariabella if she considered our work together in *Sensors* "engineering," she noted:

Mariabella: I didn’t know it was engineering. I thought it was more like environmental justice…what I was doing. But I didn’t know it was engineering until you told me it was engineering (laughs) (Mariabella Transcript, 02/13/2020).

What Mariabella described as “environmental justice,” which she clarified as the “leader part of engineering” and being out in the community to collect data, are front-end design practices related to problem definition and exploration work. In this, she suggests that front-end design work felt like work *for* justice or fair treatment and meaningful involvement in work involving the environment (Costanza-Chock, 2020; Holifield, 2001). Environmental justice was a common topic of discussion at the community center and was of personal interest to Maribella due to where she lived. In this way, front-end design work was meaningful to her.

In the same breath, she felt like she did not do “the engineering part” of the program:

1 Mariabella: Yeah. I mean, I guess I don’t really do the engineering part of it.

2 Jacquie: What do you think is the engineering part of it?

3 Mariabella: Putting it together and like, installing it. I can’t do that. I don’t like to do
4 that (laughs).

5 Jacquie: Do you think that you could if you wanted to? …

6 Mariabella: Yeah, I could if I wanted to, but it’s just not something I’m interested in (Mariabella Transcript, 02/13/2020).

Although she hsared expanded views of engineering design work that include data-supported problem definition and solution development, Mariabella discussed these practices separately, as distinct moments. The work to explore the problem, the community data collection, and analysis, which guided solution development, was not the “engineering part of it” for Mariabella. Instead, building processes felt more like engineering to her (lines 3-4). Experiencing this distinction, and connecting significantly more to front-end design work, meant Mariabella felt like she did not engage in engineering (line 1), even though she helped build solutions in *Sensors*. For her, this was potentially positive, given her disinterest in the building and installing work (line 6). Front-end design practices were more inviting, aligning with her commitments to justice work. However, Mariabella's example raises how dissimilar or disjointed front-end design practices might feel for youth in an engineering-specific experience. Depending on the goals of the program, these distinctions might raise challenges for developers.

The youths' experiences of engineering feeling more like "solving for and building solutions" are essential as we think about engaging all youth in engineering design. Particularly, this becomes a question of our goals: How are programs being designed to support youth in becoming knowledgable participants in the design world and becoming potential designers of it? If, as Mariabella shares, youth are not interested in specific dimensions of the work and assume that those dimensions are all that engineering design is, then we may not invite young people who could bring perspectives like those of Mariabella regarding the people for whom engineering solutions are crafted. If youth think engineering design is one-dimensional and do not see their interests, goals, or commitments represented in that work, it would be challenging to imagine themselves in engineering experiences, let alone the field. Equally important, if the experiences we offer them focus only on building solutions according to predetermined problems or solutions (e.g., building and adapting a robot in a particular way), then some youth may walk away from those experiences in favor of others that feel more centered on human problems and critical concerns.

Rodrigo, Red, Adina, and Cesar, who already held emerging interests in technological work, also experienced front-end design work differently than other aspects of *Sensors*. In this, youth experienced front-end design work as supporting different goals than their goals of becoming engineers. While focal youth reflected on their work in *Sensors*, these different practices often elicited different reactions when reflecting with me. For example, during our interview together, Rodrigo watched two videos of himself from *Sensors* work (Table 6-1). For context, both videos were pulled from the fifth iteration of *Sensors*, which focused on design work improving a local park. In the first, Rodrigo and his peers were engaged in a problem-definition conversation around seating in a local park, discussing design constraints. In the second, Rodrigo sketched a scale draft of the bench he and his colleagues developed as their solution concept.

	Problem definition discussion	**Sketching bench prototype**
Jacquie: What do you remember thinking about?	**Rodrigo:** They're just ordinary benches. Putting them around, but **we just can't do that 'cause you know, it's somebody else's property.** **Jacquie:** Yeah. What do you remember feeling when you were doing some of this work? **Rodrigo:** I felt happy and surprised **I'm actually doing something good for the community.** **Jacquie:** Why were you surprised? **Rodrigo:** Well, 'cause I didn't know about the history of it. The little, the little what's it called? Park. **Jacquie:** Yeah. **Rodrigo: The history of the park, I didn't know about it.** About the guy who didn't like the homeless guys. **Jacquie:** Oh, yeah. (laughs) The guy who just ripped up all the benches and left spokes there. **Rodrigo:** Yeah	**Rodrigo:** What I remember was just I felt, **I felt like a little engineer** (emphasis added by author)**.** **Jacquie:** What do you mean? **Rodrigo:** 'Cause a lot of engineers gotta, you know, design what they're gonna do…and draw. **Jacquie:** So this, where do you feel like this fits in in your like- **Rodrigo:** What, engineering thing? **Jacquie:** Yeah, yeah. (laughs) **Rodrigo:** Basically in construction. **Jacquie:** Okay. **Rodrigo:** Or, yeah… 'Cause like, in construction you gotta do a blueprint.
Jacquie: Was this process meaningful to you?	**Rodrigo**: Yeah… 'Cause we're actually helping out the community, trying to put new benches where you can sit instead of sitting on the floor.	**Rodrigo:** Yes…That I could take the lead on it…Like, like you said. I was actually, I didn't even know, but I was actually telling people what to do. I was in my zone (laughs).

Table 6-1. Comparing Rodrigo's discussions of different engineering practices (Rodrigo Transcript, 03/11/2020, emphasis added)

Putting these reactions in conversation, Rodrigo seems to attribute distinct purposes and meanings to the different experiences within one design project. While reflecting on front-end design work, he discusses his and his colleagues' work as "helping the community," noting that the work was meaningful because of the community action it supported. Supporting a different type of goal, Rodrigo describes front-end design work as creating the overarching purpose of the whole project and contributing to community improvement. While discussing these practices, he does not employ the terminology of "engineering." Whereas, when he reflects on modeling the group's concept through sketching, he connects this practice to a particular engineering purpose, describing how engineers might use blueprints. The meaning Rodrigo makes of this practice seems connected to a more personal goal than in problem definition: This particular engineering work allowed him to "lead" and "be in his zone." For Rodrigo, front-end design work took on a different meaning than work in the later design, particularly as he sought ways to connect himself with how he saw engineering work.

Similarly, Cesar described the majority of the work in *Sensors* as, "[c]ommunity building…[y]ou work as a team to help out the community, or whatever you can help" (Cesar Transcript, 08/14/19). He went on to say:

Jacquie: And how would you describe…the day-to-day work to somebody?

Cesar: In (*Sensors*)?...Research, analyzing, and then... **making it happen**.

Jacquie: (laughs) Making it happen.

Cesar: Yeah.

Jacquie: Alright. And what part of that, or all of that, is engineering? What parts of that are engineering, if anything are? Of research, analyzing, and making it happen.

7 Cesar: I feel like mostly on the last part.

8 Jacquie: The making it happen (laughs) is the engineering part?

9 Cesar: Yeah, and also probably in the analyzing a little ’cause it’s... it’s like... you have
10 to design- design something to- to analyze it.

11 Jacquie: Okay.

12 Cesar: So maybe like a table or graph that works with the things on your like design.

13 Jacquie: Okay. That makes sense. And then what’s research?

14 Cesar: Research- research can have it, too. Because it’s like, you gotta design
15 something where you can get the most data possible, but also real data (Cesar Transcript, 08/14/2019, emphasis added).

When I asked what of those three pieces he considered engineering, Cesar noted that most of the engineering happened in the “making it happen” aspect of his description, like developing a bench for a local park. “Research and analyzing,” which were more a part of front-end work, were supportive in the efforts to make a design (e.g., having data available to support the design). This is not to say that Cesar did not consider these important processes, or that he did not consider them to be somehow connected. He offers important thinking around how data supports design, demonstrating skilled design practice (Crismond & Adams, 2012). What is notable, however, is that he sees the work in *Sensors* as three distinct experiences. He does not name engineering as all of these, but part of these. Front-end design work supported a different interest for Cesar, as he connected the larger arc of the work to “community building” and “helping.” Cesar framed his participation in practices like problem exploration predominately through connection with his community rather than developing engineering design skills. Like Rodrigo, he made distinctions in his experience in *Sensors*, seemingly positioning problem definition and exploration work separate from solution development.

Opening or Closing Opportunities for Engagement. In this section, I put examples from Mariabella's and Cesar's profiles in conversation, looking at some of the affordances and challenges that emerge if youth experience front-end design work as different or not engineering. For Mariabella, the distinctions she made supported her to take what she liked from the experience and leave the rest. Mariabella connected strongly with design work in a park that helped their community. When I most recently asked her to describe engineering, she offered:

> **1 Mariabella:** …[W]ell at first I would... Before, like if somebody were to ask me this
> **2** question I'd be like, "Oh, engineering is just like building stuff and like, computers and
> **3** stuff." But now I'd describe engineering as like, **I don't know about the other views**
> **4 of the building, 'cause I wasn't really in that, but like-…the like, part of it where**
> **5 you like, lead the team in not building, but like, the steps before building.** Like, I
> **6** don't know, I don't know how I would, how I would really explain it. Like, just now I
> **7** know there's just way more to engineering than just building like, the sensor or like,
> **8** putting in, putting in the sensor. **Like, I would never want to be in that part of**
> **9 engineering** (shakes head). **But, I like the leader part of engineering**. Like, giving
> **10** out the surveys and stuff. Collecting the data and like, yeah (Mariabella Transcript, 02/13/2020, emphasis added).

Mariabella distinguishes the "steps before the building" from the building work often associated with solution development. Unprompted, she labeled problem definition and research work as "leader" work and distinguished it from the building part of engineering (lines 9-10). These distinctions allowed her to assert the parts of engineering she would (and would not) want to be a part of. Experiencing front-end design practices in *Sensors* work ultimately opened up an opportunity for Mariabella's imagine ways she might participate in engineering experiences. She learned about engineering as a potential tool for change in her community. Experiencing front-end design work as aligned with her goals and interests seemed to invite Mariabella into work she may not otherwise have sought out. Notably, Mariabella asserted that she liked this leader part of engineering and "would never be" in the building or tech-centered engineering part (line 8). Mariabella demonstrated an increased understanding of how the designed world is developed but continued to express little interest in the building and implementing work. Although it is not the goal to make everyone engineers, nor do I think Mariabella needs to be an engineer, learning from this aspect of Mariabella's experiences presents a broader challenge. Mariabella – who was not previously interested in engineering – found a dimension of engineering that was meaningful to her personally. Yet, as a field, engineering is both the "leader" work and the "building" work. This raises the question: In engineering education and engineering, how do we better bridge these socio-technical dimensions (the front-end and back-end of design) together so that youth like Mariabella – who have such a strong commitment to justice - might also see themselves in the building work?

Alternatively, not seeing the problem exploration and research work as skilled engineering work may have closed off some of Cesar's opportunities to belong in design fully. Drawn to technology-centric work, Cesar considered concept development to be the "engineering work" of the *Sensors* program. Over three summers of participation, he often asked for more "hands-on" experiences with the sensors:

1 Cesar: Um, I feel like we could... It’s something that would be easy and not too much,
2 would be like, have the participants like, **actually build the sensor and stuff**.
3 Jacquie: Okay.
4 Cesar: Like make-
5 Red: Yeah, like more interaction to, with the sensors.
6 Cesar: Like it can all be, it can already be coded. Just like, building them. (Transcript, 08/14/18, emphasis added).

In the next summer, he went on to say about the *Sensors* program:

7 Cesar: It’s fun.
8 Jacquie: Yeah?
9 Cesar: Yeah. **It’s something that you can do with not a lot of skill**.
10 Jacquie: Okay. Say more about that.
11 Cesar: Hmm... basically, um, anybody who wants to do it could like, start doing it. If
12 you don’t really need to have the **skill of sensors-To work with sensors. You don’t**
13 need the skill to build things-because there’s different parts to it and somebody will
14 have a- a spot for each one that you can do (Cesar Transcript, 08/14/19).

Putting these two interactions into conversation, Cesar points to the breadth of engineering design practices subsumed with the *Sensors* program as helpful for multiple people to find their place in the work (lines 11-14). However, potentially due to what Cesar seemed to count as engineering, the *Sensors* program does not fully meet his needs (lines 1-2, 6). Seeming to associate engineering “skill” with the building or assembling sensors (line 9), Cesar makes distinctions between the “parts” of the design work, like front-end work and technocentric work.

In this, the emphasis on front-end design work in *Sensors* may not have felt like an "engineering enough" experience for Cesar. Cesar experiencing front-end design practices as distinct from how he understood engineering may have foreclosed an opportunity to see himself as gaining engineering skills in *Sensors* and belonging in the front-end. Like Mariabella, Cesar's experiences raise a question about connecting front-end work to back-end work in engineering design. Interrogating how to connect front-end and back-end design better could support youth like Cesar – who are already interested in technology – in valuing the skills involved in just problem framing, engaging stakeholders equitably, and community data collection.

