Abolitionist Engineering: An Autoethnographic Approach to Understanding How Abolition Can Transform Materials Science and Engineering

by

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Dedication

To those that have, are, and will continue to caretake hope and engineer the life-affirming infrastructures that keep us alive and present.

Acknowledgements

Hundreds of people and interactions have guided me among this journey and this work is an impossibility materialized as a result of those relationships. They have expanded my imagination of what this world is and could be while shown me ways of being that bring it into reality. There are many people for me to thank. While at UM, the folks I've met through CAWS, GEO, SFTP, RG, ESJP, and other organizing spaces that have taught me how to be in shared struggle. Melvin Parson at We the People Opportunity Farms for changing the soil in my life and helping me learn from the land. The Coleman family for how they've embraced me and Niarra for the ways we've grown together and holding me accountable for getting this done. My roommates over the years Paul, Izzy, Reggie, and Phil. My fellow grad student workers and friends in MSE. The folks in grad-SHPE. The folks in EER 601 and 602 for the perspective on what this field could be. The folks in the Sakamoto lab and my collaborators. The scholars and writers whose works have challenged and reshaped my perspectives. The funding sources of the Department of Energy, Joint Center for Energy Storage Research, University of Michigan Rackham Merit Fellowship, and the Bill & Melinda Gates Foundation.

At MIT, the B-Entry folks, EVT folks, and the MSE community.

Back home in Miami, FL, my parents and the rest of the Valles, the Bilskers, the Serranos, the Garcias, Richard, Dayana, Yadira, Ms. Reyes, Ms. Miriki, Ms. Donohue, Mr. Hernandez, Ms. Pallidine and my Cambridge Global Studies Academy peers at Braddock. Y'all have shown me love that has kept my spirits high through tough times.

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Abstract

Climate change is pushing many ecosystems toward collapse, bringing irreversible consequences for life on Earth. Climate change is driven by colonial relations and the undermining of Indigenous sovereignty; however, I posit that this understanding is not reflected within dominant materials science and engineering (MSE) specifically and dominant engineering more broadly. The research problem addressed in this study is how the assemblage of dominant engineering enacts performances structured to separate Indigenous land from life, focuses on properties that expand industrial complexes rather than transforming material conditions to affirm life, and upholds processes that refuse accountability to sociopolitical and socioecological contexts of dominant engineering labor in order to maintain the U.S. settler colony. I leverage a theoretical framework of queer theory and abolition to unpack relationships among settler colonialism, heteropatriarchy, and dominant engineering. In doing so, I discuss the narrow set of ways of knowing and ways of being legitimated within dominant engineering and how I have come to understand them as incommensurable with my relationships and obligations. I put in conversation conceptual frameworks of the materials tetrahedron as a representation of relevant relationships within dominant MSE, the concept of a third university from la paperson that holds a mission of decolonization, and a prototype engineering inquiry ecosystem that (re)centers the purpose of engineering inquiry as liberation/land back.

I use the self-study methodology of autoethnography alongside the scientific method to tell stories rooted in my experiences as a settler labor organizer, community organizer, MSE student worker, and engineering education researcher at and around University of Michigan –

Ann Arbor. As an electrochemical energy storage (battery) researcher, I studied impacts of changing lanthanum content in the lithium lanthanum zirconium oxide (LLZO) structure Li6.5La2+xZr1.5Ta0.5O12 and observed an increase in ionic conductivity from 0.649 mS/cm at x=0.2 to 0.789 mS/cm at x=1.0. Transitioning to a sodium solid electrolyte NASICON, I observed that changes in particle morphology from spray drying and heat treating NASICON particles at 900C resulted in an increase in total ionic conductivity from 0.292 mS/cm to 0.596 mS/cm. Methodological incommensurabilities of that labor with undoing relationships driving climate change pushed me to take accountability for harm I have been complicit in through studying within this dominant construction of engineering. I propose abolitionist engineering as a paradigm shift from dominant engineering capable of transforming the conditions and behaviors structuring harm in dominant engineering. I offer a deconstruction of dominant engineering, discussing its relationship to the maintenance of the U.S. settler colony through a metaphor from higher education studies called the house modernity built as well as the assemblage of an engineering-industrial complex. I discuss abolitionist labor organizing as a means of transforming harm that dominant engineering perpetuates, rooting in experiences of engineering student workers that participated in an abolitionist labor strike to name strikes as a form of liberatory pedagogy for engineers. Finally, I offer an example of how an abolitionist MSE education lesson might look by connecting crystalline ‘defects’ from dominant MSE to sociological theories of change used in a workshop series aimed at undoing barriers multipli-marginalized engineering undergraduate students face in bringing their whole selves into engineering spaces. From that lesson I propose a nucleation and growth theory of change to shift from dominant engineering to abolitionist engineering alongside life-affirming technologies like mutual aid and taking responsibility for normalized harm in institutions.

Chapter 1 Introduction

> "I acknowledge that the University of Michigan, named for Michigami, the world's largest freshwater system and located in the Huron River watershed, was formed and has grown through connections with the land stewarded by Niswi Ishkodewan Anishinaabeg: The Three Fires People who are the Ojibwe, Odawa, and Potawatomi along with their neighbors, the Seneca, Delaware, Shawnee and Wyandot Nations. I encourage others to acknowledge the original peoples of this land and to cultivate relations of accountability and active decolonization that reflect this acknowledgment."

The above land acknowledgement has been a part of my University of Michigan email signature line for a couple years now, coming by way of an Anishnaabe scholar at UM. Anishnaabe writer Hayden King describes that

> "A territorial [or land] acknowledgement, as they have evolved, is sort of a political statement encouraging primarily non-Indigenous people to recognize that they're on Indigenous land and hopefully do something about it.
>
> It's sort of an intervention into the business-as-usual conversations that are held in universities or government where we typically see these land acknowledgements." (CBC Radio, 2019).

My acknowledgement of the land that I have been studying and working on as a graduate student worker at UM and the Indigenous nations that steward it reflects obligations that I am continually learning how to be in better relationship with as a settler in the settler colony of the

United States. I was born in Miami, FL, traditional homelands of the Tequesta and Calusa and today home to the Seminole Tribe of Florida and the Miccosukee Tribe of Indians of Florida (FIU Global Indigenous Forum, n.d.). I am the child of Ruth Bilsker-Valle and Genaro Valle, white Jewish and Brown settlers themselves born in Miami, FL to immigrants from Mexico, Puerto Rico, and present-day Belarus. Many of the connections I have to the lands of my grandparents and generations before them have not been maintained over the years, and my knowledge of family history does not extend far beyond immigration stories. Growing up I held the assumption that because I was a citizen of the United States living within the territory of the United States, the lands I grew up on were my lands. My understanding of Indigenous peoples was shaped by harmful stereotypical media portrayals “frozen in time” and seeing Miccosukee and Seminole casinos when we’d take trips to the Everglades or drive up the Florida Turnpike toward Broward County rather than any significant interpersonal relationships (Leavitt, Covarrubias, Perez, & Fryberg, 2015). Acknowledging whose land I am on in graduate school has led me down a path to understanding otherwise. As Tuck and Yang describe in *Decolonization is not a Metaphor*,

> “In order for the settlers to make a place their home, they must destroy and disappear the Indigenous peoples that live there. Indigenous peoples are those who have creation stories, not colonization stories, about how we/they came to be in a particular place - indeed how we/they came to be a place,” (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 6).

I grew up in a working-middle class, predominantly Latinx suburban neighborhood in the same 3-bedroom house from birth until leaving for undergraduate studies. My grandmother, Juana Valle, lived in a house down the block from me and often babysat me. She was a short, Brown Mexican woman with graying, braided black hair, a calm and soothing demeanor that seemed to always let stress just slide off, with a way of nursing back to health just about any animal you brought her. My parents and grandmother taught me ways of being in the world that aimed at making it a better place. I attended Miami-Dade public schools from pre-K at 3 years old through high school and was generally a straight-A student with a supportive learning environment at A-grade schools. I was raised a boy and felt cared for by family, teachers, and friends. In elementary school I had a tendency to cause trouble because I did not feel challenged in the classroom. I was not often punished for such behavior, likely because I was a white and male presenting child and my mom knew many of the school instructors and staff from her time working there (Rosenfeld, 2013). As a child I enjoyed playing basketball, going out to the beaches and parks to be in nature with my mom, watching the Miami Heat and Miami Dolphins on tv with my brother James and dad, and playing video games. Growing up I thought I wanted to be a football player for the Miami Dolphins or a historian, because my brother was pursuing a degree in political science at Florida International University (FIU) up the street and would continually talk about U.S. history and current political events.

My mom was a unionized special ed teacher turned curriculum support specialist for the school system and my dad a unionized repair technician at the power company. My dad was a kind, caring, tall, fit Brown man with black hair who was proud of my academics, enjoyed watching me play basketball with my brother as my coach, kept our lawn well mowed, looked after his mom and family, and always seemed to have a smile on his face. He did that all while working long hours, leaving for work in his blue uniform and brown boots with his blue work bag he'd usually keep in our bathroom before I'd wake up and often working overtime to give us financial stability he didn't have growing up. When I was in middle school, he got diagnosed with and died of cancer, a premature death that altered all of our life trajectories. I believe overworking was a large contributing factor to his death.

At our house after his wake, I remember meeting many of his work buddies who I'd heard of but never met before, all singing his praises. I remember being presented with his work helmet, signed by all of them along with a collection they'd struck up and given to my mom. Although I didn't know it at the time, I've now come to understand that as the power of a union, the solidarity that comes from supporting each other as workers especially during times of hardship. His death had come in 2009, the year after the recession kicked in. His union had won the health insurance that allowed him to get treatment, had folks looking after him when he was still going into work, sick days and paid leave for when he could no longer work, and life insurance that kept us afloat after he died. Without any of that, I know that I wouldn't be here as a graduate student worker today. That recognition has been a driving force for why I have organized with my own labor union, the Graduate Employees' Organization American Federation of Teachers Local 3550 (GEO), moving from member to departmental steward to officer to union president as a way for me to honor his memory and care for others. When we went on strike in Fall 2020 to counter conditions of premature death our employer UM was exposing people to, I wore that helmet every day on the picket lines. This will be discussed more in chapter 7.

His death also left me trying to wall off a lot of emotions, which led me to put my energy toward my school work and got me a spot in the Cambridge Global Studies Academy magnet program for high school. In high school I quickly recognized I had a knack for science and my physics teacher Ms. Reyes was also the advisor for our high school's engineering club. Her room was one of the hangout spots that made it easy to just start tinkering around with whatever she had in the back during class, if we were heading to her room to skip, or after school. The clear cut, right/wrong answers in science gave me a sense of accomplishment since I often would get them right, and particularly the balsa wood bridge building competitions in engineering club gave me a creative outlet and way to iterate on designs. At the same time, I could develop the interest in the environment my mom had instilled in me through helping revive the recycling program at our school. It was those sorts of experiences coupled with the science classes I had talking about global warming and conservation that helped me form a conviction in high school that I carried through to grad school. I knew that the skills and abilities I had in physics, chemistry, and engineering could be applied toward renewable energy, specifically electrochemical energy storage research, as a way to combat climate change and make the world a better place. Conveniently, purposefully, it didn't require me to reflect on my own ways of knowing and being, since that subjectivity doesn't really matter in dominant engineering.

In my undergraduate studies at Massachusetts Institute of Technology (MIT) I was introduced to the sort of abundance that comes from a massive university endowment, tons of research dollars, and low barrier access to millions of dollars' worth of equipment. Early on I joined the MIT Electric Vehicle Team (EVT) and was able to get trained on machines like band saws, drill presses, welders, mills, lathes, water jets, and other computer numerical control (CNC) machines to take design from paper to Solidworks to fabricated parts and assemblages. EVT gave me a way to work on the application end of batteries as a compliment to the battery synthesis work I was learning about in classes and in research opportunities, but more importantly I kept coming back for the sense of community. Most of the other core team members were Latinx or other Black, Indigenous, People of Color (BIPOC), so we'd often have Reggaeton blasting in our shop space in the Edgerton Center just down the street from main campus and we’d frequent our sponsor Beantown Taqueria which was out in front of the shop. While lab classes gave me the opportunity to use some of these tools more toward my third and fourth year, EVT offered opportunities to plan out longer term, multi semester/year projects like designing battery mounting systems for an electric car conversion. Those sort of resources and environment gave me the impression that you could design and build anything you want to, where the problem solving seemed more oriented around what can we do instead of why we might be interested in doing it in the first place or what the impacts might be. Most of my coursework that allowed for those sorts of questions came in my first year, with an optional course on principles of engineering practice that I took as well as an optional summer course that included investigating environmental impacts using life-cycle assessment (LCA) software. As I progressed through coursework over the years, the technical nature of my engineering courses arched the problem solving more toward technical considerations and solutions, leaving the questions of why these technical solutions might be the most preferred faded into the background.