Looking across these two young people's commentaries raises essential considerations for engineering program development for youth. Cesar and Mariabella worked together for two summers in the engineering program. Both youths contributed substantively to their group's projects each summer. Although they both made purposeful distinctions among problem definition, community research, and concept or solution development, these distinctions meant different things for their personal goals. Mariabella often rejected the technology, expressing disinterest in tech-focused programming sessions and asserting, "I love people, but I hate technology" (Transcript, 07/18/2018).

Conversely, Cesar sought to have more hands-on experience with the technology in the *Sensors* program. Had the program solely focused on building and using technology, Mariabella would likely not have participated for two summers. Yet, while Cesar kept coming back to support his community, he felt like he could not gain the desired engineering skills. None of the focal youth experienced front-end design work and building or sensor use as necessarily interdependent. Thus, it becomes necessary to imagine educational designs that reflect the breadth of ways engineering and design can meaningfully interact within communities, both with and beyond technology-focused approaches.

Translating Design to Future Goals

Discussing the distinctions they felt within *Sensors* seemed to prompt youth to reflect on their commitments and goals. These conversations brought their future career goals to the fore for focal youth Elizabeth, Cassidy, and Adina (who are closer to their college decision-making). In later interviews, youth reflected on how skills they build in front-end design work were translatable to their future career contexts. For example, in reflecting on her time in the program, Elizabeth, who had declared a future goal of working in business, stated:

> **1 Elizabeth**: ...And like, I mean it's cool, like people doing [coding]. Like, you know
> **2** people like, they get to like, think and learn how to like, languages and all that. I'm
> **3** like... that's cool, **but (it's) not for me**. Yeah.
> **4 Jacquie**: [D]o you feel like that kind of other piece, that like survey piece and the
> **5** analysis and figuring the problem out-
> **6 Elizabeth**: Mm-hmm [affirmative].
> **7 Jacquie**: How do you feel about that? Do you feel like that's for you?
> **8 Elizabeth**: Yeah, **I feel like that's for me**. Like, business is a lot of things to do with
> **9** like, **analysis and...finding…what people need and you bring them to it**. Or like,
> **10** same thing like the money, the money behind the business. **I prefer doing that**
> (Elizabeth Transcript, 02/04/2020, emphasis added).

In this conversation, Elizabeth reflects on what aspects of *Sensors* felt like herself. Although she sees value in technological skills like coding (lines 1-2), she does not see this as engaging her interests or goals (line 3). When I asked about community research (lines 4-5), work Elizabeth led over the years, she described it as *for her* (line 8). She elaborated how analyzing a problem space connects to her goals in business and finance (lines 9-10). In this, Elizabeth discussed how front-end design work translated into other areas of her life and supported her in her future goals in ways coding did not. Thinking about developing inclusive engineering experiences that invite all youth to engage with the design world, Elizabeth's reflection raises an interesting point: What else could these experiences offer youth? Thinking expansively about "what counts" in an engineering experience (e.g., framing the experience with front-end design practices) might create more opportunity for youth to find aspects of the experience that resonate with how they imagine their future, regardless of they see themselves entering the field of engineering or not.

Cassidy's reflections provide another example of front-end design skills translating into a non-engineering context. When I asked her to react to the phrase, "engineering is helpful to me," she responded**:**

> **Cassidy:** Mm... Engineering is helpful for me ... because like, **I take a lot of skills from everything and just like, apply it to other things. Like the problem solving, like the planning everything out step-by-step**. Just things like that. Just taking other skills and trying to see if I can like, make them work with other things (Cassidy Transcript, 02/17/2020, emphasis added).

Cassidy explicitly discussed translating skills from early and later stages of front-end design work into other experiences in her life. Seeking degree programs in hospitality, Cassidy answered my questions about how she defined and understood engineering using examples from her work in a culinary afterschool program. For example, as she discussed engineering involving a "…mindset to keep doing it," focusing on analyzing and testing a design, she discussed retracing her steps when she messed up a lemon curd or when her whipped cream was gritty. I asked her specifically about these examples I heard her using to describe framing and optimization practices:

> **1 Jacquie:** … So, do you see a connection between like, engineering and-
>
> **2 Cassidy:** Yeah.
>
> **3 Jacquie:** In culinary?
>
> **4 Cassidy:** Yeah, **'cause it's just like, you have to…test**. With culinary, you have to
> **5** like test the flavors. You gotta … do these things and if it like, doesn't taste right,
> **6** obviously you just can't like, present that. So, you have to like, make sure that it's
> **7** good. You gotta like, test all of these different things. Make sure like, the balances of
> **8** everything are correct and make sure the flavors mix. 'Cause like, some flavors just
> **9** don't mix sometimes. But if you can get them to, then like, that's good. But like, most
> **10** flavors like, don't mix. **And like, with engineering you just have to like, keep**
> **11 working to test it and like, make sure everything... It's like at the end with**
> **12 culinary engineering, you have to just make sure like, everything like, flows**
> **13 together** (Cassidy Transcript, 02/17/2020, emphasis added).

Here, Cassidy connected the role of testing and prototyping in front-end design (or engineering) work to work she does while she cooks and bakes (line 4). She translated the "flow" of design work with the flow of a recipe, balancing flavors and perspectives (lines 10-13). This translation aligns with her current goals to go to culinary school and work in hospitality. Although this was an interview, this moment with Cassidy points to a pedagogical design direction. Having space to reflect seemed to allow Cassidy space to connect her design experiences and culinary interests concretely. As I write this, I wonder: What if I had asked Cassidy how engineering helps her personally during *Sensors* work (not in my research)? Eliciting and understanding the diverse, evolving goals youth hold is another way to design better engineering education experiences. Not only might we invite more youth through designing toward a more diverse swath of goals, but we might then create more opportunities for youth to feel a sense of belonging. Using Cassidy's example, what might "building" look like in a culinary space? How do culinary techniques, like "testing" and "flow," help engineering? Learning that focal youth connect different design practices to distinct purposes in their life underscores the importance of including diverse design practices – like front-end design work - in young peoples' engineering education experiences (Costanza-Chock, 2020; Rosner, 2018). It also creates design challenges around framing all design practices as interconnected with more technologically-focused aspects to serve youth holding interests in that particular image of engineering.

Youths' Experiences With the Broader Engineering Discipline

In the next section, I overview another set of patterns emerging from my conversations with youth about their more general engineering experiences. While discussing *Sensors'* experiences with me, youth also discussed their engineering experiences more broadly. Outside of the *Sensors* program, focal youth had encountered a wide range of engineering experiences, ranging from informal camps to formal classes. They also learned about engineering in conversation and media. Across our conversations, these experiences contributed to how each youth constructed what "engineering" was to them and how they saw themselves in relation. Although not directly related to the *Sensors* program or front-end design practices, these conversations are germane to the over-arching goal of developing inclusive engineering experiences. In my definition, inclusive engineering experiences should support: (a) informed and critical engagement with the designed world and (b) welcome and invite participation in the engineering profession. Youths discussions of engineering particularly help us think about this latter design goal of inviting all youth into the engineering field, should that be an area of interest for them.

Stable With Time: Engineering as the "STM" in STEM

One way all focal youth constructed engineering in our conversations was as a combination of other disciplines. Youth defined "engineering" to be the sum of other disciplines, besides engineering, in STEM. Some of the ways they experienced engineering was requiring and building upon mathematics and science knowledge, technological knowledge, or some combination. This other disciplinary knowledge or activities could be one aspect of engineering work in these constructions or serve as proxies for engineering work. Constant across discussions, focal youth discussed engineering as being made of these other disciplines. What varied across cases was what this meant for youth personally. Acknowledging the role of mathematics, science, and technology thus implicated any and all "STM" experiences in youths' imagining around engineering. Focal youth also varied around a "chicken-or-egg" type question: What came first – their engineering experiences and constructions or their experiences with STM? I am not trying to assert any causal or directional connections about focal youth made meaning of their engineering and STM experiences; however, looking through this lens provides insight into how some experiences may work for some youth and not for others.

Engineering Supporting Math, Science, and Technology. For Adina, Rodrigo, Red, and Cesar, constructing a view or understanding of engineering through STM disciplines also created opportunities for focal youth to connect with engineering. For example, in our first interview together, Adina describe engineering this way:

> **Adina**: I feel like engineering is a science…like engineering is math and science…like is basically STEM in one. Because, for like, our robot, they actually taught some of the math that we're going to be learning in a few years to start, like with the robot's structure. We couldn't have too much weight in the front, but then we couldn't have too much weight in the back because if we did, it would fall over and we wouldn't be able to compete. But if we measured it out right, then we would be okay. Science uses the same thing. It's math as well (Adina Transcript, 06/30/2017).

As an 8th grader, Adina's engineering experience supported engaging with math and science content. It provided her a particular context and purpose (her robotics club with her sister) to learn math and science in a meaningful way. She also amalgamated science and math together, seeing these STEM disciplines as fluid and supportive of one another. At the time of her final interview, Adina had a goal of pursuing a degree in aerospace engineering. I asked her if there were anything in engineering she would like to improve on, she answered:

> **Jacquie:** Okay….is there any particular part of engineering that you feel that you want to be better at?
>
> **Adina:** All of it. (laughter) Um, I'm, I don't really, **I'm not really good at numbers** so I'm just like, really need to improve there. But like every, **science I'm pretty good at**. But uh, I think just mostly the math a- aspect of it (Adina Transcript, 02/27/2020).

Here, Adina constructed engineering as a field where she needs to be good at both math and science. Maintaining that engineering is significantly driven by these other disciplines, she positioned herself as good at science while improving mathematics. By answering the question (when she also had the option not to), Adina affirmed how her interest in engineering drives these goals. Further, her desire to improve in mathematics did not deter her from her interest in engineering; instead, her confidence in science and interest in engineering seem to support her math improvement goals, aligning with the greater engineering field. When I asked her if there were other aspects to engineering work, she replied:

> **1 Adina:** Art.
>
> **2 Jacquie:** Art, yeah?
>
> **3 Adina:** Yeah. I love the **STEAM instead of STEM because like, it includes art and**
> **4 that's like, a big part of it**. That's a big part of STEAM, in a way, because no matter
> **5** what you do, it's art…So like, making um, making a rocket, that you have to see like,
> **6** geometry inside of it, **which is math**. And then you have to see like, how it's going to
> **7** impact the environment, **which is science**. And then you have to see like, **it's gonna be**
> **8 pretty** (laughs) Or it's gonna be pretty in outer space, so (laughs) (Adina Transcript, 02/27/2020).

Adina also constructed engineering, and STEM *writ large*, as requiring art (lines 3-4). Her engineering construction is not of a separate field; rather, one that depends on other disciplines. An artist herself, Adina's art-dependent engineering construction added another dimension through which she experienced seeing herself as part of the field.

Similarly, Rodrigo constructed engineering through STM fields while also sharing how his sincere interest in engineering aligned his interest in science and mathematics in school. While describing personal goals, Rodrigo shared:

> **Jacquie**: You said you want to end up doing work you like. What is [that]?
>
> **Rodrigo:** Anything with engineering, like architectural engineering. Civil engineer, mechanical engineer, uh or electric-, like electrician engineer (Rodrigo Transcript, 3/10/2020).

Later in the interview, he unpacked that this interest is specifically tied to the construction work he was raised around and participated in with his uncles. When I asked him about his favorite subjects in school, he shared:

> **Rodrigo:** Science ’cause we can combine chemicals and see the reactions, and **I’m a need that in the future ’cause like, when you’re putting cement together you gotta put like... It’s basically chemicals.** You know? **And math, ’cause you need a lot of math with engineering and everything** (Rodrigo Transcript, 3/10/2020, emphasis added).

At this moment, Rodrigo constructed engineering as a field drawing heavily on math and science to measure or build. Having defined engineering as also relating to construction and his previous construction experiences, Rodrigo shared how his goal to pursue engineering specifically connected and aligned his wants from school learning. Knowing he would need to use science and math in engineering and construction jobs and would need to know it to potentially pursue it as a degree, Rodrigo’s interest in engineering oriented him towards these subjects as “favorites.”

Math, Science, and Technology Experiences Discourage Engineering. For Cassidy, Elizabeth, and Mariabella, experiences in and around the STM disciplines were less encouraging of engineering-specific goals. These youth pointed to particular elements of STM disciplines as significant to engineering and as a reason for disinterest in engineering. For example, along with the coding experiences she shared with me over time (Chapter 4), Cassidy also pointed to science as contributing to her choices to pursue other interests besides engineering. In an interview with Cassidy, she described herself as a math person but “was still figuring out if [she was] an engineering person” (Cassidy Transcript, 03/13/2018). Later, I asked her again about being an engineering person, and she expressed the following:

Jacquie: Gotcha. Do you…the first part of that question where you said you weren’t sure if you considered yourself an engineering person, do you consider yourself an engineering person now?