What my graduate studies have shown me is that there are many forms of good that can be done in the world, but the forms that shaped my conviction around ‘renewable’ energy and that I’ve engaged in through my education and research in dominant materials science and engineering are maintained by ignoring many harmful relationships. In a way, I knew this all along and just chose to ignore it, playing innocent in order to avoid confronting harms and the violence maintaining those harms. I was engaging in what Tuck and Yang describe as a settler move to innocence, “those strategies or positionings that attempt to relieve the settler of feelings of guilt or responsibility without giving up land or power or privilege, without having to change much at all,” (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 10). What connecting with organizing spaces and the folks in them like the Collective Against White Supremacy (CAWS), Science for the People (SFTP), and GEO allowed me to do was unsettle that innocence, gain a sense of how to cultivate relationships of accountability, and act to transform the conditions that both allow for the maintenance of that innocence and the violence it seeks to hide. They gave me a way to be in my integrity, finding greater alignment between my actions and my values. They were also some of the first spaces I got to be in with a bunch of other queer people, helping me shape a politics around my identities that dominant engineering simply did not allow for. The care work of so many fellow organizers and friends helped me transition down this path and work through the pit in my stomach of feeling like what I was doing and how I was being was wrong, but not knowing really why or what to do about it.

As IPCC reports signal dire, irreversible consequences for inaction around climate change as many ecosystems near collapse, in the U.S. police budgets are ballooning amidst growing calls to defund and abolish the police, more oil infrastructure is being built, wages are suppressed, white supremacists and fascists are shooting up Black grocery stores and Brown schools, trans rights and abortion rights are being stripped, a housing crisis grows, global supply chains are being strained, and the COVID-19 pandemic rages on. All of these are interconnected through centuries long legacies of colonial violence that dominant engineering actively maintains, 'renewable' energy technologies and all. The Red Nation frames the choice ahead of us as decolonization or extinction, discussing in *The Red Deal* that, "if they weren't before, our eyes are now open: the police and the military, driven by settler and imperialist rage, are holding back the climate justice movement," (The Red Nation, 2021, p. 8). Rather than the sort of quick technological fixes pushed in dominant engineering, they highlight how "we need a revolution of values that recenters relationships to one another and the Earth over profits," (The Red Nation, 2021, p. 13). They focus on caretaking, naming that

> "While making up only 5 percent of the world's population, Indigenous peoples protect 80 percent of the planet's biodiversity. Indigenous peoples and local communities who have distinct cultural and social ties to ancestral homelands and bioregions still caretake at least a quarter of the world's land," (The Red Nation, 2021, p. 24).

This thesis offers reflections on the winding path I've taken away from dominant engineering toward abolitionist engineering as a means to "recenter relationships to one another and Earth over profits," (The Red Nation, 2021, p. 13). In doing so, I discuss dominant engineering as a way to keep the power relations within engineering front and center (Liboiron, Pollution Is Colonialism, 2021a). In chapter 2, I work through ways of knowing and ways of being, including the forms that are acceptable within dominant engineering, and how I understand relationships between those ways of knowing, ways of being, settler colonialism, and heteropatriarchy. From there I shape a theoretical framework of queer theory and abolition that connects conceptual frameworks discussed in chapter 3 of the materials tetrahedron, a third university, and a liberatory engineering education model. I engage autoethnography as a storytelling methodology, using a personal narrative structure I learned and leveraged as an organizer to stitch together and contextualize publications I've taken part in within both materials science and engineering (MSE) through the scientific method and engineering education research (EER), described in chapter 4. In chapter 6, I offer a deconstruction of dominant engineering, demonstrating a need to decouple engineering from industry and reconfigure its relationships to the state, framing labor unions as one means to do so in chapter 7. In chapter 8, I unpack the Undergraduate Engineering Collaborative Growth Series (UECGS) as a workshop series training undergraduate engineers in organizing skills, make connections to coming out as non-binary, queering concepts within dominant MSE to shape an infrastructural, nucleation and growth theory of change, and offer life-affirming technologies that have a place in abolitionist engineering and are disregarded within dominant engineering. Throughout this thesis when I speak in general terms, they are contextualized in my relationships from Michigan, Massachusetts, and Miami, FL within the U.S. and aren't intended to make global sense (Liboiron, Pollution Is Colonialism, 2021a).

Chapter 2 Theoretical Framework: Queer Theory and Abolition

This chapter moves through an introduction of ways of knowing and ways of being in major paradigms found in academia moving to a focus on engineering ways of knowing. From there, I discuss Indigenous critiques of Euro-Western meta understandings that separate ways of knowing from ways of being and uphold settler colonialism, setting a stage for discussing interconnections between settler colonialism, racial capitalism, and heteropatriarchy. I introduce queer theory and abolition as the theoretical framework used throughout this dissertation and the basis for understanding and navigating these interconnections. Building from this theoretical framework, the central research questions of the dissertation are presented at the end of the chapter.

2.1 Epistemologies and Ontologies in Paradigms

It wasn’t until I learned more formal educational theories in the 4th year of my PhD that I could better use the language of the academy to contextualize the gap that felt like it’d grown into a chasm between the ways I was tangibly, qualitatively experiencing how to improve living and working conditions and how I was being and had been professionalized to do so as a materials scientist and engineer. Through engineering, I was ostensibly acting to make the world better but doing so in ways that pushed me to repress many relationships to the communities and conditions I am embedded in. The chasm turned from an impassable divide to a set of barriers, a problem that in and of itself could be and had been studied as I experienced concientização, or a process of critical consciousness raising (Freire, 1970). That’s what I understood engineering education research (EER) to allow for, that shifting of perspective, and my first EER class helped me put form to that feeling by offering ways to integrate the other forms of education I'd been engaging with outside of the disciplinary borders constraining materials science and engineering. In EER 601: Foundations of Engineering Education Research, I learned about the terms epistemologies and ontologies, orientations on the nature of knowledge and reality or ways of knowing and ways of being. Concurrently, engaging in a strike as liberatory pedagogy by being present in the significance of the work we were doing in the Graduate Employees' Organization (GEO) pushed Corin Bowen (Corey) and I to send a cold email to Donna Riley (Donna) and formed collaborations that resulted in my first two EER papers: *Liberatory Potential of Labor Organizing in Engineering Education* and *Experiences of Engineering Students Participating in an Abolitionist Labor Strike* (Valle, Bowen, & Riley, Liberatory Potential of Labor Organizing in Engineering Education , 2021); (Valle, Ali, Bowen, & Riley, 2021).

Epistemologies and ontologies gave me language for metaunderstandings that are structured in such a way that make my and many other folx's ways of knowing and being in the world illegible within the disciplinary bounds of dominant engineering fields. This language and the readings it came from denaturalized that structuring, showing it as a foundation for the chasm I perceived and one paradigm amongst many. A paradigm is an assemblage of assemblages, a construct, where relationships amongst component parts of an assemblage are not permanent, stable, or fixed, but rather fluid, exchangeable, or otherwise alterable. Looking toward qualitative research shows four major interpretive paradigms, combinations of epistemological, ontological, and methodological premises formed into a framework, see Table 1 (Merriam, 2009). A positivist/postposivitist paradigm constructs reality as objective, singular, and external to the researcher with a function to predict, control, and generalize knowledge. A constructivist or interpretivist paradigm constructs reality as multiple and contextually bound in the subjective, where knower and responder or subject and object cocreate understandings. A constructivist or interpretivist paradigm typically has a purpose of describing, understanding, and interpreting knowledge. A critical paradigm also constructs reality as multiple and bound in the subjective alongside a constructivist or interpretivist paradigm, where a critical paradigm situates the subjective within political, social, and cultural contexts where one reality is privileged. A critical paradigm holds a purpose of critiquing and challenging dominant conditions toward transformation and empowerment. A post + (e.g. poststructural, postmodern, postcolonial) paradigm emphasizes a social construction of social reality, where identities are fluid as opposed to fixed and all truths are partial, generally with a purpose of deconstructing, problematizing, questioning, and interrupting existing conditions. Poststructural/ postmodern/ postcolonial paradigms engage inquiry that "would question and 'disrupt' the dichotomies (for example completer-noncompleter, successful-unsuccessful, graduate-dropout) inherent in the research problem," (Merriam, 2009, p. 12) that finds alignment with queer theory discussed later in this chapter. Constructivist, Critical, and Poststructural paradigms are considered incommensurable with positivist forms, meaning they do not share a common understanding or basis for judgment with positivism, while they can find commensurability amongst each other (Guba & Lincoln, Ch. 8 Paradigmatic Controversies, Contradictions, and Emerging Confluences, 2005). Understanding that incommensurability of positivism with constructivist, critical, and poststructural paradigms in particular showed me why I had felt a gap, as positivism is the dominant paradigm engineering is taught through within academia as the dominant location for legitimized engineering education in the U.S.

Table 1: Epistemological Perspectives, reproduced from (Merriam, 2009, p. 11).

	Positivist/ Postpositivist	Interpretive/ Constructivist	Critical	Postmodern/ Poststructural
Purpose	Predict, control, generalize	Describe, understand, interpret	Change, emancipate/ empower	Deconstruct, problematize, question, interrupt
Types	Experimental, survey, quasi-experimental	Phenomenology, ethnography, hermeneutic, grounded theory, naturalistic/ qualitative	Neo-Marxist, feminist, participatory action research (PAR) critical race theory, critical ethnography	Postcolonial, poststructural, postmodern, queer theory
Reality	Objective, external, out there	Multiple realities, context-bound	Multiple realities situated in political, social, cultural contexts (one reality is privileged)	Questions assumptions that there is a place where reality resides, “Is there a there there?”

As a component of a multidisciplinary inquiry on engaging future engineers, Figueiredo, writing in the 100th anniversary issue of the Journal of Engineering Education, posits four intertwined, transdisciplinary dimensions of engineering, see Figure 1 (Adams, Evangelou, English, & al., 2011). Along with Holly Jr., while I don’t completely agree with the framing of these dimensions, I find this model helpful in discussing the transdisciplinary nature of engineering (Holly Jr., "Of The Coming of James": A Critical Autoethnography on Teaching Engineering to Black Boys as a Black Man, 2018). Each of these four dimensions and shifts in framing are discussed in the following paragraphs.

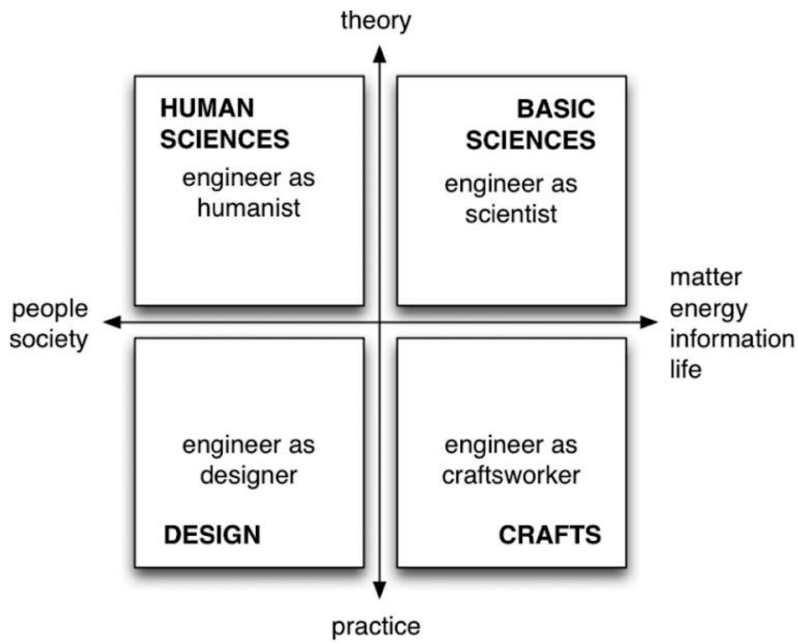


Figure 1: The four dimensions of engineering as presented by Figueiredo, reproduced from (Adams, Evangelou, English, & al., 2011).

According to Figueiredo, in the basic sciences dimension, a positivist epistemology is engaged to apply natural and exact sciences, valuing the discovery of first principles (Adams, Evangelou, English, & al., 2011). Liboiron names how the labor framed as "discovering" scientific phenomena is really laboriously crafting phenomena in ways that maintain the power of universalism, discussed further in chapter 6 (Liboiron, Pollution Is Colonialism, 2021a). It is important to recognize that there are a multitude of other epistemologies through which what is referred to here as basic sciences are engaged with (e.g. Indigenous science (Hernandez, Fresh Banana Leaves: Healing Indigenous Landscapes Through Indigenous Science, 2022) and anticolonial science (Liboiron, Pollution Is Colonialism, 2021a)).

In the human sciences dimension, Figueiredo discusses engineers existing as social experts, managers, and businesspeople recognizing the social complexity of our positions

(Adams, Evangelou, English, & al., 2011). A component of this thesis discussed in chapter 7 reflects my understanding that this expectation of engineers as managers and businesspeople should instead be replaced with community and/or union organizers (Valle, Bowen, & Riley, 2021) (Valle, Ali, Bowen, & Riley, 2021). This dimension centralizes values of satisfaction of the end users and the creation of social and economic value. In chapter 3, I discuss a liberatory engineering education model (LEEM) prototype centrally valuing liberation/land back.

In the design dimension, systems thinking holds a higher value than analytical thinking while existing as a contested space between positivist and constructivist paradigms (Adams, Evangelou, English, & al., 2011). The design dimension values compromise, leveraging non-scientific thinking as necessary, and using intuition and experience as guides to decision making in the face of incomplete knowledge. Owing to the commensurability of constructivist paradigms with critical and post+ paradigms, this contested space reflects the incommensurability of positivism with nearly all other ways of knowing, including those not encompassed within constructivist, critical, and post+ paradigms (Guba & Lincoln, Ch. 8 Paradigmatic Controversies, Contradictions, and Emerging Confluences, 2005).

The dimension of engineering as craft holds a focus on getting things done, valuing the ability to change the world through overcoming resistance and ambiguity (Adams, Evangelou, English, & al., 2011). As Figueiredo notes, considerable conflicts in values, methodologies, and goals can be anticipated and emerge amongst these dimensions in this transdisciplinary space. This names the transdisciplinary space of engineering as contested terrain as opposed to a positivistic monolith. Importantly, the dimensions of engineering are demarcated along lines of theory to practice and matter, energy, information, and life to people and society. Often within engineering these dimensions are considered separable, where one of the ideologies upholding this separability is technical/social dualism.

2.2 Epistemology-Ontology Divide

Cech and Waidzunas describe technical/social dualism as a central ideological component of the dominant engineering identity (Cech & Waidzunas, 2011). A false distinction in practice, this dualism acts as “ideological separation between ‘technical’ activities and skills (such as design, science, and math-related activities) and ‘social’ tasks and skills (such as management, communication with other employees and clients, etc),” (Cech & Waidzunas, 2011, p. 4). Cech also describes how this dualism combines with an ideology of depoliticization that externalizes sociopolitical issues and is reinforced by an ideology of meritocracy (Cech E. A., 2013). Meritocracy, a belief that success is the result of individual talent, training, and motivation, acts to minimize reflections on the conditions and contexts engineers exist in. While theoretically a push toward diversity, equity, and inclusion (DEI) exists within dominant engineering, the actions and ideologies upheld within dominant engineering drives a dissonance. Freire discusses action and reflection upon the world in order to transform it as praxis, a key component of liberation that dominant engineering distorts through a positivist paradigm (Freire, 1970).

Vanessa Watts discusses a dissonance between theory and praxis as an epistemological-ontological divide, naming how “frameworks are designs of understanding and interpretation. They are the basis for how humans organize politically, philosophically, etc. Frameworks in a Euro-Western sense exist in the abstract. How they are articulated in action or behavior brings this abstraction into praxis; hence a division of epistemological/theoretical versus ontological/praxis,” (Watts, 2013, p. 22) Grounding in the historical accountings of the

Haudenosaunee and Anishnaabe, Watts discusses how there is an inseparability of theory from praxis within Haudenosaunee and Anishnaabe frameworks, focusing on the spiritual, feminine, and the agency of Land. Land here is capitalized to denote “the unique entity that is the combined living spirit of plants, animals, air, water, humans, histories, and events recognized by many Indigenous communities,” (Liboiron, Pollution Is Colonialism, 2021a, p. 7) Watts discusses these theoretical understandings of the world via physical embodiment as Place-Thought, “based upon the premise that land is alive and thinking and that humans and non-humans derive agency through the extensions of these thoughts,” (Watts, 2013, p. 21). The understanding of humans as extensions of the Land drives an obligation to communicate with the Land. Watts puts this understanding in comparison to a Euro-Western meta-understanding in which agency is limited to humans in Figure 2.

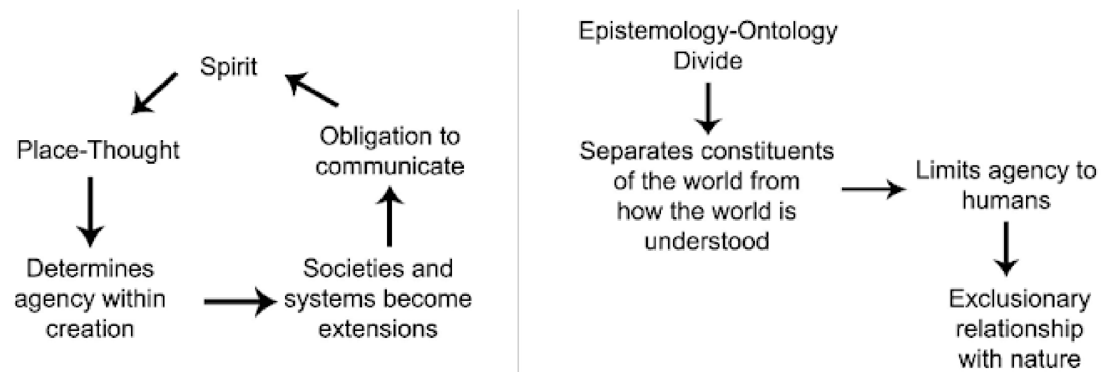


Figure 2: "a visual representation of [Haudenosaunee or Anishnaabe and Euro-Western] framings. On the left is a depiction of how an Anishnaabe and/or Haudenosaunee cosmology might be represented. On the right, the process by which a Euro-Western meta-understanding can contribute to colonization of these Indigenous cosmologies," (Watts, 2013, p. 22).

The technical/social dualism within the positivist paradigm drives a division between the object of inquiry from its subject, separating constituents of the world from how it is understood. The way I’ve learned this through my education in materials science and engineering is the commonplace notion that *everything* is a material, a representation of an exclusionary relationship with nature enabling us as researchers to manipulate materials in whatever way we see fit as we limit agency only to ourselves. This exclusionary mentality is deeply connected to and drives a colonial understanding of land as resource, separate from life, depoliticizing notions of property to invisibilize a "parasitic and genocidal relationship to Indigenous and Black peoples," (King, 2019, p. 68) cited in (Liboiron, Pollution Is Colonialism, 2021a, p. 9). As la paperson discusses, this dualism acts to separate land/life, where "land/life is shorthand I use to emphasize that land/life are in relation within Indigenous cosmologies but are actively being separated by colonizing operations," (la paperson, 2017, p. 5).

Leanne Simpson discusses how the frameworks generated by the place-based practices and knowledge of Place-Thought form the base of Nishnaabeg

> "political systems, economy, and nationhood, and it creates process-centered modes of living that generate profoundly different conceptualizations of nationhood and governmentality - ones that aren't based on enclosure, authoritarian power, and hierarchy … this *procedure* or practice of living, theory and praxis intertwined, is generated through relations with Michi Saagiig Nishnaabeg land, land that is constructed and defined by our intimate spiritual, emotional, and physical relationship with it." (Simpson L. B., As We Have Always Done: Indigenous Freedom Through Radical Resistance, 2017, p. 23)

Kyle Powys Whyte argues how for many Indigenous peoples, injustice occurs when "the social institutions of one society systematically erase certain socioecological contexts, or horizons, that are vital for members of another society to experience themselves in the world as having responsibilities to other humans, nonhumans and the environment," (Whyte, 2016) Understanding the systems of oppression that structure social institutions in the society I exist within, particularly the academy as a social institution, can offer both a means of understanding how the socioecological contexts of other societies are erased, my complicity within those modes of erasure, and forms of agency I have within those structures to transform them. I understand dominant engineering as a key social institution for developing infrastructures toward this systematic erasure of horizons. As Max Liboiron names for the field of geoscience that I believe fits for dominant engineering as well, “we should accept that sometimes the anticolonial move is to stop,” (Liboiron, Decolonizing geoscience requires more than equity and inclusion, 2021b, p. 876)

2.3 Settler Colonialism

At the first meeting of Science for the People (SFTP) that I attended at UM, we held a discussion on Tuck and Yang’s *Decolonization is not a metaphor* (Tuck & Yang, Decolonization is not a metaphor, 2012). While at the time so much of it flew over my head, it is a text that I continually return to as a way to reflect on my own complicity in colonial violence and understand the structure of settler colonialism in greater detail. Structure is a core component of what is researched within dominant materials science and engineering, yet the structure of settler colonialism was never raised as a topic in my undergraduate and graduate coursework. Tuck and Yang discuss how postcolonial theories generally focus on two forms of coloniality, two operative modes of colonialism described as external colonialism and internal colonialism. External colonialism expropriates and extracts fragments of Indigenous worlds, animals, plants and human beings to build the wealth and privilege of colonizers. External colonialism often requires military colonialism, “the creation of war fronts/frontiers against enemies to be conquered, and the enlistment of foreign land, resources, and people into military operations,” (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 4). External colonialism recasts bodies and earth as natural resources, *everything* as a material to be manipulated. Internal colonialism focuses on the “domestic” borders of imperial nations and the biopolitical and geopolitical management of people, land, flora and fauna within them through modes of control.

Settler colonialism operates through both internal and external colonialism as there is no spatial separation between the nation-state exercising colonial power and the colony (Tuck & Yang, Decolonization is not a metaphor, 2012). Settler colonizers arrive with the intention of making a home on the land and exert sovereignty over Land. This intention is reasserted daily through occupation, an injustice upon which social institutions of systematic erasure are built. As Patrick Wolfe named in *Settler colonialism and the elimination of the native*, “settler colonialism is a structure not an event,” (Wolfe, 2006, p. 388) a structure which remakes Land into property. This remaking acts to sever Indigenous peoples from land, where land “(more general term) refers to landscapes as a fixed geographical and physical space that includes earth, rocks, and waterways; whereas, ‘Land’ (the proper name) extends beyond the material fixed space. Land is a spiritually infused place grounded in interconnected and interdependent relationships, cultural positionings, and is highly contextualized,” (Styres & Zinga, 2013, pp. 300-301) in (Liboiron, 2021a, p. 6). Settler colonialism exists in opposition to decolonization, described bluntly by la paperson as “the repatriation of land, the regeneration of relations, and the forwarding of Indigenous and Black and queer futures - a process that requires countering what power seems to be up to,” (la paperson, 2017, p. xv). Understanding settler colonialism as a structure makes space to understand the ways this structure is engineered through a set of technologies, its infrastructures, superstructures, and processes discussed further in chapter 6.

2.4 Settler-Native-Slave Triad

One set of technologies common in settler colonial studies is the settler-native-slave triad. The settler-native-slave triad uses a triadic analysis to undo the assumption that white supremacy is the centralizing component of oppression (la paperson, 2017). Instead, it places a focus on how everyone is complicit in ongoing colonization through varied participation in the colonization of other peoples and places. In the triad "settler", "native", and "slave" are not inherently identities, but more prominently describe different power relations with land as sites of exception. Their interactions offer a window into the underlying logic of settler colonial power, its superstructures, as each acts at a different scale and takes a different form. Table 2 shows the form of each site of exception along with the technologies sustaining each form.

Table 2: sites of exception in the settler-native-slave triad. The form that each site of exception takes along with the technologies that sustain those forms (la paperson, 2017).

Site of exception	Form	Sustaining Technologies
"settler"	Space - Juridical space of exceptional rights	Settler: citizenship, private property, civil and criminal innocence, normative settler sexuality
"native"	Land - World to be obliterated	Indigenous erasure: military material and methodologies to carry out terror or genocide or containment; frontier law that legitimates murder, rape, torture, and abduction; racial science of disappearance (such as blood quantum); the partitioning of earth into "natural resources" that can be

		separated, owned, sold, and developed; land privation, privatization, fungibility, and development; boarding schools and institutions of cultural assimilation; resource development and cultivation
“slave”	Corporeal - Ontology of total fungibility and unending property	Anti-Blackness: ontological illegality or criminal presence, landlessness, lethal geographies, carceral apparatuses, trafficking and abduction, non-personhood, the production of the Black body as in itself the pre-eminent site for anti-Blackness

The “settler” in the settler-native-slave triad is the “idealized juridical space of exceptional rights granted to normative settler citizens and the idealized exceptionalism by which the settler state exerts its sovereignty. The “settler” is a site of exception from which whiteness emerges. Whiteness is property; it is the right to have rights; it is the legal human; the anthropocentric normal is written in its image,” (la paperson, 2017, p. 10). The juridical space of the “settler” is a state, a settler state. Ruth Wilson Gilmore and Craig Gilmore describe a state as:

> “a territorially bounded set of relatively specialized institutions that develop and change over time in the gaps and fissures of social conflict, compromise, and cooperation. … states are ideological and institutional capacities that derive their legitimacy and material wherewithal from residents,” (Gilmore & Craig, Ch. 7 Restating the Obvious, 2013, p. 143).