Cassidy: I feel like I could be, but I just don’t know like, what kind of engineering. And yeah, so like, like there’s so many. I just don’t know like, which one I would consider myself to be. But I think I could, if I really decided to, I could go to school for engineering, but like... (Cassidy shrugs, laughs) Yeah.

Jacquie: What’s that, what causes you to shrug when you think about engineering?

Cassidy: ’Cause it’s just like, **engineering isn’t just math. It’s math and science, and I don’t think my interest in science (laughter) is big enough-**To like, for me to go for it. **’Cause like, I know what it is; it’s both math and science.** It’s not just math. Like, if it was solely math, I feel like I could probably (laughs) do it. But it’s

13 like, it's math and science, and it's like, I don't know a lot about science as much as I **14** do with math (Cassidy Transcript, 02/17/2020, emphasis added).

At the time of this interview, Cassidy finishing up her senior year in high school. She had participated in three separate engineering summer camps and multiple years of robotics and *Sensors*. During this moment, Cassidy constructed engineering as relying heavily on the disciplines of mathematics and science (lines 9-12). She experienced engineering as potentially weaving these disciplines together, noting that her strong interest in mathematics might not be enough to sustain her in an engineering degree (lines 12-14). As Cassidy looked at herself in relationship to engineering in this moment, she disclosed some reasoning around why engineering no longer served her interests and goals, why she shrugs thinking about it (line 7). Less about her belief in her *engineering* ability (lines 6-7), Cassidy's school mathematics and science experiences shaped her engineering construction and how she saw herself in relation (lines 13-14). Focal youths' experiences in science and mathematics spaces appear to offer insight into how they understand themselves relating to engineering.

Focal youth also pointed to specific activities within the STM disciplines that they associated with engineering. Focal youth pointed to coding and robotics as primary engineering activities, a view of engineering that had implications for their desire to be part of the field. For Elizabeth, Cassidy, and Mariabella, these activities were not engaging (Elizabeth), became less interesting over time (Cassidy), or were actively disliked (Mariabella). For example, while describing why she was no longer interested in industrial engineering, Elizabeth had this to say:

Elizabeth: Like, I feel like I'm an old grandma at technology. Like, sometimes like, old people like, "Oh, you know, you could down-"... My mom was like, "Oh, you're good at

> it," and I'm like, "Mom, you're not as young, but like, there's people who…do more." **Like, my friends they all do coding 'cause they all wanted to go into engineering…**And I'm like, "No, I'm good. Like, I'll do the business plan" (Elizabeth Transcript, 02/04/2020, emphasis added).

Even though her mom supported her as a good technology person, Elizabeth described both disinterest and uncertainty about her coding abilities. Her understanding of coding being part and parcel of engineering work seemed to produce misalignment. In this data excerpt, Elizabeth pointed to coding as an entry point (and potential gate-keeper) into engineering. She noted that her peers engage in coding as a means to pursue engineering. Likely, pop culture images of engineering, which tend to center coding, also informed her view. Although not a form of participation in her *Sensors* work, the technological activity of coding helped inform Elizabeth's understanding of engineering. In this conversation, she imagined engineering as a particular kind of community, one that does not beckon her in based on her lack of affinity for coding. Disconnecting from engineering from her experiences, she described instead pursuing a future in business, a profession she felt interested in and connected to her family. In *Sensors*, Elizabeth critically analyzed designed spaces, moving into increased participation as a citizen in the designed world. Yet, if we also consider how we might invite youth like Elizabeth into the engineering profession, her experiences cause pause. Her explanation suggested she experienced her lack of interest in coding as a gatekeeper. This begs the question: In what ways does this hold true, or not, in the reality of the engineering field? Is this what we want? If not, what types of experiences might support Elizabeth to feel invited to the field?

Given the general newness of engineering in K-12 spaces (Moore et al., 2015), it is understandable that focal youth would draw upon more familiar disciplines and activities to construct what engineering is to them. Further, as a discipline, engineering relies heavily on other disciplines. Practicing engineers may discuss engineering as "applied science" and point to "math readiness" for first-year engineers (e.g., Ellis et al., 2016; Gottfried & Bozick, 2015). Educators may signal engineering work in science or mathematics classes (Carlsen, 1998). What is more notable about this way youth construct engineering is that it implicates science, mathematics, technology, and all associated activities, in making meaning of engineering experiences. Experiences in these disciplinary spaces may not be distinct when it comes to youth understanding themselves in relation to engineering. Further, the "chicken-or-egg" question potentially raises novel and intricate specifications for educational designers. If robotics or coding engages some young people and not others, how does one design a space where all youth can meaningfully participate in these technical engineering dimensions?

Stable With Time: Race, Gender, and Class in Engineering

In our conversations, another way each focal youth constructed engineering was by acknowledging that engineering predominately comprises white, upper-class men as a field and discipline. In our discussions, I named this fact and named my research interests in making the field into a diverse, non-oppressive space. I say this to recognize that I raised this topic in conversation, and it is not surprising that youth then returned to it later in our discussion. However, what is notable is the connections youth drew between their identities, their goals, and what they believed engineering could – or could not – do for them.

While discussing this topic, Mariabella and Cassidy shared specific ways where race, gender, and/or class had been visible in their experiences. For example, in an earlier interview, Mariabella compared an experience from the "STEM" class she took when she went to school in the Nearby City school with *Sensors* at the Community Center:

> **1 Mariabella:** Okay. At [the Community Center, in *Sensors*], I learned engineering has
> **2** like different- different roles. Like- There can be an engineer person like, who's like the
> **3**…let's say like the head of like, the design….versus people who actually put the design
> **4** together. And like, there's people who go and collect data, like human data
> **5** research. And like- like analyze the research, go out and talk to people, get other
> **6** people's opinions. And like, at school we didn't do that. **We just like, we were forced**
> **7 to be technicians** (Mariabella Transcript, 08/19/2019, emphasis added).

Sharing this comparison, Mariabella surfaced a conflict arising between experiences with engineering practice. The Nearby City school constrained the way she could participate (building), whereas her experience at the community center provided her different roles to participate in (leading, data collection, analysis, building). Mariabella said she would not join an engineering group outside of Community Center in our most recent interview. She returned to this idea of "roles," surfacing race and class in this distinction. When I asked what she thought would be different about another engineering group, she offered:

> **1 Mariabella:** No, I don't think that the, that it would be like... Like, I feel like- like if it
> **2** was at like, at like um, like a white person school, **they wouldn't like, separate the**
> **3 roles.** I feel like everybody would like, just go like, into the building part. And like,

4 they would make you do that part. Like I feel like they wouldn't take into consideration
5 your feelings, and like um, yeah. I feel kind of like, um, weird. Not weird, but like um,
6 uncomfortable **'cause like, 'cause I know like, the big engineering groups are like,**
7 white people. Like a white, a white kids' groups. Yeah, and…their engineering
6 groups are like, the ones that like, get the big opportunities and … they go to like,
7 different colleges and stuff. And like, they participate in different things…And yeah,
8 I'd feel weird being in one of those groups. **I'd feel like I would have to be something**
9 that I'm not. Yeah (Mariabella Transcript, 02/13/2020, emphasis added).

Mariabella's observation revealed a personal definition of engineering that indexes the systemic inequities in engineering and engineering outreach. For Mariabella, engineering outreach spaces could represent racialized, gendered, and classed othering, not just in the interactions with peers but within the *actual engineering practice*. Her answer provided an example of the complexity of how constructions of engineering might draw on the intersection of identities and experiences. She connected a techno-focused, narrow version of engineering, one focused on building, with a "white people" school, group, and general perspective. In this, she asserted that this building-focused, white-kid group would "make" everyone do the building part, not considering feelings or alternative roles. Layering in social class, she was aware that these larger, white kid groups (e.g., she clarified for me, like robotics at a white school) are likely to receive material opportunities for their participation. Mariabella saw engineering spaces outside of Community Center as subtractive for her identities and interests: she would have to be something she was not and would feel uncomfortable and, likely, unsafe. In her words, "Yeah. I feel like I wouldn't be able to be as outspoken 'cause they'd be like- 'Dang, she's ghetto.' Yeah." (Mariabella

Transcript, 02/13/2020). Mariabella also shared a particular understanding of how race and class work more broadly, and how she sees that as being reflected in engineering. Outright, I asked her if she thought engineering was a classed space. She offered:

> **1 Mariabella:** Well yeah, I do. Actually, yeah…I feel like really successful engineers are
> **2** always those who have like, good money. ’Cause like they have like, the money to go
> **3** to a good college. Yeah, there’s like scholarships, opportunities, but you know how
> **4** many people go to those scholarships? Like, you know how many people apply to those
> **5** scholarships? Like, you’re not always gonna get that scholarship. So I feel like a lot of
> **6** people turn down opportunities to go to like, great colleges…when they don’t have
> **7** enough money or they end up dropping out- ’Cause like, they don’t have enough
> **8** money. **And I feel like that’s an advantage towards the upper class, like, people.**
> **9 Because like, they have the money like, to succeed and like, be like, great**
> **10 engineers. And I feel like that’s like, the main reason why like, it’s all**
> **11 predominantly white people in engineering** (Mariabella Transcript, 02/13/2020, emphasis added).

From her knowledges and experiences around racism and classism, Mariabella shared a working understanding of engineering as a place where people have money (lines 1-2). Whether or not she was aware of this, she pointed to the money as necessary to fund what is materially the most expensive degree to attain at many colleges (lines 8-11, Cappelli, 2020). Mariabella constructed engineering as classed, raced, and thus exclusionary by connecting money, opportunity, and engineering. Her construction raises significant concerns for the field. As a 16-year-old, Mariabella is already constructing engineering to be a place where only particular types belong and succeed. Exercising her agency, Mariabella chose at this moment in her life not to participate in spaces that might position her harmfully. Mariabella's example makes visible how engineering outreach may operate for youth historically marginalized in engineering: as reflections of larger engineering spaces that create others. This construction of engineering as a place safe for – or not safe for – particular groups of people seemed consequential for youths' understanding of what engineering is and if it is a place they belong.

Cassidy also shared a particular experience where she felt she struggled to belong in an engineering experience. In her story, it was because of her gender. When I asked Cassidy if she had ever had an engineering experience that made her uncomfortable, she described a summer career exploration camp, where she participated in the engineering and entrepreneurship track. On the experience, she said:

> **1 Cassidy:** Yeah, so it was basically like... I don't remember how many of us there was,
> **2** but there were a lot of us and out of everybody **there were only three girls…So we**
> **3 basically just stuck together the whole time**…So yeah, it was three of us. **Just three**
> **4 girls at that**.
> **5 Jacquie:** Geez.
> **6 Cassidy:** Yeah.
> **7 Jacquie:** And how did that make you feel?
> **8 Cassidy:** It was like, I don't know really. It was kinda just like, why? (laughter) Like
> **9** it's just like, it's only like, I was like in shock. I'm like, "Oh, it's so, it's like, really

> only three of us." 'Cause like there's a lot, **there's a lot of girls in the program as a whole**. I just didn't think we would be like, the **only three in engineering** (Cassidy Transcript, 02/17/2020)**.**

In this story, Cassidy relayed a shift in her construction of engineering as her experience became gendered (lines 2-4). To her surprise, she had to grapple both with her "one of three" experience within the program's engineering section and see how girls were underrepresented in the engineering section more broadly (lines 7-8). Cassidy constructed engineering through this changing awareness of her gender in the experience, becoming aware that she was one of so few (line 10). Although this did not stop her from participating, it shaped her participation as she sought out the other girls in the group in solidarity. Further, it seeded a question of if she belonged there, as one of three, instead of other spaces in the group.

Although understanding or experience engineering as a racialized, gendered, and classed space caused Mariabella and Cassidy discomfort, Adina and Elizabeth shared similar understandings that seemed to motivate (or contribute to motivating) their persistence. For example, when responding to a sentence starter about being better at engineering, Adina offered:

> **Adina:** Um, because I am part of LGBTQ and I'm African American and a couple different other nationalities. And so, me being like, "Oh, if I can do it then everybody else that's just like me, or anybody else that's different from the norm can do it" (Adina Transcript, 02/27/2020).