The settler state maintains the settler colony, which I understand must be abolished on a path toward decolonization. As the Red Nation names,

> "Colonialism has deprived Indigenous people, and all people who are affected by it, of the means to develop according to our needs, principles, and values. It begins with the land. We have been made "Indians" only because we have the most precious commodity to the settler state: land. Vigilante, cop, and soldier often stand between us, our connections to the land, and justice. "Land back" strikes fear in the heart of the settler. But as we show here, it's the soundest environmental policy for a planet teetering on the brink of total ecological collapse. The path forward is simple: it's decolonization or extinction. And that starts with land back," (The Red Nation, 2021, pp. 6-7).

Some of the technologies that sustain the settler state la paperson identifies are citizenship, private property, civil and criminal innocence, and normative settler sexuality (la paperson, 2017).

The "native" in the settler-native-slave triad is a world to be obliterated and reconstructed into resources; the socioecological contexts or horizons systematically erased by the social institutions of the settler state (la paperson, 2017). As la paperson describes,

> "The "native" is a site of exception for that which and those who are written as premodern, primitive, and thus "before" law and "before" rights. The "native" is thus exceptionalized from having any recognizable laws or rights that matter in modernity," (la paperson, 2017, p. 10).

The notion that *everything is a material*, the tagline that for years would kick off how I described my major of MSE to people, to be manipulated in whatever way we see fit is revealed to be manufactured from technologies of Indigenous erasure. Dominant engineering materializes these technologies through industrial complexes, discussed in chapter 6. These technologies makes possible

> "not only the gathering of "natural" resources as assets but also the externalizing of the "cost" of the accumulation in the form of contaminated water, disease, and other traumas of the "natural," nonpropertied, that is, "indigeneous," world," (la paperson, 2017, p. 11).

One of the forms these externalized costs of technologies of Indigenous erasure takes is pollution. In Pollution is Colonialism, Max Liboiron discusses how "pollution is not a manifestation or side effect of colonialism but is rather an enactment of ongoing colonial relations to Land," (Liboiron, 2021a, p. 6). My electrochemical energy storage research produced a lot of pollution that went into white plastic hazardous waste bucket after white plastic hazardous waste bucket.

The "slave" in the settler-native-slave triad "describes how blackness is transfigured into enslavability and murderability," to be analyzed as

> "an ontology of total fungibility and unending property constitutive of the very world order of settler colonialism. That is, the logic of racial capital creates an indefinite being of property to be exchanged, to be shipped or stored, to be parted out, to be disposed," (la paperson, 2017, pp. 11-12).

Ruth Wilson Gilmore discusses this through the extractive nature of the prison, where what is extracted from those considered totally interchangeable, extractable, and extracted from their communities is the resource of life - time (Gilmore, 2017). Gilmore names that

> "criminalization transforms individualism into tiny territories primed for extractive activity to unfold - extracting and extracting again time from the territories of selves. This process opens a hole in a life, furthering, perhaps to our surprise, the annihilation of space by time," (Gilmore, 2017, p. 336)

Racial capitalism inextricably links racial differentiation to capitalist extraction, producing the Black body as the pre-eminent, corporeal site for anti-Blackness (la paperson, 2017) (Robinson, 2000).

The technologies sustaining each of the sites of exception in the settler-native-slave triad differentially act on bodies. Grasping even small facets of the violence of what I have been professionalized to enact as a settler materials science and engineering graduate student worker hurt. It hurt a lot. It still hurts. As bell hooks describes, “I came to theory desperate, wanting to comprehend - to grasp what was happening around and within me,” (hooks b. , 1994, p. 59). Deepening my connections to and involvement with organizers inside and outside of the academy gave me an understanding of how to be present with what was happening around me alongside avenues to transform the injustice I was enacting. That hurt and being present in it gave rise to moments of vertiginous consciousness, described in *A Third University is Possible* where,

> “Julie Burelle notes that the “moments of vertiginous consciousness” are these sudden apprehensions of the fatal couplings of the personal and structural scales: “a sensation of sudden clarity, a sinking of the solar plexus if you will, about the violence that continues to hold one’s settler-colonial privilege in place,” (Burelle, 2015) in (la paperson, 2017, p. 63).

Tuck and Yang discuss how settlers often try to reconcile the violence of this privilege through settler moves to innocence (Tuck & Yang, Decolonization is not a metaphor, 2012). They name six settler moves to innocence, describing them as “strategies or positionings that attempt to relieve the settler of feelings of guilt or responsibility without giving up land or power or privilege, without having to change much at all,” (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 10). These moves to innocence are listed in Table 3. Each offers a distinct means by which settlers try to disappear their own hurt and discomfort while maintaining settler colonial relationships and access to land. Each provides guidance on how (not) to navigate (my/our) complicity in settler colonialism as I grapple with other intersecting systems of oppression, one of which is heteropatriarchy.

Table 3: Six settler moves to innocence and their descriptions outlined in (Tuck & Yang, Decolonization is not a metaphor, 2012).

Move to Innocence	Description
Settler Nativism	Locating or inventing a distant Native ancestor as an "attempt to deflect a settler identity, while continuing to enjoy settler privilege and occupying stolen land," (p. 11)
Settler Adoption Fantasies	Adopting Indigenous practices and knowledge as a means to absolve settlers "from the inheritance of settler crimes" and bequeath "a new inheritance of Native-ness *and claim to land*," (p. 14) that keeps settler futurity dependent on the foreclosure of Indigenous futurity.
Colonial Equivocation	Homogenizing experiences of oppression as colonization without describing their relationship to settler colonialism.
Free your mind and the rest will follow	Allowing the cultivation of critical consciousness to stand in for, divert, or distract from the need to relinquish stolen land, power, and privilege.

A(s)t(e)risk peoples	Erasing and then concealing "the erasure of Indigenous peoples within the settler colonial nation-state" and moving "Indigenous nations as 'populations' to the margins of public discourse," (p. 22).
Re-occupation and urban homesteading	"Claiming land for the Commons and asserting consensus as the rule of the Commons, erasing existing, prior, and future Native land rights, decolonial leadership, and forms of self-government," (p. 28).

2.5 Heteropatriarchy

Heteropatriarchy is the system of oppression intertwining heterosexism and patriarchy. Heterosexism normalizes cis-gendered, heterosexual relationships by constructing a rigid gender binary and stigmatizing all other forms of romantic and sexual relationships as outside of this norm. Patriarchy further entrenches this rigid gender binary and the enforcement of gender roles while normalizing the supremacy of those identified as male within its framework. As la paperson describes, normative settler sexuality is one technology maintaining the juridical space of the "settler" (la paperson, 2017). Heteropatriarchy operates as a mechanism of control over self-determination, acting to restrict ways of being to those deemed acceptable in and by the settler state and systematically erase others.

Leanne Simpson discusses heteropatriarchy as a foundational violence and dispossessing force used by the state because "it is a direct attack on Indigenous bodies as political orders, thought, agency, self-determination, and freedom," (Simpson L. B., As We Have Always Done: Indigenous Freedom Through Radical Resistance, 2017, p. 52). Heteropatriarchy operates to destroy intimate relationships that make up Indigenous nations and structure queer worlds. This is reflected in genocidal violence of Missing and Murdered Indigenous Women, Girls, and Two-Spirit Peoples (MMIWG2S) (The Red Nation, 2021); (Simpson L. B., As We Have Always Done: Indigenous Freedom Through Radical Resistance, 2017). Breaking down the logic of this violence, The Red Nation names that

> "because Indigenous bodies stand in the way of access to the land and because women are seen as the producers of Native nations through the European heteropatriarchal lens, violence against women, particularly sexual violence, is used as a means of separating Native people from the land. Nonmen represent alternative political orders that replicate Native nationhood. Violence upon queer and feminine bodies was used as a primary tactic for the obliteration of Indigenous governance structures," (The Red Nation, 2021, p. 99).

Heteropatriarchy operates within dominant engineering culture in a multitude of ways, including the adherence to technical/social dualism through its reliance on strong gender and sexuality distinctions between the masculine and heterosexual (legible as the technical) and the feminine and queer (legible as the externalized social) (Cech & Waidzunas, 2011); (Riley D. , The Island of Other: Making space for embodiment of difference in engineering., 2013). While for me engineering education research has been a way to engage the feminine and queer made illegible in dominant engineering, EER is also a field where transgender and gender nonconforming (TGNC) people are nominally erased (Haverkamp, Bothwell, Montfort, & Driskill, 2021). The conditions in EER were different enough to give me some breathing room, but simply because the oppressive conditions in EER are structured differently does not mean they are any less harmful. Haverkamp et al. name how the overwhelming majority of studies conducted in EER bound themselves within a reductive gender binary (Haverkamp, Bothwell, Montfort, & Driskill, 2021). Pawley et al. conducted a review of articles published in the Journal of Engineering Education (JEE), one of the most prominent EER journals, between 1998-2012 and found no articles mentioning transgender people (Pawley, Schimpf, & Nelson, 2016). Haverkamp et al. conducted a review of articles in JEE and at the accompanying American Society of Engineering Education (ASEE) conference in the years following the release of Pawley et al.'s study and saw little improvement (Haverkamp, Bothwell, Montfort, & Driskill, 2021). In EER, the experiences of TGNC folx are usually nested in the lesbian, gay, bisexual, transgender, and queer (LGBTQ+) umbrella, obfurscating the experiences of TGNC folx rather than revealing them. Haverkamp et al. call for a paradigm shift in how gender is studied in EER toward an understanding of gendered terms and categories through their ongoing racial and colonial contexts. They also suggest that naming TGNC experiences in engineering can be a site to unpack how engineering spaces are regulated by gender and make other connections to broader systems of power.

As a non-binary person, my adherence to the norms imposed under heteropatriarchy is an adherence to my own erasure. It is something that at my core I refuse to do because of the violence it materializes, yet I am expected to do so in order to obtain a doctoral degree in materials science and engineering; it is what I am professionalized to do. The rigorous bounding, disciplining, and asserting of settler white male heterosexuality as engineered objectivity constructs what is (valuable and valued) materials science and engineering in the dominant paradigm (Riley D. , Rigor/Us: Building Boundaries and Disciplining Diversity with Standards of Merit., 2017). It is constructed as valuable for me to capitalize on my own erasure and the erasure of others through the adherence to technical/social dualism and positivism more broadly that telescopes quickly into upholding a rigid, colonial gender binary and maintaining erasure through an epistemology-ontology divide. The dignity and respect that I have as a human being is incommensurable with dominant engineering and reflects the dignity and respect I owe to members of other societies and the horizons vital to their existence. As I was taught when I was a child, treat others the way that you want to be treated. In the same way that I do not want my own horizons erased through ensnarement in the violence and oppression maintaining the structure of settler colonialism, I do not want to predicate my own horizons on the maintenance of this structure that erases many worlds and horizons beyond my own.

When I took an intro to sociology course that my department refused to accept toward my degree progress, I was introduced to the streaming service Kanopy that is available to UM students for free. I had not heard of Kanopy in MSE and had I not taken the course, I likely wouldn't have heard of it at all. In Kanopy, one of the films I watched was the documentary *Precious Knowledge* about a Mexican American Studies Program at Tucson High School in Tucson, Arizona that was shut down by the state (Palos & McGinnis, 2012). In it, one of the daily practices of a class is reciting part of Luis Valdez's narrative poem *Pensamiento Serpiento: A Chicano Approach to the Theatre of Reality* (Valdez, 1990). In Lak'Ech draws from Neo-Mayan, Chicano philosophy:

IN LAK'ECH: Tú Eres Mi Otro Yo. *[You are my other me.]*
Si te hago daño a ti, *[If I do harm to you,]*
Me hago daño a mi mismo. *[I do harm to myself.]*
Si te amo y respeto, *[If I love and respect you,]*
Me amo y respeto yo. *[I love and respect myself.]*

I think of the way I was taught to treat others the way I want to be treated as a way to connect to In Lak'Ech, honoring my roots that trace back to Mexico. It helps me accept that in the academy, “my right to think aloud is contingent on the apparatus of legitimated colonial knowledge production that ought to be abolished,” recognizing that I have an obligation to “commit to analyses that make space for Indigenous sovereign work, to commit to making room for Black and queer thought,” (la paperson, 2017, p. xxiii).

In Teaching to Transgress, bell hooks names how

> “when our lived experience of theorizing is fundamentally linked to processes of self-recovery, of collective liberation, no gap exists between theory and practice. Indeed, what such experience makes more evident is the bond between the two—that ultimately reciprocal process wherein one enables the other,” (hooks b. , 1994, p. 61).

I sought this link to unlearn the epistemology-ontology divides and forms of genocidal erasure that my engineering education specifically and settler society more broadly taught me. I sought to (re)learn other forms of engineering aimed at stopping the systematic erasure of “certain socioecological contexts, or horizons, that are vital for members of another society to experience themselves in the world as having responsibilities to other humans, nonhumans and the environment," (Whyte, 2016). I sought resonance, wanting to put into practice theories of change that would shift (my own, and hopefully others) engineering horizons toward the affirmation of life rather than its systematic erasure. My search pointed me to queer theory and abolition.

2.6 Queer Theory and the post+ colonial

Queer theory fluidly exists as “a dynamic and shifting theoretical paradigm that developed in response to a normalizing of heterosexuality and from a desire to disrupt insidious social conventions,” (Adams & Holman Jones, 2011, p. 110). Queer as a reclamation of a violent epithet engages a non-normative politics, a counter to assimilation into heteronormativity (Riley

D. , The Island of Other: Making space for embodiment of difference in engineering., 2013). The fluidity of queer theory flows from that of queerness, which shifts as societal norms shift (Jennings, Deese, & participants, 2021). One of the shaping elements of queer theory is a focus on what makes and remakes identities, how identities are defined, factors governing those definitions, and how those governing factors can be subversively repurposed toward liberation. Jennings discusses how queerness celebrates otherness and subversiveness rather than rigidly seeking their erasure, offering paths to revolutionary, subversive praxis within the STEM institution.

Queer theory feels like a liberatory sort of (academic) theorizing space I can be present in as a queer person, as contingent as the meaning of that identity may be; a place where I'm able to process the ever shifting intersections of my power, position, and privilege while intervening on the dominance of dominant engineering from within its disciplinary bounds (hence this thesis as a departure from the normative materials science and engineering; acting as a new nucleus seeking to grow. We'll talk about nucleation and growth in chapter 8). Riley discusses this presence as embodiment, a link in queerness as theoretical and experiential, while "engineering, in its adoption of mind-body dualisms as part of its construction of objectivity, is able to ignore these experiences or render them unrecognizable," (Riley D. , 2013, p. 4). This ignorance of objectivity as a construct is epistemological and actively, ontologically reproduced. Feminist scholar Nancy Tuana describes how an epistemology of ignorance,

> "should not be theorized as a simple omission or gap but is, in many cases, an active production. Ignorance is frequently constructed and actively preserved, and is linked to issues of cognitive authority, doubt, trust, silencing, and uncertainty … tracing what is not known and the politics of such ignorance should be a key element of epistemological

and social/political analyses, for it has the potential to reveal the role of power in the construction of what is known and to provide a lens for the political values at work in our knowledge practices." (Tuana, 2004, p. 195)

Queer theory and posts+ feel particularly helpful in tracing these sorts of ignorance as critical sites for undoing fatal couplings of power and difference in engineering, engineering education, engineering education research, and society more broadly (Gilmore, 2002). These sites of ignorance can become nucleation sites for growth of the affirmation of life, discussed further in chapter 4. Abolitionist geographer Ruth Wilson Gilmore discusses how fatal couplings of power and difference are multiscalar objects of analysis, where fatalities are premature deaths caused by violence. Violence itself produces political power asserted through hierarchical organizations of difference, causing group differentiated vulnerability to premature death, with Gilmore taking a particular focus on racism. As Gilmore describes,

> "racism functions as a limiting force that pushes disproportionate costs of participating in an increasingly monetized and profit-driven world onto those who, due to the frictions of political distance, cannot reach the variable levers of power that might relieve them of those costs," (Gilmore, 2002, pp. 16, emphasis original).

In queering academic postcolonial discourse toward the post + colonial, la paperson discusses how

> "posts+ are not "exit signs" from colonialism, like the way postracial or postcolonial is sometimes conceived, but sites for reanalyzing colonial and decolonial activities. Apprehending the post+colonial is to feel the beyond and before of it, "the not yet and, at times, the not anymore" of Indigenous sovereign land and life," (la paperson, 2017, p. xxii)

posting in relation to colonialism. Shorter offers a visualization of this sort of post+ing through The Great Chain of Being, a sixteenth through nineteenth century concept through which "European intellectuals understood our entire system of life as a great chain wherein power and intelligence extended from the highest point (God), down to the most lifeless substances, rocks," (Shorter, 2021, p. 30), see Figure 3. This concept focuses on a hierarchical differentiation of beings and is largely what dominant science is predicated upon. In it, the triangle

> "represents how settlers like to imagine Native people: behind them in terms of civilization, below them in terms of societal advancement, or, in the rare instances that assume contemporaneity, perhaps above settlers in terms of not being tainted by capitalism or materialism," (Shorter, 2021, p. 31).

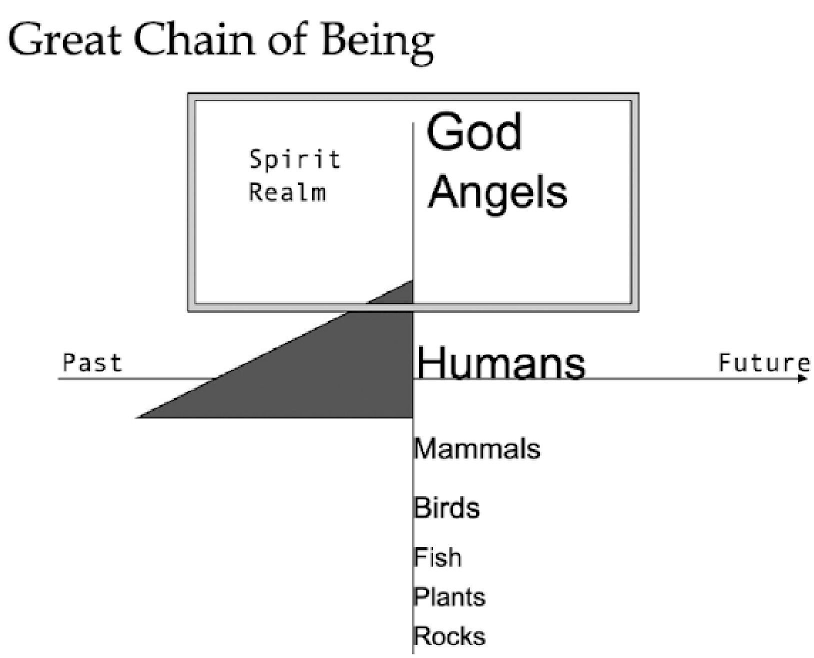


Figure 3: Shorter's "visualization of the Great Chain of Being with the time axis and representations of Indigenous people," Figure 2 from (Shorter, 2021, p. 33).

The posts+ can give insight toward the degree to which the triangle and y-axis expand or contract through re-entrenchment or dissolution of colonialism as an assembled set of technologies and the infrastructures maintaining those technologies; posts+ can be an anticolonial technology. Max Liboiron discusses anticolonial technologies in the assemblage of anticolonial science, where:

> "Anticolonial sciences, even when they run parallel to or overlap with Indigenous sciences and practices, make space for settler and other scientists as well as allies in unexpected places. … Anticolonial sciences are characterized by how they do not reproduce settler and colonial entitlement to Land and Indigenous cultures, concepts, knowledges, and life. … To be clear, anticolonial sciences are not just technical tweaks to dominant science. Anticolonial sciences function more like infrastructures, underlying "the ways knowledge-making can install material supports into the world - such as buildings, bureaucracies, standards, forms, [instruments], funding flows, affective orientations, and power relations." (Murphy, 2017, p. 6) … Regardless of the specifics of your approach, doing anticolonial science within a dominant scientific context is simultaneously a commitment to dominant science and a divestment from it, which makes it uniquely compromised. … we are always caught up in the contradictions, injustices, and structures that already exist, that we have already identified as violent and in need of change. … Compromise is what happens when you have obligations to incommensurabilities," (Liboiron, 2021a, pp. 129-136).

Within EER, Holly Jr. and Masta discuss this need to move past identifying that we are caught up in contradictions, injustices, and structures through a need to "depart from a problem-posing approach to a problem-solving approach," (Holly Jr. & Masta, 2021, p. 800). Gaining a historical understanding of the powers upholding the engineered infrastructures that manufacture and maintain these technologies, the energy these technologies use and leverage, and the forces that drive the movements giving decolonization historical form and context (can) help me(/us) situate the position and trajectories of dominant engineering, engineering education, and my(/our)selves within. As la paperson describes, “decolonization is the double movement of anticolonialism and rematriation - restoring the futures that Indigenous land and life were meant to follow,” (la paperson, 2017, p. xxii). Max Liboiron’s documentation of how CLEAR lab, an anticolonial science lab, methodologically engages in anticolonial science offers guidance on how to act from within dominant science contexts on at least one of the two movements shaping decolonization (Liboiron, 2021a). Moving through the guilt brought on by moments of vertiginous consciousness, the guilt that very often turns into shame as a result of the normalized violence dominant engineering enacts, obligates me to take the sort of movements Sandy Grande names in Refusing the University:

> “turns upon a theorization of the academy as an arm of the settler state— a site where the logics of elimination, capital accumulation, and dispossession are reconstituted— which is distinct from other frameworks that critique the academy as fundamentally neoliberal, Eurocentric, and/ or patriarchal,” (Grande, 2018, p. 47).

In *The Undercommons: Fugitive Planning and Black Study*, Harney and Moten give name to the undercommons as a site for waryness of the constant misalignment between theory and praxis (Harney & Moten, 2013). They discuss the undercommons as a constantly shifting constellation in but not of the university that constitutes a “nonplace of abolition,” that is

> “not so much the abolition of prisons but the abolition of a society that could have prisons, that could have slavery, that could have the wage, and therefore not abolition as

the elimination of anything but abolition as the founding of a new society," (Harney & Moten, 2013, p. 42).

The undercommons reconfigures the pursuit of knowledge toward the eradication of oppression in all its forms as opposed to a pathway for upward mobility and material gain. I sought the undercommons as a site of embodiment grow from. Doing so from within dominant engineering led me toward transformations to my own engineering education, one of the sorts of agency that I have, as part of my self-discovery.

2.7 Abolition as Theory and Praxis

In my own experience, one means of shifting hegemonic normativity toward closing the epistemology-ontology divide is through abolition. As Angela Y. Davis points out, a number of streams of contemporary abolitionist thought draw from the work of W.E.B. DuBois in *Black Reconstruction*, his study of the U.S. Civil War and the period immediately following slavery in the U.S (Du Bois, 1935), (Davis, 2005). In it, DuBois discussed how the negative process of legally disestablishing slavery as an economic institution was insufficient to fully abolish the oppressive conditions produced by slavery. The U.S. settler nation-state remained intact. DuBois advanced the term abolition democracy to discuss how comprehensive abolition involves not only the negative process of tearing down oppressive institutions, but also building up and creating new democratic, life-affirming institutions. As Davis discusses, a result of the failure to enact abolition democracy is the prison industrial complex that we know today.

Critical Resistance, a U.S. based organization seeking to end the prison industrial complex (PIC), discusses the PIC as "a term we use to describe the overlapping interests of government and industry that use surveillance, policing, and imprisonment as solutions to economic, social and political problems," (Critical Resistance, 2021) see Figure 4. Critical

Resistance goes on to describe PIC abolition as “a political vision with the goal of eliminating imprisonment, policing, and surveillance and creating lasting alternatives to punishment and imprisonment.” PIC abolition holds the understanding that prison and policing systems cannot adequately address harm, especially as they themselves are sites of inordinate violence and harm. Furthering this, they discuss how abolition is a broad strategy about undoing the society we live in, building models today representing how we want to live in the future, and developing strategies that allow us to live this vision in daily life. Abolition is a strategy to transform horizons that is deeply rooted in centuries of Black-led organizing, resistance, and refusal toward liberation. Through understanding abolition as both a practical organizing tool in daily life and a long-term goal, Critical Resistance provides an understanding of PIC abolition as an interconnected theory and praxis.

Figure 4: The Prison Industrial Complex, reproduced from (Critical Resistance, 2021).