In this response, Adina noted an existing "norm" in engineering, and her queer, Afro-Latina identities exist outside of this. She wants to participate in engineering spaces to serve as a representation of her identities for others. Like Mariabella and Cassidy, Adina was very aware that she might not belong in engineering in its current state. However, she hoped she could contribute to changing that. Sharing another awareness for how race and ethnicity operate in engineering spaces, Adina also discussed popular engineer and “science guy” Bill Nye just getting to be Bill Nye, whereas Black or Latina/o/x scientists’ achievements are often racialized:

> **1 Adina:** When you see a picture of um, Bill Nye on- on a newspaper, right? You’ll
> **2** never see somebody, or you’ll never see the newspaper say, “White man says this.” It’ll
> **3** always be, “Bill Nye.” Or if there’s like, another person who is non-color or something
> **4** like that, you’ll always see like, their name…But once you see like, a Black person or a
> **5** Mexican person or a Puerto Rican person, you’ll always see their race or their ethnicity
> **6** on the paper before you see what they’ve done. Instead of that, just put their name
> 7 and then continue. And then in there, you can add like, “Oh, he is the first black
> **8** person to do this, or he was the first Mexican or African American,” or any of that
> **9** stuff…Underneath it. Then we’ll actually realize, okay this is like, normal to us now.
> **10** So we don’t have to be like, afraid of it (Adina Transcript, 02/27/2020).

Like Mariabella, Adina shared how she views race and racism playing out in engineering (and broader STEM) spaces (lines 1-4). Particularly, she demonstrated how this happens in media (line 1-2). Although Adina’s perspective did not surface structural features of engineering that might prevent participation (e.g., Ong et al., 2020), she pointed to the importance of how Black and Latina/o/x scientists and engineers are represented in media and beyond (lines 5-8, Knight & Cunningham, 2004). Her comments revealed a potential tensions Adina, and those like her, might face: (a) negotiating “us” versus “them” in engineering spaces and (b) negotiating the celebration of her Black and Latina identities in engineering without reifying difference (McGee, 2016; 2021). Seemingly not a deterrent to her goals, Adina experienced engineering with this knowledge in mind.

Elizabeth reflected similar constructions while discussing her interest in engineering before switching to business:

> **Elizabeth:** I feel like I liked [engineering] ’cause…I wanted to try something. I know my whole family was like, into business. I’m like, maybe I want to try something new…Like engineering seemed cool. I know a lot of women weren’t in engineering. That had, that kinda played a lot, a big factor. I’m like- like, there’s not a lot of women in engineering (Elizabeth Transcript, 02/04/2020).

Both Elizabeth and Adina discussed engineering as a space where their identities are uncommon. In this, their constructions of engineering reflect spaces where they, and those holding similar social identities, would be others. Both Adina and Elizabeth expressed interest in engineering because Adina hoped to use her otherness to inspire those like her, and Elizabeth was intrigued to succeed as one of few. Their examples raise the question: Will they be able to sustain their enthusiasm for changing the composition of the engineering field in the face of the marginalization they are likely to face as they pursue their degrees? Although their understandings of engineering as gendered, racialized, and ultimately inequitable spaces partially shaped an interest in pursuing engineering, they also make visible an invisible weight marginalized youth interested in engineering may carry. This is consequential in designing inclusive spaces that invite all youth to engineering work: How do we invite youth to a space that may already feel harmful? How do we design to *repair* that?

For all focal youth, going into engineering as a field, or for some, even joining an engineering experience outside of the Community Center, meant active decisions to go into spaces where they may be the only girl, the only Black or Latina/o/x person, or least financially secure. Being the only person to identify in a particular way in a group can produce a sense of marginalization (Miller et al., 2020; Osterman, 2000; Rodriguez & Blaney, 2020). Ultimately, this presents a challenging conundrum –How do we invite marginalized youth into spaces that engage them in engineering without risking more marginalization? As stakeholders in the design of their engineering education, the engineering field's realities – the homogeny, the inequity, the injustice – were not lost on these youth. With ages ranging 14-18 years old, most of these young people were actively aware of or had personally experienced how systems of oppression operate in engineering. Red was the only youth to share otherwise. When I asked him if he had ever felt uncomfortable in an engineering experience, he shared:

> **1 Red:** Um... I can't say I have been, or off the top of my head 'cause I feel like, like you
> **2** said, most of my engineering interactions have been here at [the Community Center]
> **3** and this place is a very welcoming place-Where it comes to anything, or engineering.
> **4** Even just creating your own ideas here. So I can't say I've never not been welcomed
> **5** into the space of engineering here, but I have not been like, been in (laughs)
> **6** engineering outside of the Community Center so far (Red Transcript, 03/06/2020).

Although Red described feeling welcomed in all the engineering spaces he's participated in, he also connects this to his participation at the community center. Whether he meant to or not, his connections surfaced the importance of racial-ethnic, gender, or other counterspaces in engineering, like identity-based societies or clubs (Ong et al., 2018). The youngest participant, his discussion also pushed us to imagine: What does it mean to make *all* engineering spaces welcoming? Knowing that youth see and experience engineering in reference to their identities, we cannot ignore how their identities might be positioned or experienced in an engineering context. Nor should engineering curriculum developers attempt to develop "identity-blind" programming. Instead, the challenge for educational design becomes how to sustain these identities in engineering work. Further, learning from these youths' awareness challenges the field to interrogate what critical STS scholars of design have been asking: How are inclusion and exclusion is operating across design values, practices, narratives, cites, and *pedagogies*?

Shifting Over Time: Outcomes Constructing Engineering

Whereas most of the youth constructions of engineering appeared to not change with time in our conversations, an engineering construction that did appear to shift with time was what engineering could *do*. That is to say, how youth discussed what was achieved, or could be achieved, with engineering evolved and seemed to grow more consequential in our conversations. Across cases, the youth discussed engineering as a means to an end. Engineering was constructed as a tool that supported helping or improving on multiple scales. For Mariabella, Cassidy, Rodrigo, and Cesar, these constructions emanated from personal outcomes, such as what engineering afforded them in the present day or what it might allow them or others to do in the future. Elizabeth, Adina, and Red's constructions were broader, locating engineering as "everywhere" and discussing present or future engineering outcomes for society.

Engineering Becomes Personally Meaningful. For example, when I asked Mariabella to define engineering in her final interview, she offered, "[W]ell at first I would... Before, like if somebody were to ask me this question I'd be like, "Oh, engineering is just like building stuff and like, computers and stuff…" but then went on to articulate a new understanding of engineering that has multiple roles, "the leader part of engineering. Like, giving out the surveys and stuff. Collecting the data and like, yeah. Further, while reacting to a statement about what she liked best about engineering, Mariabella offered:

> **Mariabella: Helping people…**Yeah, helping the community. Yeah.
>
> **Jacquie:** So you like to see that like, the, what comes out of it. Like the-
>
> **Mariabella:** Yes. **Like I like to see something out in the community**. Yeah (Mariabella Transcript, 02/13/2020, emphasis added).

Shifting from a participant who did not like anything about engineering when she first started *Sensors*, Mariabella begins to construct engineering as multifaceted and through an outcome she believes engineering might produce. It is the potential effect of engaging in engineering work, seeing a tangible benefit in her community, that Mariabella emphasizes. Notably, she forefronts the transformation that engineering might facilitate, as opposed to the engineering work itself, as an essential aspect. Later in the interview, Mariabella returned to this idea:

> **Mariabella:** Um, [engineering] is helpful for me because like, it **makes me feel smart**. Or like, it makes **me feel empowered**, I guess. 'Cause like, **I'm doing something to help the community**. And yeah, it makes me feel like um, good, leading a group. And like, them coming to me, asking me questions. Me answering them (Mariabella Transcript, 02/13/2020, emphasis added).

Again, Mariabella constructs engineering as something she can use to help her community. She points to a positive positioning of herself as smart, empowered, and leading as another outcome of engineering work. Mariabella constructs engineering as a tool, something she might use to achieve the outcomes she seeks in her community. Her construction de-emphasizes technocentric engineering understandings. She instead highlights a connection she draws between engineering, society, and herself. Cassidy, Cesar, and Rodrigo mirrored this type of connection. Cesar shared he stayed with *Sensors* (despite the lack of sensors) because, "…I just ended up liking like, helping out the community problems. And there's not much, not much more. I just really enjoy helping out." (Transcript, 7/23/2019). This type of construction, one highlighting community action, might open opportunities for other youth to connect to engineering in ways other constructions might preclude. More personally, Cassidy shared, "[e]ngineering is helpful for me... because like, I take a lot of skills from everything and just like, apply it to other things." (Cassidy Transcript, 02/17/2020). This type of construction, where engineering is supportive of personal skills, also supports an engineering connection that does not necessitate youth to become an engineer. As we think about designing experiences for *all* youth, these evolving constructions youth shared surface imperative design goals for engineering experiences – how do we make engineering equitably meaningful – sustaining and supporting the connections youth are already making to their own lives?

Engineering Becomes Globally Meaningful. In other instances, focal youth discussed engineering to progress or make things better in society. Relating to problem solving, Elizabeth constructed engineering as a process through which problems are addressed, and things may be improved. For example, as we wrapped up our most recent interview (Is there anything else you are thinking about from your time in Sensors?), she responded:

> **Elizabeth** Hmm, think about? Probably like, when I go to parks, how they organize it. Or like when I, like I live by a park so like how they- they did a sidewalk. So like, I was like,

> "Oh like, they did some weird lines. Like, why would they do this? Like, they could've just did one straight and like", I don't know. Just that about like, thinking how they think. I was like, "Maybe they thought of this and..." it was like a whole bunch of thinking (Elizabeth Transcript, 02/04/2020).

Reflecting on her experiences, Elizabeth shared how she now "sees the design" within her local park. Perhaps something she was less aware of before, she points to the questions subsumed within the design and how they could be improved. Tangibly, she also pointed to engineered products that she encountered in their lives as outcomes engineering shaped. When defining engineering, Elizabeth offered:

> **1 Elizabeth:** I feel like, you like, take a problem... Oh, I had it. Okay, like **you take a**
> **2 problem, but you make, you use like the science and mathematics** around it and
> **3 like, improve it.** So like, saying like, you know, an antennae. Like you find like the
> **4** issue, like sometimes it will like, "Oh, hear more," but like, they made a box now
> **5** where it's just like...Yeah. Oh, I don't know. It just, I don't know, **engineering is very**
> **6 complex**…Very complex. **It's just like, everything's engineered.** Like the table, oh, it
> **7** used to like, just be a- **a wooden table. Now there's metal and there's everything**.
> **8** There's chairs now that are plastic that used to just be wooden. And you know, use
> **9** engineers behind the math of it. Like, how can you make it stable so it wouldn't fall.
> **10** (points to rolling chair) And now you have rolly chairs. Like, what happens like, how
> **11** can you make the like, the- the roll, like the- the wheels turn? Instead of it just like,
> **12** stopping, making it look like that. It's like that's like, **I feel like that's the engineer**
> **13 behind like, the engineering behind it** (Elizabeth Transcript, 02/04/2020).

Elizabeth constructed engineering as a process that contributes to the constant iteration of physical products, like tables and chairs (lines 7-10). In her discussion, engineering was a means to make changes, and potential improvements, to existing technologies (line 3). Elizabeth points to the ubiquity of engineered outcomes in the room we were in for the interview and reveals potential problems they might have been addressing (lines 12-13). She constructed engineering as a strategy for improvement and “saw design” across several places. Here Elizabeth engaged in an informed interaction with the designed world, seeing the ways design and engineering were operating in the products around her (Dunne & Raby, 2013). Moving beyond *Sensors* and other engineering experiences, she demonstrates necessary skills to be a critical citizen in an increasingly designed and technological world. That said, her perspectives raise a question: How might this reading of the design world be leveraged to support inviting her into designing the designed world?

For Red, this pattern of construction could also delve into the intangible. Having questioned initially if *Sensors*’ work was engineering because “I thought there was only a certain type of engineer” (Transcript A, 08/09/2017), Red moved toward a construction of engineering that seemed to focus on outcomes in different grain-sizes and time-scales and could also become speculative. For example, he offered the following explanation while discussing how he would define engineering for a friend:

> **Red:** Engineering... Well, I think mechanics and like, coding. I would, when it relates to those, I would say **making or even help make the future for everyone** on this earth to **have an equal chance at life…**Or to even have an equal chance of surviving this life.

5 Jacquie: Okay, interesting. So I'm hearing you say.. making-

6 Red: The future…But also to make a future where **it helps people and it doesn't hurt**

7 anyone (Red Transcript, 03/04/2020).

In this construction of engineering, Red offered engineering as a way to make change in the world (lines 2-3). Mainly, he constructed engineering as one potential means of helping people navigate what challenges the future may hold, imagining the ways engineering might show up in the future (lines 6-7). Subsumed within this construction is an understanding of engineering as a tool or set of tools – it is a discipline that makes and builds. Red also constructed engineering as a means of societal improvement, suggesting engineering could contribute more equitable experiences. Like Elizabeth, Red "read" how engineering and design exist in the world in powerful ways (Costanza-Chock, 2020; McGowan & Bell, 2020). His conversation raises an interesting question in designing inclusive engineering experiences: In programs for youth, are engineering and design are framed in the thoughtful ways Red suggested? If not, how do we ensure that they are?

Overall, this shifting in construction suggests youth can come to see engineering as a powerful tool in their lives, potentially as a means to make the change they would like to see in the world. For youth who value community change and social justice, this could open up significant ways to connect to engineering as a discipline — constructing engineering as a helpful, socially impactful discipline positions engineering to serve humanized aims and be a tool towards progress (Rodriguez & Berryman, 2002). However, pairing this construction with other constructions might cause discordance in making meaning of their experiences (Rosebery et al., 2010). As youth traverse through their engineering experiences, this aspirational image of engineering might get supplanted by technocratic or exclusionary constructions.

The Ongoing Role of Personal Relationships Constructing Engineering

While discussing their engineering experiences with me, each focal young person referenced an important player that helped shaped engineering for them. Cassidy, Elizabeth, and Red discussed experiences or conversations with family members. Mariabella and Cesar shared experiences about STEM mentors. Adina and Rodrigo pointed to both of these categories. Illustrating the sociocultural nature of engineering contexts, focal youth constructed engineering through the relationships in their lives. Engineering constructions were shaped through the nature of these conversations and experiences. Thus, these relationships supported or destabilized youths' understanding of themselves in engineering design work.

Mentors Shaping Specific Engineering Experiences. For conversations about a mentor, the focal youth talked about experiences in and around a specific type of engineering experience, like coding or robotics. For example, on top of sharing about her sister bringing her to robotics, Adina also shared about her robotics mentor and the teamwork she experienced within robotics. . While we discussed her robotics experience compared to professional engineering, she shared:

1 Adina: Um, probably have... Well I know they have mentors, but I don't think their
2 mentors will work with them as much as ours do. **Our mentor is pretty much the**
3 father. (laughter) Like, he is our father. We go to him with any problem we have, **not**
4 just like the robot's problems. Like if we're having a bad day, we'll just go up to him
5 and be like, "Hey. I'm having a bad day. I need a nap." And he will be like, "Snack's in

6 the back. Go ahead." And so we have like, really, really strong bond with our like, our
7 robotics dad. And so, we're all a really big family and I know that's probably
8 something like at work, but like, here we're kids. So like…None of our problems really
9 stay. So, when we're arguing about something, our robotics dad is just like, "Shut up.
10 You'll forget about it by tomorrow." (laughter) **And then we're just like, back- back**
11 to work the next day and we're just like, "Hmm. Don't like you still, but we're
12 cool." (laughs)

13 Jacquie: … What's the most important thing in doing engineering work?

14 Adina: A team (Adina Transcript, 02/27/2020, emphasis added).

The story Adina shared about her experiences with her robotics team focused not only on robotics but also on the care she feels (lines 3-4). She described her robotics team as a family where she lives – eating, sleeping, arguing, alongside working on the robot (lines 5-7). Although robotics focus is very technical, Adina relayed a humanization and connection she feels within her robotics team. Her engineering construction as team-dependent appeared to be shaped by her team's dynamics and mentorship experience. In this, the positive team relationship was helpful for Adina and seemed to support her engagement with robotics.

Cesar offered a similar story when reflecting on who taught him engineering:

1 Jacquie: Who personally has taught you about engineering, do you feel?

2 Cesar: Mm, probably... my robotics coach…In 8th grade. No, it was... yeah, it was in
3 7th grade…'Cause she basically, we had a big group, but like, the people really just
4 wanted to build and they didn't want to plan anything. So, **she made us, before we got**
5 any of the parts out to build the robots, she made us decide on a design. And after

> **6** we started building, we didn't even finish our design because we had to, we had a claw
> **7** to make, and we had to restart that claw like, five times because we didn't finish our
> **8** design (Cesar Transcript, 08/14/2019, emphasis added).

Although my questioning prompted Cesar to reflect on engineering instructors in his life, his reflection relayed how his coach help construct an understanding of engineering beyond building the robot (lines 3-4). Her requirement of the team to plan their design supported Cesar's understanding of engineering as requiring planning to avoid redoing work. The mentor seemed to support an understanding of engineering that required front-end design work, exploring the building plan before building the robot (lines 4-5). These examples of engineering mentors facilitating youths' connection to and understanding of engineering echoes significant literature examining the benefits of robotics mentorship (Gomez et al., 2016; Ziaeefard et al., 2017). Alternatively, Rodrigo and Mariabella shared negative moments with mentors. For example, Rodrigo shared that he felt excluded from extensive planning conversations by a corporate mentor in his first robotics experience. This mentor, he described, divided the students so that some worked on coding, others worked on strategy, and others (like Rodrigo) built the robot:

> **1 Rodrigo: It was kinda scary**. Like I was scared at first. But at the same time I felt left
> **2** out 'cause I was just, you know, building it 'cause they told me to build it and
> **3** everything, but I was never there for the programming when I was there for the
> **4** conferences or like, other things. Like if I went there, "Oh, you? You don't, you go on
> **5** the robot. We're gonna have to do a little conference." I'm over here like, "Okay. I
> **6** don't know what they're talking about, but they just want me to build it." (Rodrigo
> Transcript, 3/10/2020, emphasis added).

Although this did not deter Rodrigo from participating, he described it as an experience where he felt "left out" and on the margins (lines 1-4). The way this mentor designed the roles within the space highly shaped how Rodrigo could participate. Unsurprisingly, for focal youth, these mentoring relationships seemed to shape how youth made meaning of engineering.

Family Members Shaping Broader Understandings of Engineering. Moving beyond specific engineering mentorship experiences, five of the focal youth described experiences in their lives where friends or family members shaped their engineering understanding. Unlike how youth shared experiences in their robotics experiences or coding classes, these experiences ranged in context and purpose as youth constructed engineering in our conversations. For Rodrigo and Adina, it was participating in an experience with a central figure in their lives. Cassidy, Elizabeth, and Red discussed or grappled with said figure's beliefs about engineering or technology. For example, when I first asked Rodrigo to describe his engineering experiences in our most recent interview, he shared the following story:

1 Rodrigo: But yeah, we were construction, we were constructing a house…A house
2 next to it, they'd already built, but we were building a garage 'cause he had a
3 trailer…So it had to be as big as a trailer [to] fit…And well, they already had the base
4 and everything out, so we were just you know, on top of the garage, fixing it. 'Cause he
5 wanted a house up there. I'm like, "Okay."…And in that house, we were laying bricks.
6 You know, all that. **We, instead of, we didn't have modern technology over there**.
7 So we had to use strings to straighten like, you know, to see if it was straight…We had
8 to use a tube, like a straw, but like more you know, str- uh, what's it called?
9 Flexible…And we had to put water inside and we had to see if it was leveled out or

> **10** not…**So it was just like, old school engineering**…And the cement, it was different
> **11** ’cause we had, we had to like, rocks. We had rocks, sand, dirt. We had to mix that up
> **12** to make cement…Instead of, instead of cement we already have. **Yeah, we made,**
> **13 have, we had to make our own** (Rodrigo Transcript, 3/10/2020, emphasis added).

While reflecting on his engineering experiences and constructing engineering, Rodrigo drew upon an experience with his uncles. He experienced what he referred to as “old school engineering” during a family trip to Mexico. Unlike the robotics experiences, Rodrigo felt like he could fully participate in building the garage. Through this experience, Rodrigo constructed engineering as something he could enjoy doing with his family. His family defined the building project and invited him into it, creating opportunities for Rodrigo to participate in a common goal with his uncles and connect to an engineering task. In this example. Rodrigo also described engineering as highly related to construction, building, and solutions. He and his family solved for the height of the trailer and not having modern technology. In sharing the story as an engineering example, Rodrigo already made connections between these “everyday” engineering experiences with his uncles and engineering *writ large*. Although he points to it as “old-school” (not using machines or digital tools), this experience contributed to the way Rodrigo viewed engineering. This experience seemed to inform a construction of engineering that bridged construction and engineering as fields, centered building, and emphasized family and elders as sources of engineering knowledge.

Other focal youth discussed experiences with significant relationships not doing engineering but discussing it. In this, the person themselves – their opinions or beliefs – seemed to influence a young persons’ construction of engineering. For example, while Cassidy was discussing her college choice and selecting a major, she described how engineering was still on the table, although she wished to pursue a culinary degree:

> **Cassidy:** It's like engineering is there, but it's mainly 'cause like, **that's what my mom is hoping me to go for** (Cassidy Transcript, 02/17/2020, emphasis added).

When I ask why her mom was interested in her pursuing engineering, Cassidy responded:

> **Cassidy:** Because **they make a lot of money**. (laughs) That's like-That's really why. And then like she's persis-, very persistent on that. (laughter) So it's like, she's like, blocked out all ideas of like, me going for like, anything else. But like-…If I find something else that could also make me money, like I could also go for that. And she's just like, "No." **It's guaranteed that you couldn't go from engineering to like, this** (Cassidy Transcript, 02/17/2020, emphasis added).

At this moment, Cassidy's construction of engineering seemed to be shaped by her mother's expectations and understandings of engineering. Her engineering construction accounted for her mother's construction of engineering as a lucrative or secure career choice. Engineering was not Cassidy's outcome but an outcome for a significant relationship in her life. Focal youth are continually traversing and building personal relationships in their lives, so it is not surprising that these relationships show up in their engineering meaning making (Wilson-Lopez et al., 2016). However, what is important to note is the significance these relationships might have as youth construct engineering and question if it is a place where they belong. Further, experiences shaped through one personal relationship might conflict with others (e.g., Rodrigo's mentors vs. family members), and youth make meaning of engineering through this conflict. This raises the need to not only think more particularly about how mentors or practitioners enact engineering design programs with youth – but also how we might elicit and leverage these familial relationships and everyday knowledge to better program design.

Learning From Youths' Discussions: Designing Across Youths' Experiences

As was evident in these examples, focal youth experienced and discussed engineering in ways that intersected across categories. Cassidy's mom encouraged an engineering career as a socioeconomic lever. Diego's discussion of working with his uncles prompted technology and building images connected to time in Mexico. Mariabella's critique of engineering programs was connected to technologically focused activities and mentor's expectations. From a sociocultural perspective, "engineering" then becomes an evolving amalgamation of these young people's knowledge and experiences (Bang & Medin, 2010; Moje & Lewis, 2007; Nasir & Hand, 2006). What is clear from my interviews and interactions with these young people is that their out-of-school experiences largely informed their varying images of engineering. Since these youth did not have consistent access to engineering or design experiences as part of their regular school day, what they imagined engineering to be was dependent on ad hoc opportunities.

Moreover, other youth who do not participate in out-of-school time engineering and design programs are likely to have even more limited perspectives on these increasingly dominant fields in our society. If the field and our society truly want diversity and broaden participation in engineering, we need to provide all youth opportunities to explore their options. This underscores the NGSS call for engineering design experiences within the school day. That said, how teachers, leaders, and curriculum designers craft those experiences should take into account the voices of youth like Cassidy, Mariabella, Elizabeth, Rodrigo, Cesar, and Red to ensure the design of meaningful and liberatory engineering experiences that invite a range of youth into exploring the profession and into knowledgeable participation in the designed world.

Looking across youths' discussions, it also becomes clear that flexible, real-world design is not a "silver bullet" in designing inclusive engineering experiences. Several funds of knowledge (Moll et al., 1992), histories of engagement (Gutiérrez & Rogoff, 2003), and others' expectancies and values (Eccles Parsons, 1983; Eccles & Wigfield, 2020) were at work before, during, and after youths' time in *Sensors*. They held weight in how focal youth came to position themselves as participants in the designed world and potentially on engineering paths. For example, Rodrigo drew on a deep familial fund of knowledge in his experiences with his mom, dad, and uncles to construct engineering (Moje et al., 2004; Moll et al., 1992; Wilson-Lopez et al., 2016). In these working and construction environments, he came to know about himself in engineering. Like Rodrigo, each youth pointed to some fund of knowledge and particular socializer shaping their engineering construction. These findings extend work across sociocultural and psychological spaces that point to *who* socializes one into a space is as important as *what* the space is (DiGiacomo & Gutiérrez, 2016; Wigfield & Eccles, 2000). Mackenzie's and Elizabeth's mothers, Cesar's and Adina's robotics coaches, and Red and Mariabella's mentors contributed to how youth made meaning of their *Sensors* experience and themselves in relation to engineering broadly. As we endeavor to design inclusive engineering experiences for youth better, how might we better engage these knowledges? These important figures in youths' worlds? Continuing to explore the relations between youths' engineering constructions against the larger backdrop of their lives may offer new directions for developing youths' critical participation in the designed world and their belonging in engineering.