Tuck and Yang nuance this understanding through discussing how “decolonization as material, not metaphor, unsettles the innocence of these [abolitionist] movements,” (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 28). They name how “the abolition of slavery often presumes the expansion of settlers who own Native land and life via inclusion of emancipated slaves and prisoners into the settler nation-state,” (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 29) urging an understanding “where enslavement is a twofold procedure: removal from land and the creation of property (land and bodies). Thus, abolition is likewise twofold, requiring the repatriation of land and the abolition of property (land and bodies),” (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 30). Tuck and Yang name an ethic of incommensurability as a guide for holding distinctions between projects of decolonization compared to human and civil rights based social justice projects. Incommensurability is unsettling in the ways it offers opportunities for solidarity.

Dylan Rodriguez discusses abolition as

> “a praxis of creativity - abolitionism articulates a fundamental critique of existing systems of oppression while *attempting to actively imagine as it practices forms of collective power that are liberated from hegemonic paradigms*, including but not limited to forms of power constituted by the logic of carcerality, patriarchy, coloniality, racial chattel, racial capitalism, and heteronormativity.” (Rodríguez, Abolition as Praxis of Human Being: A Foreword., 2018, p. 1612).

The drive to actively imagine and practice forms of collective power coupled with critique of existing systems of oppression we are embedded within often holds the tension of contradictory ways of knowing and incommensurabilities that guide our reflexivity. Claris and Riley discuss how reflexivity may entail self-critique, changes in praxis, reflections on power relations in reflection itself, relevant socio-political or socio-historical contexts, the process and subjectivities of research, and/or epistemic assumptions (Claris & Riley, 2012).

Abolitionist educator Mariame Kaba describes this sort of reflexivity as one of the sites for beginning an abolitionist journey, inviting the question “what can we imagine for ourselves and the world?” over “what do we have now, and how can we make it better?” (Kaba, 2021, p.

3). Kaba holds a focus on relationships and how we address harm, reminding us that first we ourselves need to transform as “we have so thoroughly internalized these logics of oppression that if oppression were to end tomorrow, we would be likely to reproduce previous structures,” (Kaba, 2021, p. 4). Alongside this component of self-transformation is the second component she identifies, imagining and experimenting with new collective structures enabling more principled action while noting that less hierarchical and more transparent structures tend to reduce violence and harm. Third she notes a focus on engaging strategies to reduce contact between people and the criminal legal system as moves toward divesting from these systems. Finally, creating the new democratic, life-affirming institutions a different world is built on requires not just changing how harm is addressed but requires changing everything, as the PIC is interconnected with all other systems.

In *Building an Abolitionist Trans and Queer Movement with Everything We’ve Got*, Morgan Bassichis, Alexander Lee, and Dean Spade discuss lineages of radical politics challenging the exploitation and elimination the U.S. is built upon, where “radical politics offer queer communities and movements a way out of the murderous politics that are masked as invitations to "inclusion" and "equality" within fundamentally exclusive, unequal systems,” (Bassichis, Lee, & Spade, 2011, p. 28). They offer the following lessons generated from the intersections of prison abolition and gender justice:

- We refuse to create “deserving” vs “undeserving” victims. “Seeking to understand the specific arrangements that cause certain communities to face particular types of violence at the hands of police and in detention can allow us to develop solidarity around shared and different experiences with these forces and build effective resistance that gets to the root of the problems," (p. 33)

- We support strategies that weaken oppressive institutions, not strengthen them. "We want strategies that will reduce and ultimately eliminate the number of people and dollars going into prisons, while attending to the immediate healing and redress of individual imprisoned people," (p. 34)
- We must transform exploitative dynamics in our work, otherwise "even our most "well-intentioned" strategies and movements will reproduce the prison industrial complex's norms of transphobic, misogynist, and racist sexualized violence," (p. 35)
- We see ending trans imprisonment as part of the larger struggle for transformation. "Building a trans and queer abolitionist movement means building power among people facing multiple systems of oppression in order to imagine a world beyond mass devastation, violence, and inequity that occurs within and between communities. We must resist the trap of being compartmentalized into "issues" and "priorities" and sacrificing a broader political vision and movement to react to the crisis of the here and now. … Struggling against trans imprisonment is one of the many key places to radicalize queer and trans politics, expand anti-prison politics, and join in a larger movement for racial, economic, gender, and social justice to end all forms of militarization, criminalization, and warfare," (pp. 35-36).

With this interconnectedness and the state sanctioned violence wrought by the capacity (infrastructures, discussed in chapter 6) and political willingness (superstructures, discussed in chapter 6) to eliminate and neutralize populations, Rodríguez discusses how abolitionist praxis is currently primarily pedagogical acting within and against the system it occurs within (Rodríguez, 2010). Fundamentally, understanding my connection to the capacity and political willingness that sustains what Rodriguez describes as “a proto-genocidal prison regime that is without precedent or peer” (Rodríguez, 2010, p. 10) felt like an unsettling means of navigating incommensurabilities within materials science and engineering and one that prompted inquiry into the pedagogical forms of my engineering education. What I have seen within the academic spheres of engineering, engineering education, and engineering education research, a praxis of abolitionist engineering has been severely under engaged.

In *Disentangling engineering education research's anti-Blackness*, James Holly Jr. discusses how as a Black male educator and researcher, his own perspectives and those of people like him are often rejected, neglected, and devalued within the EER community (Holly Jr., 2020). He connects this rejection to the anti-Blackness endemic in dominant constructions of engineering, engineering education, and EER today. Naming the tolerance of everyday racism and a “failure of the engineering field to recruit, retain, and graduate Black students without racial trauma,” (Holly Jr., 2020, p. 630) he describes a twofold situation where “on the one hand, we as a community must acknowledge and abolish the policies and practices that tear down Black people; on the other hand, we must amplify the policies and practices that favor the assets of Black people,” (p. 630). Holly Jr. advances pro-Black engineering education research (PEER) as a means of disentangling engineering education research from anti-Blackness. In doing so, he offers multiple recommendations. For one, using theoretical frameworks that honor the agency of Black people through anti-deficit, asset-based lenses and mention enduring Black suppression in discussing race and white supremacy. Additionally, he recommended the intentional choice of methodologies that generate equitable relationships between researcher and research participants such as autoethnography and participatory action research. Finally, he recommended the practices of citing the work of Black people and intentionally constructing research questions that recognize and support Black ingenuity in engineering.

In *We Tell These Stories to Survive: Toward Abolition in Computer Science Education,* Jones and melo leverage Black Critical Theory (BlackCrit) and abolition as a framework to unravel anti-Blackness woven into computer science education and strategize toward futures of computer science education that center Black Joy rather than suffering (Jones & melo, 2021). In doing so, they leverage speculative fiction, described by Ruha Benjamin as "refashionings through which analysts experiment with different scenarios, trajectories, and reversals, elaborating new values and testing different possibilities for creating more just and equitable societies" (Benjamin, 2016, p. 2). Educating with stories, they show paths by which computer science education neglects its anti-Blackness, including its deep connections to the prison industrial complex, and leads toward social and physical Black death in contrast to paths where computer science education takes seriously and values Black Life. Speculative fiction helps to name the horizons offered by the current path and speculates on how refusal can open up entirely different worlds of possibilities. Speculative fiction helps sustain the horizons that dominant engineering acts to erase and offers a map to a healthier ecosystem through the construction of life-affirming institutions.

2.8 Research Questions

As a person, abolition has become a means through which I understand how to approach the logics of elimination, capital accumulation, and dispossession engineered in the academy and broader society. It offers paths to focus on what makes engineers, forces and power struggles governing those forming processes, and how to act in ways that subvert and disrupt those processes toward liberation; speculative pushes toward the beyond and before of the post+colonial, shifting horizons of hope for the future through radical reconstructions of the present. Leaning into abolition as a praxis of human being is a key part of building an abolitionist trans and queer movement with everything we've got, moving queer theory and the post+ into practice. To help me lean in, this thesis is centralized around the following questions:

- How have I been professionalized to be a materials scientist and engineer?
- What has felt incommensurable between my ways of being and how I have been professionalized? How have I come to grasp and navigate that incommensurability?
- How can an abolitionist praxis transform materials science and engineering?

The theoretical framework of queer theory and abolition is one of space making, a means of nurturing worlds systematically targeted for destruction within dominant engineering. It is a way of perceiving the beyond and before of dominant engineering, a space for navigating incommensurabilities, and a grounding for conceptualizing and constructing transformative ripples in the patternings of power toward a reversal of the role of dominant engineering from death making to life affirming.

Chapter 3 Conceptual Frameworks

I think of theory as lenses, a way to see and understand the space you're in. A theoretical framework reflects those understandings. Conceptual frameworks are what you construct in that space, what you pay attention to through your lenses. They are helpful in elaborating and honing in on relationships amongst concepts, constructs, characteristics, properties, etc. To answer the central questions of this dissertation I focused on three constructions to form my conceptual framework. These constructions are

- the materials tetrahedron: symbolic of core relationships in materials science and engineering,
- a third university: a university more interested in operating as a decolonizing university than in decolonizing the university, and
- a liberatory engineering education model: an engineering education model aimed at recentering the purpose of engineering inquiry as liberation/land back.

Bringing these constructions together into a conceptual framework allows for a deconstruction of my dominant engineering education alongside tensions I've encountered in forwarding non-dominant forms of education that have been foundational in shifting the trajectory of my engineering education.

EER opened up paths for me to name dominant engineering as a construct, an assemblage structured to form a set of disciplines. The dominant assemblages of engineering are upheld through the maintenance of fatal couplings of power and difference that ensure group differentiated vulnerabilities to premature death (Gilmore, 2002). A focus on dominant engineering as an assemblage of assemblages, a construct, and particularly the fatal couplings of power and difference maintaining relationships between assemblages in dominant engineering can elucidate pathways transforming those relationships by reducing frictions of *political* distance. However, that focus and the engineering labor associated with the abolition of these fatal couplings of power and difference, abolitionist engineering, is largely unrecognized and unresourced within the dominant construction of engineering today. It is this labor that is key to answering the central questions of this dissertation, and the lack of recognition and resourcing stems from the dominant ways of knowing and being uncritically adopted by engineers geared toward the maintenance of the U.S. settler colony. Averting further climate catastrophe requires transformations to what is considered and resourced as engineering. The following three concepts helped me grasp at the roots of dominant ways of knowing and being within engineering, engineering education, and engineering education research to contextualize my engineering labor in relation to these necessary transformations.

3.1 The Materials Tetrahedron

The materials tetrahedron is a common figure used to describe core relationships within materials science and engineering, see Figure 5. The materials tetrahedron highlights relationships between structure, properties, processing, performance, and characterization. Materials structure can be understood across a continuum of length scales, from specificities at the atomic scale to macroscopic features, and is a key component to understanding materials properties. Structure can be manipulated through alterations to processing conditions and methods, often with the goal of achieving a certain performance arising from a combination of properties valued in a specific application. Characterization is how meaning is made of relationships between structures across scales, processes to shape structures, salient properties, and intended performances. Through these interrelations, the materials tetrahedron can be understood as a conceptual framework for materials science and engineering.

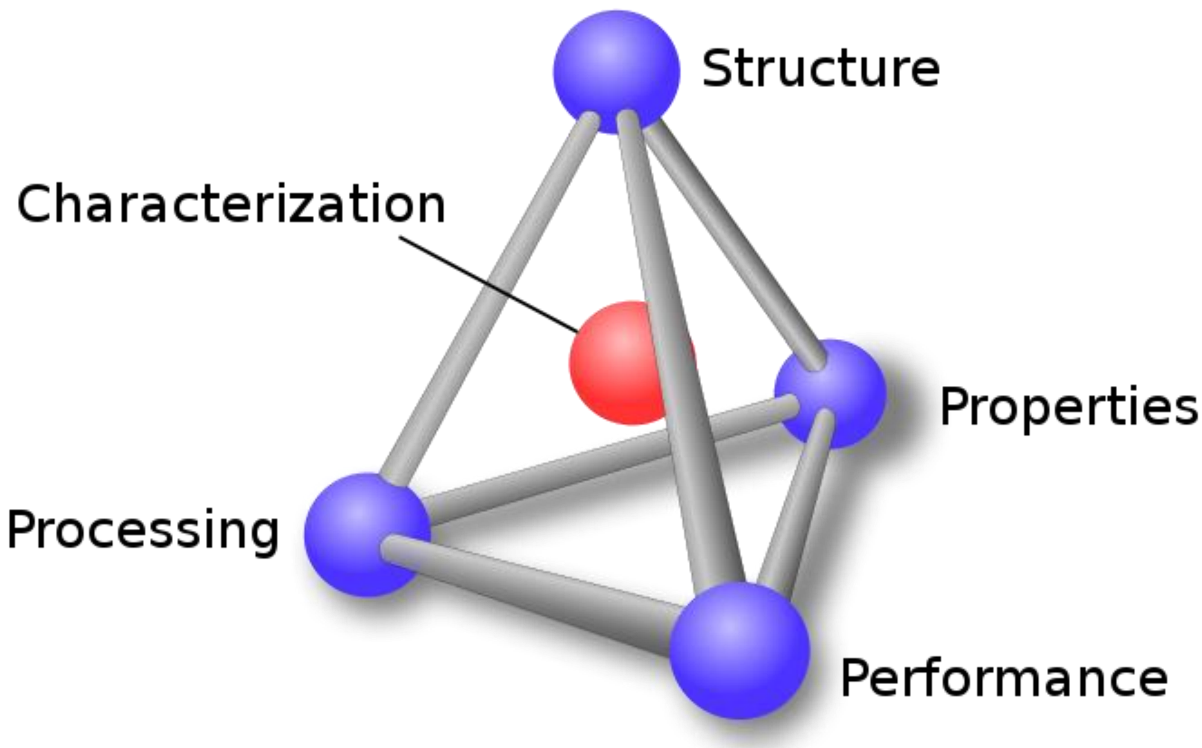


Figure 5: The Materials Tetrahedron represented by blue spheres indicating structure, properties, processing, and performance. The blue spheres are connected to each other by gray cylinders. A red sphere indicating characterization is located in the center of the tetrahedron (Wikipedia, 2022).