CHAPTER 7 Implications and Conclusions

In Chapter 1, I presented several ongoing challenges in engineering education related to engaging youth in engineering work to grow, broaden, and diversify participation in engineering. I also presented a reframe to thinking about engaging youth in engineering" youth are critical stakeholders in their own engineering education – they are the immediate users, and liberatory, just design principles suggest they be engaged in the process of this developing these experiences. To paraphrase an earlier quote from McGowan & Bell (2020), creating more and earlier engineering design experiences is not an equitable model without a critical examination and transformation of the engineering design presented to youth. I add to this to argue that developing meaningful, consequential engineering design experiences for all youth – not just those already aligned with the field - is also necessary for equitable engagement. To begin to think about my proposed reframe, I looked to explore youths' engagement in *Sensors'* design work and discussion of their engineering design experiences. In a sense, I sought the contribute to the exploration of this larger, messy-yet-wonderful challenge of engaging young people in engineering. Studying focal youths' practice and learning from their discussions is foundational to new experience designs.

As youth participated in the *Sensors* experience or other engineering experiences, they made meaning of this experience in their own lives. Young people posed questions about the field, speculating about if and how they would belong in the experience and what value it might add to their lives. In turn, the *Sensors*' experience supported moments of possibility where youths' experiences meaningfully shifted design. While they engaged, new opportunities emerged for youth to revisit the meaning they made of their participation, accessing – or being cut off from – new goals and identities (cf. Nasir, 2002). Returning to my anecdote from Chapter 1, thinking about youth engineering programs only in terms of "STEM pipeline," "increasing interest," or "fun memories" underestimates the immense work youth from marginalized backgrounds may do as they traverse these sites over time. This chapter offers implications for (re)engineering and (re)imagining pre-college engineering design work toward more inclusion of youth and their knowledges and experiences.

Reviewing Findings

From the analysis presented in Chapters 4, 5, and 6, I argue that as focal youth participated with time, they shifted and grew their engineering design skills and engaged in design that moved toward more liberatory ends. All focal youths' engagement in *Sensors*' work shifted toward more nuanced practice, reading the designed world in problem framing, stakeholder exploration, and community research. Each focal youth pointed to data as a means of making a better design and described growing acceptance towards both problem framing and failure. To do this, they drew on personal experience and saw new ways design was relevant to their lives. In this way, youths' engagement in *Sensors*, perhaps in the messy reality of a design process, seemed to support youths' design skills and invite and purposefully draw upon their experiences and interests in design. Further, youths' interactions with the *Sensors'* program created moments of liberatory design possibility, where the openness and messiness of the front-end design structure invited youths' critique, question, and critical reflection.

Youth also shared a myriad of personal experiences, interests, goals, and understandings of themselves in the discussions of their *Sensors* work. Reflecting, they described different meanings they made of the experience and engineering more broadly. For example, there was not enough technology-focused skill development for Cesar, whereas Mariabella described working with sensors, despite her lack of interest, as a compromise. Elizabeth described how aspects of the design supported her in developing her analytical skills for business, whereas Red described how his creativity and ideas were supported. Whereas focal young peoples' engagement in design practice exhibited similarities, aspects of their participation took on a different meaning. These young people described their *Sensors'* experiences, broader engineering experiences, and the connections they made in ways that might be invisible in their practice. Youths' stories underscored the immense amount of work youth do to understand themselves in spaces in general, but particularly in engineering spaces. They also contextualized the breadth of ways youth came to the *Sensors* program as stakeholders in its design and set up the important challenge of designing youth-centered engineering spaces that take up all these aspects of youth and beyond.

In this sense, my work joins the calls of scholars to increase engineering experiences for youth in K-12 settings (Brophy et al., 2008; Purzer et al., 2014). However, instead of the experiences serving solely as a means to 'get more youth from diverse backgrounds through the door,' I aim to extend the work of scholars reframing educational spaces as sites of partnership with youth (e.g., Bang & Vossoughi, 2016; Nazar et al., 2019.; Vakil et al., 2016), and look to their experiences as important information about the value systems of engineering. Instead of being cast as distant end-users of engineering education, youth hold an incredible wealth of information that should genuinely shape the problem space.

Implications for Inclusive Engineering Educational Design

Critically, designing to deconstruct exclusion means designing ways to prepare *all* youth to engage in and design the designed world. Presenting one construction of engineering stands to maintain the field's status quo, inviting only some that fit current norms and not engaging all youth. The following section discusses implications for designing engineering programs. I first overview some strengths and limitations of the *Sensors* program from youths' engagement and discussions. Next, I discuss the potentially translatable dimensions of the *Sensors* program, digging into some nuance about the challenge of direct transfer.

Sensors*: A Real-World, Messy Imaginary*

For youth, particularly youth who came into *Sensors* with narrow engineering experiences (e.g., Mariabella, Red, and Cassidy), *Sensors* may have operated as an imaginary or a space that (re)negotiated and (re)created what it engineering might offer to them in their lives. Drawing from science education, "[i]maginaries come into being through the ongoing re-mediation of structures upon which new meanings are negotiated, as individuals collectively work to understand and envision new possibilities for knowing, being, and becoming…" (Gutiérrez & Calabrese Barton, 2015, p. 575). As speculative spaces, imaginaries provide glimpses into what could be, allowing us to backward-map how to get there. By engaging in *Sensors'* flexible, real-world front-end design work, particularly our conversations in problem definition, youth and I explored new meanings for engineering work driven by youths' purposes, goals, and commitments. This work created several new dimensions in which youth engaged in engineering design work, through developing the problem, developing data collection systems, analyzing data, ideating, or building the design itself. In this, engineering design was not a means to a predetermined end, “technology building,” or removed from our local context. Instead, *Sensors’* design work offered a set of tools *for* community problem solving. Its flexible nature allowed youths’ questions, critiques, experiences, and concerns to be adapted in real time, creating moments of possibility that moved our work closer to liberatory design. This finding supports calls for framing engineering for young people as a means to examining social *and* technical spaces together, like the newly developed Framework for Sociotechnical Literacy (McGowan & Bell, 2020). McGowan & Bell (2020) argue, “[e]quitable engineering learning and the development of engineering-linked identities require that learners are able to “read” the sociotechnical landscape in order to derive meaning about the self in relation to historical and present representation of space” (p. 994). My work supports this framework’s argument that engineering spaces should establish engineering as a sociotechnical field in a sociotechnical world, inviting and fostering criticality around ‘what’ and ‘who’ designs are for. Broadening the field of vision for what is considered ‘engineering’ work towards critical, just, and liberatory frames seems to offer new pathways for youth to traverse in and through engineering and design work. Further, it supports engaging with specific technical skills (e.g., analyzing root cause or reading the designed world) that youth narrate as supportive of their broader life goals, including designing the designed world.

Learning from* Sensors*: Challenges and New Directions

Although *Sensors’* structure was well-received by focal youth and seemed to provide an opportunity for all seven focal youth to engage in ways meaningful to them, the distinctions youth experienced within *Sensors* reveals a challenge for programs that attempt to engage in youth-driven, real-world design formats. Engineering design is *both* understanding a problem space and building or developing a solution. Learning from youth's experiences, *Sensors'* work may have muddled this interconnection. Emphasizing the important features of the socially engaged, people-centered design work on which the program was based (e.g., Buchanan, 1992; Dorst & Cross, 2001) created an opportunity for Elizabeth to explore her love of analysis, Red to dream about the future through root-cause analysis, and for Mariabella to feel like she could be a leader of technicians. Importantly, all youth felt like they helped and could help their community through research and design. However, Cesar and Red wanted more work with the sensor technology, Mariabella felt disconnected from building or "putting it together," and Elizabeth left feeling like sensors and coding were not "for her." Centering these youth as stakeholders, we did not entirely create a design integrated across the "social" and the "technical" aspects of design. Although youth engaged across these practices, they did not interconnect the experience in our conversations. Further, the *Sensors* program did not fully allow focal youth to connect how front-end, socially situated work gives value to the technical coding or building, nor how front-end socially situated work *is* technical work itself. Maintaining that engaging youth in defining real-world, messy engineering problems is critically important for developing purpose-driven by youths' personal experiences, I argue there is still work to be done to better design for this outcome and connection with other dimensions of engineering design practice.

Taking a step back, the *Sensors* curricula were not built as an engineering design curriculum but intended to position engineering design and research as some of the many tools for social change. In part, we designed it to counter common building-forward approaches that might neglect youth input and in which "…there is a risk that activities will be done merely for the sake of doing activities – making crafts – with no attention to the functional purpose of engineering and design" (Purzer et al., 2014, p. 76). By spending significant effort in the real-world, messy work of problem framing and exploration, youth then also drove problem *solving*, responding to the emerging needs of their design work. For example, Red and Cesar's suggestion to pilot designs in the park or Elizabeth and Cassidy's suggestions to offer multiple seating arrangements at the conservancy were important moments of youth solving problems part and parcel to a design they had led to that point. However, we also potentially neglected eliciting the wealth of youths' *everyday* problem-solving skills. For example, Rodrigo had significant experience problem solving in building his uncle's garage – figuring out how to get the tools up or making cement from scratch. Yet, due to the direction youths' designing went, *Sensors* did not engage this aspect of his everyday engineering knowledge. Considering this example surfaces a consideration for youth engineering experiences moving forward: how might we purposefully elicit youths' experiences throughout all dimensions of design work?

Translatable Dimensions of* Sensors' *Design

Learning from youths' experiences, what dimensions of the *Sensors* program might we move into different designs? I argue that several translatable ideas emerge from the specific *Sensors* contexts for future programs that engage youth in engineering design. Toward goals of inclusive engineering experiences for youth, I argue these dimensions supported both youths' skilled design engagement and moments of liberatory design possibility.

Messiness and Flexibility. Doing design work in a messy, real-world way seemed to support youth building design skills and bringing their ideas to design. The flexibility and messiness of defining a problem presented a challenge youth rose to. The messiness also seemed to allow youths' ideas to "fit" in the space because a rigid process was not excluding their input. In the flexibility of the work, youth brought their ideas, questions, and criticality to the design, sustaining moments of liberatory possibility.

Real-world Contexts and Stakeholders. Real-world, place-based contexts also seemed to make a difference in youth seeing and reading the designed space. For example, by working at local parks and a city conservancy, youth could make the messiness of problem definition more tangible by talking with local stakeholders. The solutions they built could exist in real spaces they traverse. Supporting youths' critical design skills in this way builds on scholarship that argues to critically engage youth in place-based work for the goals of social action (e.g., Kirshner, 2008; Nazar et al., 2019).

Multiple Opportunities to Engage. Both as youth engaged in *Sensors*' design work and discussed their experiences, it became evident that engaging with a design multiple times was an important facet of *Sensors'* work. Connected to real-world contexts, often truly implementable outcomes from youths' design work required more time than one *Sensors'* iteration. As youth returned, they continued to shape, nuance, and grow design work in similar problem spaces. This iterative practice seemed to support youth iterating the design and growing their skilled design practice while also growing criticality around the work. Further, the youth pointed to seeing this process unfold with time as meaningful. The possibility of working over longer timescales, such as months or years, seems to support important connections to design for youth.

Greater Merging of "Social" and "Technical." Learning from youths' discussions revealed a potential need to think purposefully about bridging the social and technical aspects of design work. Echoing arguments from McGowan & Bell (2020), framing engineering as a sociotechnical practice may create new inroads to engineering space. In one sense, this could help shift the narrative beyond the "math person" as a future engineer toward compassion, creativity, and problem-solving becoming more central in engineering narratives. Equally important, the socially-situated elements of *Sensors'* work supported youth less interested in technology activities to build critical, informed skills to participate in the designed world. Further bringing these aspects into conversation – or paraphrasing Adina, exploring how to "be smart" in the social aspects to support technical aspects (Chapter 4, p. 97) may lengthen these engineering inroads even further.

Skills Youth Want. Youths' discussions also suggested a greater need to elicit not just youths' interests in design work but also to elicit their goals for the programming space. By discussing these through the design, more opportunities might arise for engineering design spaces to be meaningfully integrated with youths evolving understandings of themselves, their goals, and desires. Further, important expansions of recognized design work may occur as youth and mentors seek to make connections across youths' broader interests and design work.

Valuing Youths' Input. It is important not just to ascribe youths' actions here just to respond to the program's flexibility or local engagement – as Strobel et al. (2008) argued, "people not programs" (p. 1701). I argue that there was also an important feature of youth feel like their ideas would be valued in the community center or after-school space by *Sensors* leaders and their peers. For example, Mariabella articulated that she felt like she could have her opinions in *Sensors*, and Red felt like he and the group's ideas were "taken serious" (Chapter 4, pp. 105, 124). Seeing how their ideas would be valued seemed to support youth to feel like they could critique or question *Sensors'* space and take ownership of the design work.