3.2 A Third University

In *A Third University Is Possible,* la paperson offers a technological analysis of the machinery and assemblages that structure the university, framing the institution as an amalgamation of first, second, and third universities (la paperson, 2017). These are not distinct categories of institution, or even sequential iterations of the same school: they are the multiple functionalities of the modern university discussed in the ways the university is in assemblage. As an assemblage, the university has many working parts and systems coming together to give it form and functionality. Being in assemblage, the university is imbricated with other assemblages through its operations. Assemblages make it so that scales echo into one another, "so a small glimpse into a university classroom very quickly telescopes into scales of heterosexism, racial capitalism, and so on. The webs of pedagogical machinery are at once giant and intimate. It may feel like lying face down on a monumental precipice, close enough to see the cracks in the stone as well as the chasm just centimeters away," (la paperson, 2017, p. 63).

The first university is the academic-industrial complex, the colonial space of accumulation and expansion, of neoliberal linkages between the production of knowledge and revenue generation; it is the R1 where STEM and particularly dominant engineering are situated and animated through large governmental and corporate research grants (la paperson, 2017). Simultaneously, the first university accumulates through student debt, where the "ability to turn anyone into a debtor is what fuels the first university towards inclusion" (p. 38). The first university occupies and profits from appropriated land.

The second university is composed of the independent schools and "liberal arts" colleges, ideologically committed to critical theory and critique as a means for societal transformation through the deconstruction of systems and personalized pedagogies of self-actualization (la paperson, 2017). While it can meaningfully counter the academic-industrial complex as a more democratic and participatory academy, the second university remains circumscribed within the ivory tower with an end goal as a pedagogical "utopia that everyone should and can attend," (la paperson, 2017, p. 43), with its expansion dependent on the continued accumulation of the first university. When viewed through Max Liboiron's definition of colonialism as "settler and colonial access to Indigenous Land, concepts (like decolonization and indigenization), and lifeworlds to advance settler and colonial goals, even if they are benevolent ones," (Liboiron, 2021a, p. 26) the utopian visioning of the second university can be understood as underpinned by the settler move to innocence Tuck and Yang describe as colonial equivocation (Tuck & Yang, Decolonization is not a metaphor, 2012). Colonial equivocation is where forms of social justice work are conflated with decolonization in ways that reinforce colonialism.

The third university is aimed at decolonization and materialized through the "scrap material" of the first and second universities, functioning to break down and produce counters to the first and second universities (la paperson, 2017). Building on Gilmore's (2002) multiscalar object of analysis that holds a goal of figuring out "what [and who] makes oppressive and liberatory structures work, and what [and who] makes them fall apart," (Gilmore, 2002, p. 17), la paperson seeks a multiscalar subject of power in hir use of scyborg, naming:

> "I am using subject here to include a person (the scyborg) who is interpellated in lattices of power (the scyborg is at once subjugated by power, produced as a subject by power, and a subjective participant in power) but also the wills, forces, and desires that surround and exceed a person (the scyborg in assemblage). The scyborg is a who/what that powers multiscalar dynamics in lattices of power," (la paperson, 2017, p. 64).

It is this agentic, multiscalar subject of power, the scyborg, that can act across scales of engineering, engineering education, and engineering education research. Toward this end, I looked to the set of axioms la paperson offers as propositions upon which the structure of a third university can be built:

1. It already exists. It is assembling. It assembles within the first and second universities.
2. Its mission is decolonization.
3. It is strategic. Its possibilities are made in the first world university.
4. It is timely, and yet its usefulness constantly expires.
5. It is vocational, in the way of the first world university.

6. It is unromantic. And it is not worthy of your romance.
7. It is problematic. In all likelihood, it charges fees and grants degrees.
8. It is not the fourth world.
9. It is anti-utopian. Its pedagogical practices may be disciplining and disciplinary. A third world university is less interested in decolonizing the university and more in operating as a decolonizing university.
10. It is a machine that produces machines. It assembles students into scyborgs. It assembles decolonizing machines out of scrap parts from colonial technology. It makes itself out of assemblages of the first and second world universities. To the degree that it accomplishes these assemblages, it is effective (la paperson, 2017, pp. 52-53).

Scyborg, “a queer turn of word that I offer to you to name the structural agency of persons who have picked up colonial technologies and reassembled them to decolonizing purposes," (la paperson, 2017, p. xiv) is the condition of being plugged into technological grids I grapple(d) with as an engineer, engineering educator, and engineering education researcher constructing a liberatory engineering education model (LEEM).

3.3 A Liberatory Engineering Education Model

3.3.1 The LEEM Prototype: A Construct(ed machine)

A liberatory engineering education model (LEEM) sprung up in the aftermath of an abolitionist labor strike that myself and co-author Corey Bowen participated in and grew through our connection turned collaboration with Donna Riley (Valle, Bowen, & Riley, 2021). Prototyping this model in the midst of my first and second semesters of formal EER coursework made for a clunky framework assemblage of components from within and outside of EER. Fueled by a desire to contextualize engineering labor organizing alongside dominant engineering education, the initial prototype took shape primarily from Hassan's learning-assessment interactions model and Mejia et al.'s Freirian critical consciousness model, see Figure 6 (Hassan, 2011); (Mejia, Revelo, Villanueva, & Mejia, 2018). Hassan created a model that combines assessment with learning, identifying bi-directional relationships between assessment and assessment method, as well as assessment and learning, with both learning and assessment method being influenced by learning method. According to Hassan, an assessment should be "something that affects the students' learning, confidence in themselves and their skills," where "the assessment method can enrich the learning method and they are coupled together by an appropriate methodology of learning and assessment," (Hassan, 2011, p. 327).

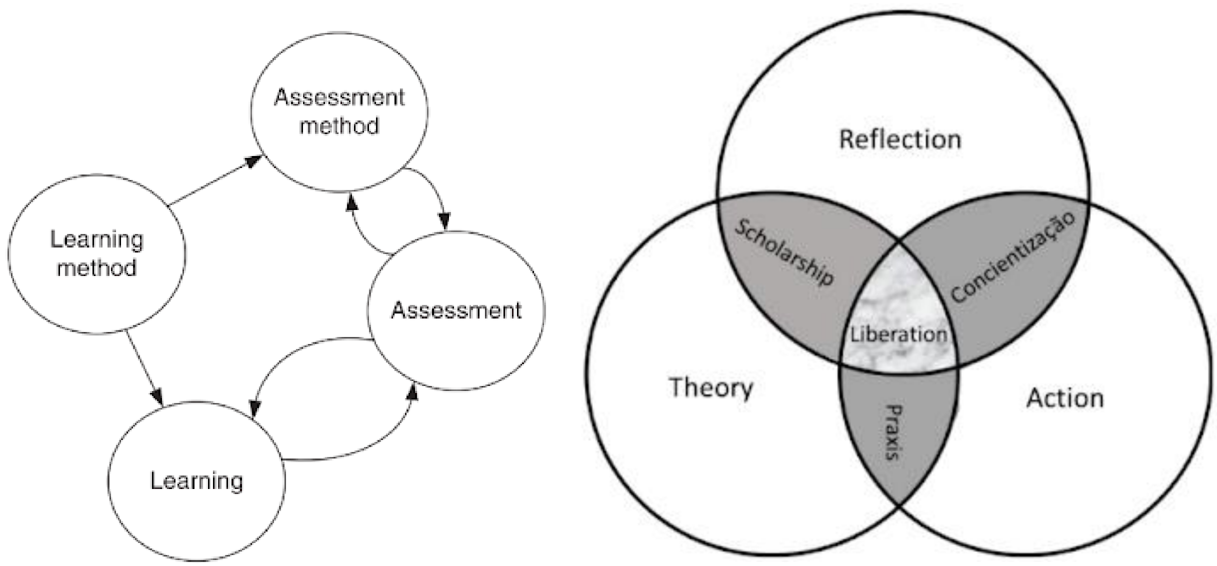


Figure 6: Left - Learning-assessment interactions model proposed by O. A. B. Hassan (Hassan, 2011), Right - Proposed critical consciousness approach from Mejia et al. adapting and expanding upon Freire's principles of critical pedagogy (Mejia, Revelo, Villanueva, & Mejia, 2018); (Freire, 1970).

Mejia et al. conducted a systematic review of engineering education literature using a methodology based on Freire's principles of critical andragogy (adult education) and pedagogy (Mejia, Revelo, Villanueva, & Mejia, 2018); (Freire, 1970). In doing so, they proposed a critical consciousness approach connecting theory, reflection, and action. They identified intersections of scholarship (theory developed from reflection), praxis (theory merged with action), and concientização or critical consciousness raising *processes* (action built upon reflection) toward liberation (theory, action, and reflection). They then provided a matrix of guiding questions for researchers to engage with throughout the process of conducting studies, prompting researchers to consider the relationships between scholarship, praxis, concientização, and liberation and theory, action, and reflection, see Table 4.

Table 4: Guiding questions for researchers using the adapted model of Freire's principles of critical pedagogy from Figure 6 (Mejia, Revelo, Villanueva, & Mejia, 2018).

Freire's Principles of Critical Pedagogy	Theory	Action	Reflection
Scholarship	Is this theory critical and am I considering the political, cultural and historical factors that play a role into the research?	In what ways is my research and my relationship with the participants ensuring that a liberating action will occur?	What is my positionality?
Praxis	Are the theories that I am trying to explore achieving the intended goal?	How do I ensure that my research results can be easily translated into practice?	How am I reflecting upon my role as a researcher in the context of the phenomenon/population I am trying to explore?
Concientização	Does the theory used assume a deficit or anti-deficit approach?	What are my assumptions about the community and the phenomenon?	In what ways was I mistaken about the population or the phenomenon I explored?
Liberation (e.g., for participants)	How can I make sure the theory development in my work is liberative and co-created with participants?	In what ways am I allowing participants to take action alongside me in order to achieve liberation from the obstacles that prevent action from occurring?	In what ways am I allowing for participants to reflect with theme about the research findings and to co-construct these narratives together?

The guiding questions outlined in Table 4 point toward complex relationships between each of the components of Figure 6 that we sought to further nuance. The LEEM prototype was a way to model this nuance, see Figure 7 (Valle, Bowen, & Riley, 2021). Dialectic relationships, inherent internal contradictions at the basis of Freire's work (e.g. between oppressor and oppressed), are represented by circle overlaps (e.g. between theory of change and methodology as framing), the solid black lines connect the concepts of methodology, learning, and assessment, and the dotted thin blue lines connecting the concepts of framing, community organizing, and positionality. Mejia et al.'s model is represented in the center of this model, showing relationships between theory, action, reflection, and concepts of scholarship, praxis, concientização, and liberation that result from their overlap (Mejia, Revelo, Villanueva, & Mejia, 2018). Hassan's model of learning-assessment interactions is overlaid, with the overlap taking the form of reflection as an assessment method and action as a learning method (Hassan, 2011). This LEEM also explicated the coupling of learning and assessment with methodology discussed by Hassan. Hassan's model did not explicitly name the bi-directional relationships of its components (e.g. the interaction of assessment method and assessment was not discussed as positionality), and the LEEM prototype builds on that work by considering bi-directional relationships as dialectics.