Care and Liberation. Regardless of youths' interests and goals spanning the sociotechnical work of engineering design, an orientation towards help, care, and liberation seemed to support youth in developing criticality in their designed world participation and design in liberatory ways. That is to say, orientation toward engineering design work as a tool for community care seemed to support multiple ways youth saw the work as meaningful and even continued participation. This is aligned with work that explores the transformative power of engineering design as valuable to youths' participation and meaning-making (Gunckel & Tolbert, 2018). Further, it strongly necessitates future work to understand just and liberatory design as an overarching framework to guide the development of engineering design experiences for youth.

Nuancing Translation

Particularly thinking about these final two dimensions, there is a need to add another layer of nuance, particularly related to the *Sensors* context. For example, it is one thing to say that it is necessary to value youths' input; it is another to make youth feel like their input is valued, that they are the ones to lead community problem solving, and as Red expressed, that their work will be "considered serious." What, then, about the interaction between youth and the *Sensors* program, particularly mentors, supported this? Although this was not the focus of this study explicitly, I offer two learnings from working with focal youth that may ground future work in this area.

Mutual Curiosity. In *Sensors*, defining and exploring a problem of interest with youth was a process of mutual curiosity between mentors and youth. It was a process of questioning – questioning what was interesting, questioning processes, questioning ideas. That is to say, as we asked the youth to explore their local area and identify and explore a problem of interest, mentors explored alongside youth. From going out on data collection efforts to sitting side by side with youth in analysis, mentors tried to be integrally involved in the process of understanding the problem. Further, mentors attempted to suspend notions of "correctness" in the discussions of design work. Seeking to listen and learn alongside youth, mentors instead actively engaged in these discussions with youth in the moment, mutually shaping design plans.

Mutual Investment. Another potential learning was the orientation of mentors to be mutually invested in the design outcomes. For example, as youth developed questions for a survey, a mentor would then type up the questions as written by youth. The mentor and youth would sit with the copy together in the next session, discussing how the survey might be edited and changed. Mentors helped support the realities of design builds, collecting materials with youth. For final design presentations, they were behind the scenes supporting presentations, not part of the audience. Said simply, mentors were invested in the outcome youths' design work as youth were.

Ultimately, these learnings suggest a necessary dimension of care, trust, and respect of youth as partners in design work. They potentially suggest a shift away from giving youth an experience to participating with youth in an experience. Thinking about future youth engineering programs, these learnings necessitate those working with young people in engineering to interrogate how they interact in the space. What are their goals? What are youths' goals? Are the adults working with youth to make them into engineers? Or are they seeking to center youths' experience, valuing them as equal participants in the designed world? This work joins calls from greater informal STEM work to interrogate the relationships and value systems of programs, not just the program's content (Goessling & Wager, 2020; Kirshner, 2008; Vakil et al., 2016; Vossoughi et al., 2021). Further, it necessitates future work unpacking how multiple layers of relationships may operate within the context.

Implications for the Engineering Discipline

From Mariabella's questioning around unsheltered persons being stakeholders to Adina's and Rodrigo's surveying of their neighbors, focal youth thought expansively about *who were valued stakeholders in the design* and *what the problem truly was*. I offer these different design decisions, and problem spaces go beyond previous diversity calls in engineering to "bring more voices to the table" (Prescod-Weinstein, 2018). Whether or not intentional, the ways these focal youth problematized and sought to understand problems resisted design initiatives driven by capitalistic gain, neoliberal improvement, or increased technocentrism (Costanza-Chock, 2020). Instead, through their problem definition, research work, and solution development, youth advanced a project ethos of care and action (Gunckel & Tolbert, 2018; McGowan & Bell, 2020). Stemming from the ongoing conversations in design milieu, youths' criticality and questioning moved us toward greater liberatory design – design expanding who and what is valued.

As such, the story becomes not if youth, particularly youth from minoritized backgrounds in engineering, *can* do the work of engineering design, but *how and why* they engage in this work. In this story, which might be one of many stories, young people are the main character, and their values, identities, and practices are the necessary materials of design. This story critically necessitates us, as engineering educators, to officially “explode the pipeline,” moving beyond recruitment models that minimize the experiences of marginalized youth or only define “success” as achieving an (often subtractive) engineering degree (Pawley & Hoegh, 2011). Instead, these findings support the many calls (Benjamin, 2019a; Eglash, 2019; Gaskins, 2014; McGee, 2021; McGee & Robinson, 2019; Nazar et al., 2019; Rosner, 2018) to reconstruct engineering in both practice and culture, to center social justice and fundamentally operate from a place of liberation and diversity.

Focal Youths’ Practice and Diversity in Engineering

The way focal youth in this program brought their everyday knowledge and practices to design contrasts with some pervasive notions of engineering work. Some dimensions of engineering culture valorize objectivity and remove the *engineer* from the *engineering* (Adams et al., 2011; Harding, 2015; Riley, 2017, 2019). Embedded within this model is the assumption that *engineering* is more significant than the people doing engineering work. From this perspective, explicitly naming or celebrating human involvement might introduce error, hindering outcomes (e.g., Wichman, 2017). Nevertheless, we know that engineering is social and human involvement is necessary (Buchanan, 2001). The way youth took up problem definition in the programming did not preclude the traditionally technical work. Discussions that supported youth bringing their knowledge to the work also supported an articulation of technical thought processes. Reciprocally, the technical process youth engaged in created opportunities for personal knowledge to be leveraged. In this, youth began thinking like engineers as the field would define it (Petroski, 1985), even as they brought other dimensions of their experiences to push back against canonical ways of doing engineering design. Thus, focal youths’ engagement in *Sensors*’ design may not have always looked like traditional engineering practice, but it supported engineering design ways of thinking and doing. More simply, examining focal youths' engagement in *Sensors'* front-end design revealed that learning design and engineering practices can be additive and expansive. Youth did not have to subtract their own experiences to take on nuanced engineering design work. This finding expands the literature asserting engineering design work benefits from the full engagement of the designer, youth, or otherwise (McGowan & Bell, 2020; Rosner, 2018).

Focal Youths' Meaning Making and Diversity in Engineering

As focal youth discussed and made meaning of their engineering experiences, it became clear that a consistent image youth held of engineering was one associated with high technology, building "things," mathematics, and the natural and physical sciences. Although varied in nature and degree across youth, all youth discussed an awareness of engineering experiences potentially being uncomfortable or othering. In our conversations, Elizabeth, Cassidy, Adina, and Mariabella connected their experiences or knowledge to the engineering field more broadly, revealing that they understood engineering as a place where racism, gender, classism, or other systems of oppression might come to bear on their participation. Interrogating focal youths' meaning making revealed an image of engineering as a technocentric, unsafe space that marginalized youth may or may not want anything to do with. Understanding engineering in this way is not unexpected. As Carlone (2017) argues:

> Science, engineering, mathematics, and computing…carry with them significant historical, racial, and gendered narratives about who fits, which makes them excellent contexts for exploring the ways in which regimes of power shape normative categories

> (e.g., gifted, disabled) in local settings (Holland & Lachicotte, 2007) and the ways in which everyday practices in local settings reinforce actors' meanings of themselves/others in relation to those categories (Carlone, 2017, p. 527).

From this perspective, if engineering is some combination of mathematics, science, and technology, all of the experiences of belonging, or not belonging, in *any* STEM space are thus implicated in understanding oneself concerning engineering. Positive or negative experiences with robotics mentors and science or mathematics teachers might shape if engineering feels accessible or not for youth. If engineering is a raced, classed, and gendered space, then one's race, class, and gender are implicated in understanding oneself in relation. Interrogating youths' meaning making creates a moment to question – is this what we, as engineering educators, want youth to think of the field? Although an important direction of addressing this question is how we design programs for youth to counter these narratives (Gunckel & Tolbert, 2018; McGowan & Bell, 2020), another critical direction is working to improve the source of the narratives: the field itself. Diversifying the field of engineering requires making the field into a space that marginalized youth, who care about social justice and community, actually want to go – making it a space where they know they will be safe and learn in ways that sustain both who they are and what they care about (McGee & Robinson, 2019; McGee, 2021). Such a reframe requires thinking about how liberatory practice might live beyond the moments and into the norms of everyday work.

Imagining New Futures: Critical STS Theories of Design and Engineering

Critical STS theories of design assert that systems of oppression continue to take root through all aspects of the engineering enterprise. For engineering design, it might be easier to point to oppressive or exclusionary person-to-person interactions. Often termed "the chilly climate" of engineering, significant research has documented bias and discrimination experienced by those on the margins in engineering (McGee, 2016; McGee & Martin, 2011; Ong et al., 2018, 2020). Importantly, critical STS theories of design assert that the story does not stop there. Oppression also lives in practice – in the canonical, normative ways of doing and being in engineering. From this perspective, several focal youths' experiences raise questions. How would Rodrigo's fund of knowledge around construction and "old school engineering" be interpreted by those in power in canonical engineering settings? What about Red's questioning of the design process? Cassidy's care of her other group members? As Mariabella directly pointed to, what engineering programs ask youth to do – or not do – carries weight for how they might imagine themselves in the space.

Further, what these programs guide youth to build – or not build – carries similar weight. Just as focal youth came to see engineering as a tool to make a positive difference in their community, the opposite could easily be true looking at a different engineering situation. For example, Elizabeth was one of several youths in *Sensors* who raised a problem space of air quality near a newly-constructed bridge that had increased truck traffic in the local area. What would a decontextualized bridge-building engineering challenge mean for youth like Elizabeth? At best, this might create a mismatch of experiences (Wilson-Lopez et al., 2016); at worst, this theoretical challenge becomes representative of larger systems of oppression embedded in the "hows," "whys," and "whats" of design (Benjamin, 2019; Costanza-Chock, 2020). Worse yet, if the theoretical bridge exercise is framed as "improvement," what does that mean for a person like Elizabeth who saw the local bridge as a problem rather than an improvement? Also important, how do decontextualized challenge projects affect youth from economically privileged and socially dominant backgrounds? Decontextualized engineering design experiences may never ask them to be critical of the designed world, interrogate potential negatives of the projects they design and build, or challenge their worldview. Instead, with messy design processes obfuscated, they are allowed to accept normative views of the designed world that hold profits and efficiency for the privileged over the lives of others (Costanza-Chock, 2020; Eglash, 2019). Changing the engineering field's perspective means that the early engineering and design experiences must change for *all* youth, not just those historically marginalized in engineering. Only inviting more Black and Brown youth, young women, or other youth from marginalized backgrounds into an unyielding space will not achieve diversity; the field needs to change to invite the diversity it seeks.

Diversity in practice offers one way toward a diverse field. We might conceptualize tenets of practice through critical STS theories of design that guide engineering design work toward liberatory, just ends. These perspectives locate marginalized youths' everyday knowledge and identities as assets and integral to design work itself. Through this lens, Rodrigo's construction work with his uncles is both a necessary experience to draw on for doing engineering *and* a reconceptualization of what engineering could be. Cassidy's care, Red's questioning, Mariabella's expansion of stakeholders all remix canonical engineering. In this, this study extends the significant history of scholarship calling for eliciting and building on youths' funds of knowledge as building blocks for STEM work (Calabrese Barton & Tan, 2009; Esteban-Guitart & Moll, 2014; Moll et al., 1992; Rodriguez, 2013; Wilson-Lopez et al., 2016).

Further, I offer that critical STS theories of design provide one (of many possible) lenses that the field might take up to begin what Bang and colleagues describe as “desettling” settled expectations (Bang et al., 2012). From her essay, “Whiteness as Property,” Cheryl Harris’ described settled expectations as ‘the set of assumptions, privileges, and benefits that accompany the status of being white … that whites have come to expect and rely on’ across the many contexts of daily life (Harris, 1995, p. 277). Indeed, Bang and colleagues (2012) mobilized this construct to name, problematize and desettle “entrenched, usually hidden, boundaries that tend to control the borders of acceptable meanings and meaning-making practices” in science (Bang et al., 2012, p. 303). Moving from science to engineering, I argue that developing experiences from critical STS theories of design offer productive paths forward for engineering education – and the engineering field – to work toward liberatory design as a cultural norm.

Broader Implications

Although this was not the core focus of the study, the findings and the youth profiles nod to implications in other areas of engineering education. Exploring the nature of focal youths’ engineering practice underscores the ongoing challenges K-12 teachers may experience teaching engineering (Hammack & Ivey, 2017; Pruitt, 2014). On top of their other commitments, science and mathematics teachers are often pulled to teach engineering within formal spaces. Further, this topic might be taken up differently depending on the local context they teach within (Capobianco et al., 2018; Roehrig et al., 2012). Whereas significant research continues to explore the supports for pre-service and in-service teachers (Bybee, 2011; Coppola, 2019; Lottero-Perdue & Parry, 2017), this study contributes to knowledge that supports teacher “noticing” around youths’ engineering work (e.g., Johnson et al., 2017; Wendell et al., 2019) by exploring what youths' engineering work may look or sound like. For example, when Red and Cesar were asked to explore root-cause in design, they pivoted into other design behaviors of stakeholder empathizing. This pivot was important to exploring and understanding their problem, but it also may look like they were off-task. Surfacing the non-linear ways youth may do design – how it might sound or feel messy compared to other work – may help teachers' see and support youths' engineering design learning. Further, it might help articulate a definition of engineering pedagogical content knowledge, thinking about the types of moves teachers need to extend youths' design thinking in messy moments (see Ball et al., 2008; Shulman, 1986). Continued work to examine how youth do engineering work and how their everyday practice connects with disciplinary practice can support practitioners to notice, affirm, and extend engineering learning.

This work may also hold broader implications for thinking about K-12 engineering policy. In its current form, the NGSS only serves as a primer to disciplinary engineering work. It was likely not the goal of the NGSS architects to deeply develop the engineering standards. However, it is important to note the conflation that happens within the standards. The NGSS might confuse practitioners because the wording of the engineering practices and disciplinary core ideas (DCIs) is similar (Cunningham & Carlsen, 2014). For example, the NGSS DCI of *Defining and Delimiting Engineering Problems* echoes the science and engineering practice of *Asking Questions and Defining Problems* (NGSS: Lead States, 2013). This overlap in language may make it more challenging to interpret and support engineering learning. The language choice seems to reflect a simplification of engineering into "…a context in which students can test their developing scientific knowledge and apply it to practical problems" (National Research Council, 2012). Although potentially satisfying the vision of depth over breadth in STEM content, the simplification of engineering design to an applied science context obscures the distinct epistemologies and complicated histories of an entire discipline (Cunningham & Kelly, 2017; Gunckel & Tolbert, 2018; Moore et al., 2015). Granting this imprecision, the NGSS enacts expectations for engineering teaching and learning in formal settings. To meet these expectations and genuinely support youth in engineering work, this work demonstrates that an in-depth study of what it means for youth to engage in engineering is necessary. Learning from focal youths' practice and discussions, working within and helping their communities was meaningful, driving engineering work that served their local parks. Gunckel and Tolbert (2018) call this framing of engineering through service the "dimension of care." This work joins their calls to center care and critique in engineering work. Further, defining these problems in a local place and critically examining them from multiple angles supported Elizabeth and Cassidy to "see the design space" around them and Mariabella, Cesar, and Mariabella to take ownership of the park's changes. To support all youths' engagement in engineering, this work supports calls to locate engineering work in local places, regardless of informal or formal setting (Nazar et al., 2019; Smith, 2002).

Future Directions: Building Bridges in Engineering

If we seek to develop engineering experiences into spaces where all youth belong, there is more work to be done by engineering educators to design toward this goal. Although supportive of building youths' design skills and connections to design work, engaging youth in real-world, messy design work is not the only answer for establishing meaning or purpose in building other technical engineering skills. What are the next steps? One direction would be to explore what type of experience would support youth like Elizabeth, Cassidy, or Mariabella to find technical skills, like coding or building, valuable and necessary. What would that experience require? How would that space draw on their experiences and identities? Conversely, for youth like Adina and Cesar, who already enjoy puzzling on codes or robotics builds, how might an engineering experience better situate these skills as necessarily driven by community need? Learning from focal youths' experiences in *Sensors* and beyond, several bridges are still to be built, one of which is connecting across all forms of engineering practice and content.

Another bridge to be built is better connecting design work to youths' lived experiences. Beyond exploring how youth participate in engineering spaces, it is also necessary to explore youths' engineering practice in everyday or home contexts. For example, in an early interview with Adina, she discussed how she problem solved while babysitting her cousins. She helped them resolve a fight, sharing that the information most necessary to her doing this was:

> …**What the problem really was**…because one of them wanted to play the game by themselves, one of them wanted to play a different game by themselves, and they were fighting because they wanted to play at the same time… They argue a lot, about a lot…**so I had to like focus on what the main problem was, which was, at the moment, it was the phone**. So, I had to see like…**how they could each have for the game, or how long the game would take for them to finish at least like 4 or 5 levels**…and then pass it on to the next person... (Adina Transcript, 06/30/2017).

In this instance, Adina engaged in a problem definition and delimiting practice within the context of her cousins' dispute (Crismond & Adams, 2012). Continuing to understand and make visible these types of connections between youths' everyday problem-solving experiences and canonical engineering practice is one direction for future research. Connecting to and building on youths' prior knowledge helps make visible critical skills necessary for engineering that they already practice in their lives (Moje et al., 2004). Eliciting youths' everyday knowledges may help align them to the discipline-specific knowledge and practice necessary for engineering design.

Another area to dig in more deeply are the interconnections between focal youths' racialized, gendered, and/or classed knowledge or experiences and their engineering-linked identities. While I only worked with seven focal youth, it is hard to ignore that three of the four participating girls in the study were disinterested in engineering at the time of their last interview, while the three boys remained interested. How do we better trace what happened in these girls' stories? What might we learn from them? Guided by the significant scholarship that has sought to connect engineering work with gender (Bix, 2004; Greenberg & Calabrese Barton, 2017; Pinkard et al., 2017), a set of next steps for my work are to examine how youths' perceptions of engineering as raced, class, and gendered operate in their identification with the field and their decision making about it. Further, how might we complicate these questions by engaging other theories (Avraamidou, 2020)? Employing intersectional frames to interrogate how youth like Mariabella, who identified as a working-class Latina from the Large Midwestern City, made meaning of engineering work over time can offer important, critical perspectives for educational design work.

Concluding Thoughts

A close study of the focal youths' engagement in *Sensors*, and their discussions of engineering beyond that, revealed several important directions for engineering experience design. Shaped by important people in their life, particular subject matters, their inclusive or exclusive experiences, or their knowledges of oppression in the world, each youths' profile is a layered collage of interrogating the designed world and belonging in engineering programs. In brief, what questions, ideas, and contributions are valued, elicited, and connected in youth engineering programs matters for youth engagement and for starting to deconstruct ways these programs might have previously been exclusionary (Gutiérrez et al., 2017). Moreover, how youth are seen, heard, and valued matters for youth engagement (Davis et al., 2020). I offer an imperative to look critically at how engineering is constructed in youth spaces, moving away from narratives that locate the lack of engineering diversity with some deficit in youth. Rather, if broadening participation and increasing diversity are goals, we also need to center diversity in youth engineering processes. When youth are positioned as stakeholders in their own education, we might better design experiences that support their needs, not just that of the field. Broadly, I argue for a continued reframe around who design is for: Youth are the key stakeholders in engineering education.

APPENDICES

Appendix A Sample Stimulated Recall Interview

Part A. Engineering Story Youth Interviews
~ 1.5 hour Interview

Talk to me about you. How would you describe yourself?
What do others want for you in 10 years?
How are you trying to get to these goals?

Stories
What is engineering?
What are the parts of engineering?
I've heard you say that you don't like engineering before. Can you talk to me about that?
In previous conversations you've discussed caring more about people then technology. Can you say more about that? Do you see that as separate from engineering?
Do you consider the work we've done in *Sensors* engineering?

Reflection
Engineering is an important part of my out-of-school life because…
What I like best about doing engineering work is…
Imagining
I am good at doing engineering because…
I want to be better at engineering because…
Engineering is helpful for me in these ways…
Aligning
What do I do in engineering that engineers do? Engineers don't do?
What most important in doing engineering work? What is least important?

Part B. Stimulated Recall Interview Plan and Protocol

Criteria for Video Selection

- 3 ~10 minute sections of video [selected from the same year of programming]
- Parallel clips across years
- [Question: Is this a separate interview? Do I focus on one of my identified spaces? Do I let youth determine?]

Spaces for determining video [based on programming design and literature]

- Analytical Space: Defining problems [potentially carry this space over time]
- Research Space: Collecting and/or Analyzing Data
- Creative Space: Developing a Solution

Connective Question Example: “Thinking work” You once described the work in “*Sensors in a Shoebox*” as “thinking work.” Reflecting on that, how do you feel now?

Reflecting on Activity [Selected snippets across time]
Talk to me about what you are doing in this clip. What's this activity?

- Prompt: What do you remember?
- Prompt: Why were you doing this activity?

What do you remember thinking about this activity as you did it?
What do you remember feeling about this activity as you did it?
What did you like about this activity?
What did you dislike about this activity?
I heard you say/I noticed, “…” Could you tell me more about that?
When I saw you do/heard you do, “…,” I thought, “…”. What do you think about as you watched or listened?
What do you get out of this activity?

- What aspect of it was meaningful to you? What wasn’t?
- How did this activity help you personally, if at allt?
- How did this activity help your community, if at all?

What other moments in our *Sensors* work did this make you think about? What were some of the parts of our work that stood out (but aren’t necessarily from this video)?

Appendix B Sample Focus Group Interview

Sensors in a Shoebox Focus Group
Final Protocol
Roughly 30 mins

We have been working on the *Sensors in a Shoebox* program now for a while, and we'd like to ask you all some questions in the group to see how it is going. Please feel free to answer honestly, and openly. We'd like your feedback to continue to improve the program and for our own insight. If you don't feel comfortable sharing in the group, that's fine too! You can speak with us after the group or set up another time with us to speak. Finally, please keep in mind that this discussion is confidential and should not be discussed outside the group.

Questions about the Project

1. To start us out broadly, how would you describe the project you worked on with *Sensors in a Shoebox* to someone who didn't know what it was?
2. How would you describe your initial expectations of the project?
    a. How did you feel as you started this project?
3. Thinking about where you started this project at, how does it feel at the end of this project?
4. How would you describe your personal goals for the project?
    a. How important do you feel these goals are?
5. ***How would you describe the goals of *Sensors in a Shoebox*?
    a. Are these goals the same or different from the personal goals you spoke about?
6. How do you feel like you worked toward these goals? Did you accomplish what you set out to do?
7. Thinking about your process, what was a challenge that you experienced (either personally or as a group)?
    a. Why do you think it was a challenge?
    b. What could have made it better?
8. Thinking about your process, what was a success that you experienced (either personally or as a group)?
    a. Why was it successful?
    b. What might have made it even better?
9. How does this work feel like engineering? How does it not?
10. Leaving this process, what is one thing you're taking with you that feels important or you didn't know before?
11. Has this process changed how you view [the Large Midwestern City]? If so, how?

Questions about the Program

12. How has *Sensors in a Shoebox* met your expectations?
13. How has *Sensors in a Shoebox* not met your expectation?
14. ***How would you describe the goals of *Sensors in a Shoebox*?
    a. Are these goals the same or different from the personal goals you spoke about?
15. Would you be interested in continuing with *Sensors* in the future? Why or why not?
16. Is there anything else you'd like to share?

Appendix C Sample Walking Interview

Interview Protocol for Problem Definition

1. Think of a time you've solved a problem in your own life. Could you tell me about it?
    a. PROBE: How did you know it was a problem?
    b. PROBE (if struggling to come up with a problem): Let's think about when we were thinking about what we wanted to study with sensors. The problem we were solving was what do we want to study.
2. Thinking of the same time you've solved a problem: What steps did you go through to solve the problem?
    a. PROBES: How did you collect information to solve the problem? Who was important in solving this problem? How did you know the problem was solved?
3. Thinking about the same problem, what types of information were important to define that problem (clarification: to understand the problem)?
    a. PROBE: Why were these information types important? How did they help you define the problem?
4. (If their own example was provided) In thinking about the example, you gave, why did you choose it?
    a. How was solving this problem important to you?
5. How comfortable do you feel solving problems, in general?
    a. PROBE: Why do you feel this way?
    b. PROBE: What about solving problems do you specifically like? Dislike?
6. In SiS, we talked a lot about facts, opinions and data. In general, whose opinions are important when defining problems? What opinion matters most?
7. How would you describe an engineering problem? How is it similar or different than other types of problems?
8. How does the word problem make you feel? How does the term engineering problem make you feel? Do these two terms feel different?
9. In SiS, we worked a lot on the problem we were wanting to study. We had different ideas, and had different locations. Why would have been important to think about location, ideas, people, ect.?
10. (If own problem is provided above) From your own experiences, and your experiences in SiS, how would you describe the work we did to figure out what problem to work on?

I'd like to switch gears from talking about problem solving to talking about engineering more generally.

11. If you had to give a formal definition of engineering, what would you say?
    a. Where does this definition come from?
    b. What makes you think that?
    c. Do you know any engineers?
    d. How is engineering different from science?
12. What do engineers do?

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