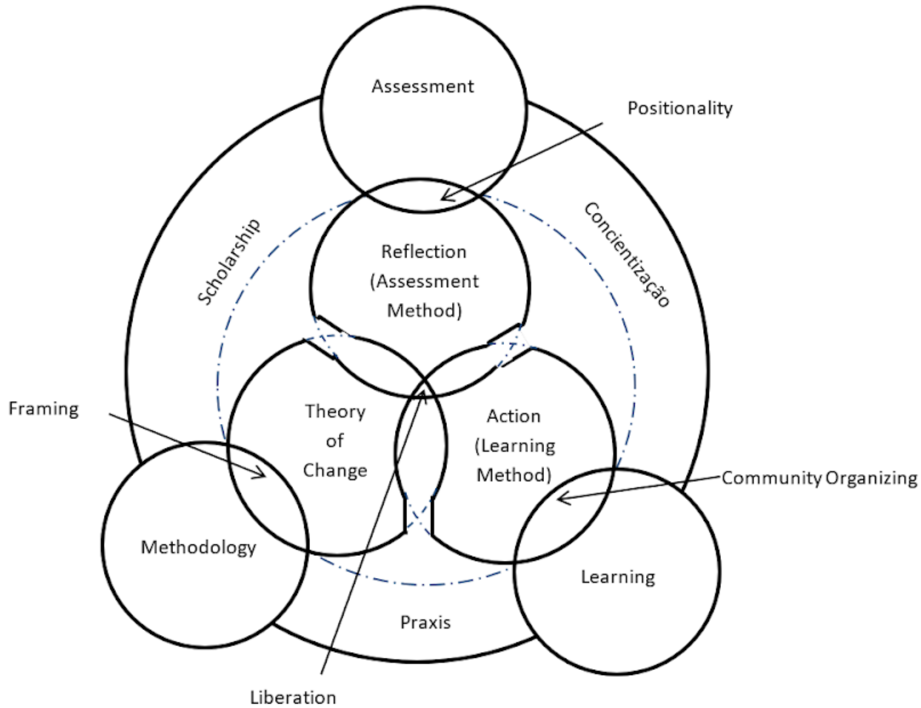


Figure 7: Proposed liberatory engineering education model developed from Mejia et al.'s Freirian critical consciousness model and Hassan's learning-assessment interactions (Valle, Bowen, & Riley, 2021); (Mejia, Revelo, Villanueva, & Mejia, 2018); (Hassan, 2011).

Reconfiguring these bi-directional relationships to be dialectic relationships allow(s/ed) us to consider contradictions that can arise from overlaps of components and identify concepts that may be useful in navigating these contradictions (Valle, Bowen, & Riley, 2021). For example, positionality is a key component of reflection (assessment method) for teacher-students and student-teachers that can contextualize contradictions or misalignments arising from forms of assessment that may negatively impact "students' confidence in themselves and their skills" (Hassan, 2011, p. 327) and make space for less harmful interactions between assessment and assessment method moving forward (e.g. shifts from deficit-based to asset-based assessments and assessment methods). Community organizing can be viewed as a means to navigate contradictions between action (learning method) and learning by considering how the learning space and learning community are organized to achieve forms of learning that take steps toward liberation. Framing can be a means to navigate contradictions that arise between methodology and theory of change.

In this model, the three regions spanning from the outermost black lines through the dotted thin blue lines to liberation in the model's center reflect scholarship, praxis, and concientização (Valle, Bowen, & Riley, 2021). Thus, each intersects with sets of dialectic relationships spanning the regions (e.g. methodology and assessment, framing and positionality, and theory of change and reflection for scholarship). These dialectic relationships represent contradictions, where the questions posed in Table 4 can guide researcher reflexivity as they navigate these contradictions. The dotted thin blue lines are simultaneously configured to represent openings between and/or constraints brought on by constructed (infrastructures, structures, and superstructures) barriers across domains of power. This allows for the model to consider how various approaches can reduce or amplify the salience, impact, or power of constructed barriers and create or constrain opportunities to navigate towards liberation.

3.3.2 Reconceptualizing the LEEM Prototype

After working with Corey and Donna on this initial prototype and trying it out in a few of our inquiries, I continued reflecting and adapting the ways I understood the model (Valle, Bowen, & Riley, 2021); (Valle, Ali, Bowen, & Riley, 2021); (Bowen, et al., 2021). One of the components of the theoretical framework that our initial prototype was constructed from was the concept of transformational resistance (Solórzano & Delgado Bernal, 2001). Solórzano and Delgado Bernal examined the construct of student resistance through qualitative inquiry and counterstorryteling around two events in Chicanx student history - the 1968 East LA school walkouts and the 1993 UCLA student strike for Chicanx studies. They leveraged critical race theory (CRT) and Latinx critical race theory (LatCrit) as a framework to do so, where they posited five themes that form “basic perspectives, research methods, and pedagogy of a CRT and LatCrit framework in education” (p. 312):

1. The centrality of race and racism and intersectionality with other forms of subordination.
2. The challenge to dominant ideology.
3. The commitment to social justice.
4. The centrality of experiential knowledge.
5. The interdisciplinary perspective (Solórzano & Delgado Bernal, 2001, pp. 312-315).

Drawing from McLaren, Solórzano and Delgado Bernal discuss theories of resistance as a means of understanding “the complexities of culture to explain the relationship between schools and the dominant society,” focusing on how “individuals negotiate and struggle with structures and create meanings of their own from these interactions,” (Solórzano & Delgado Bernal, 2001, p. 315); (McLaren, 1994). They outline four different types of student oppositional behavior, adapting a notion from Giroux that resistance follows “two intersecting dimensions: (a) Students must have a critique of social oppression, and (b) students must be motivated by an interest in social justice,” (Solórzano & Delgado Bernal, 2001, pp. 316-317), see Figure 8 (Giroux, Theories of Reproduction and Resistance in the New Sociology of Education: A Critical Analysis, 1983a); (Giroux, 1983b).

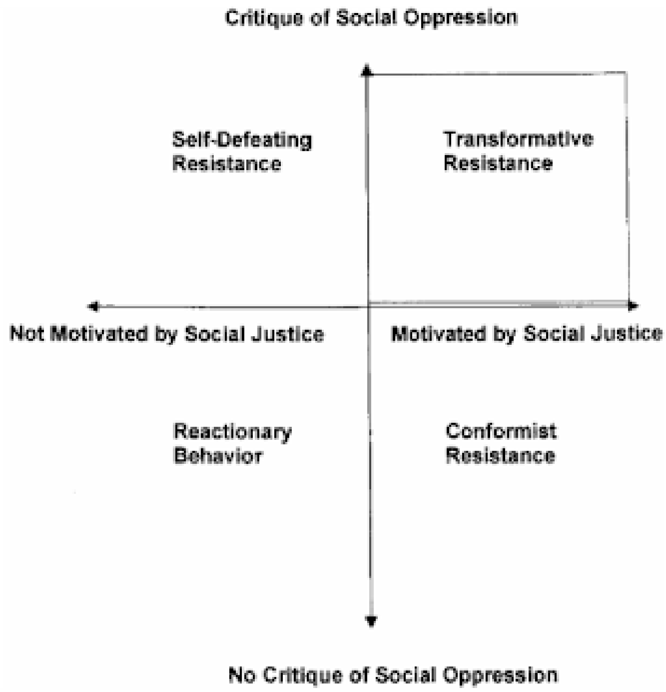


Figure 8: Reproduction of 'Figure 1 Defining the Concept of Resistance' from (Solórzano & Delgado Bernal, 2001, p. 318). Axes of critique of social oppression and motivation by social justice help to demarcate types of oppositional behavior.

Solórzano and Delgado Bernal leverage this to discuss five oppositional forms of behavior (Solórzano & Delgado Bernal, 2001). They describe reactionary behavior as not motivated by social justice and not holding a critique of social oppression, leading it not to function as a form of resistance. The four oppositional forms of behavior they describe as resistance are:

- Self-defeating resistance - Critique of oppressive social conditions, not motivated by social justice (e.g. dropping out of school).
- Conformist resistance - Motivated by social justice but does not hold a critique of systems of oppression.
- Internal transformational resistance - Holds both a critique of systems of oppression and a motivation by social justice. Engages in behavior that is subtle and appears to conform to societal expectations.

- External transformational resistance - Holds both a critique of systems of oppression and a motivation by social justice. Engaging in behavior that does not conform to institutional or cultural norms and expectations.

I considered these different forms of oppositional behavior through the metaphor of a tunnel or pipeline, discussing sites of tension between some of the forms of resistance Solórzano and Delgado Bernal offer and what I've experienced (Solórzano & Delgado Bernal, 2001). In the tunnel/pipeline, reactionary behavior is just bumping the sides of the tunnel/pipeline (e.g. out of boredom) but generally walking along the tunnel's intended path not really questioning why you are. Reactionary behavior configured in this way reflects a disengagement with concientização. Elementary school me was a prime example of this reactionary behavior.

As you move through, students that exit out of the tunnel where they came in through or 'leak out' of the pipeline to where they are systematically structured to go engage in what Solórzano and Delgado Bernal described as self-defeating resistance (Solórzano & Delgado Bernal, 2001). They frame self-defeating resistance as behavior that recreates the oppressive conditions from which it originated. I like to emphasize the tunnel metaphor a bit more than the pipeline metaphor here, since I think it offers more agency to the students who take these paths and it can fit better with asset-based approaches. Here the act of dropping out that I saw many of my friends take, particularly other queer people of color in engineering, is more reflective of the theories of change that deny the institution access to their body as exemplified "diverse" successes of institutional inclusion and assimilation strategies. I find Damien Sojoyner's ethnographic accounts of Black youth in LA to illuminate theories of change such as this through his discussion of Black fugitivity (Sojoyner, 2017). Sojoyner discusses how his conceptualization of Black fugitivity "is based on the disavowal of and disengagement from state-governed projects that attempt to adjudicate normative constructions of difference through liberal tropes of freedom and democratic belonging," (Sojoyner, 2017, p. 516). He discusses practices of refusal as "the embodied knowledge at the core of social visions of being that are irreconcilable with liberal, difference-making state projects," (p. 516). Sojoyner shows how refusal can be highlighted with a shift in "framing from state-sponsored education as a redemptive structure of social progress to an understanding of education as one of the key sources of support for forms of structural oppression," (p. 517). Refusal is central to Black fugitivity and extends beyond the self-defeating resistance discussed by Solórzano and Delgado Bernal (Solórzano & Delgado Bernal, 2001). Sojoyner cites Mohawk scholar Audra Simpson, who distinguishes refusal from resistance in how refusal does not take authority as a given (Sojoyner, 2017); (Simpson A. , 2016); (Grande, 2018).

Conformist resistance takes the approach of trying to make it through the tunnel as a way to change the tunnel, although far too often those who engage in it are captured to become part of the tunnel before they can escape it (Solórzano & Delgado Bernal, 2001). Transformational resistance actively works to transform the tunnel, opening up cracks along the way and tagging its walls with instructions of how to expand those cracks. I consider the sort of refusal Sojoyner and Simpson discuss to be more aligned with, although still very much distinct from, external transformational resistance (Sojoyner, 2017); (Simpson A. , 2016). Transformational resistance makes space for shifting tunnels/pipelines from rigid, impassable dividing structures into deconstructable, porous structures that can be reconfigured on liberatory paths.

What I desire to engineer are pathways out of dominant engineering tunnels/pipelines toward an entirely different, life-affirming ecosystem. Walter Lee's discussion of participation paradigms offers a succinct means of naming the different scales of these metaphors (Lee W. , 2019). He repositioned the metaphors of pipelines, pathways, and ecosystems as paradigms, naming each as participation paradigms relating to broadening engineering. Table 5 shows the positions of the three paradigms as different scales.

Table 5: Participation paradigm positions on selected issues (Lee W. , 2019).

Item	Pipeline paradigm	Pathway paradigm	Ecosystem paradigm
Inquiry aim	Education or work system	Individual persons	Learning or work environment
Unit of analysis	The impersonal, macro (The Pipeline)	Personal, micro (My Pathway)	Shared, meso (Our Ecosystem)
Mode of participation	Participants are passive	Participants are active	Participants are active
Issue highlighted	Access and barriers to participation via traditional routes	Signs for and deterrents from participation; nontraditional routes	Intergroup relations, interconnectedness, and engineering culture
Theoretical focus	Social reproduction; structural ability and motivation (e.g., policies, practices)	Agency; personal ability and motivation (e.g., aptitude, choices, identity)	Interpersonal interactions and contextual features; shared experiences (e.g., belonging, social capital)
Mode of progress	Longitudinal (time)	Longitudinal (time)	Localized (space)
Measure of progress	Retention; more volume and efficiency, single desired destination; linear	Persistence; smoother paths, various acceptable destinations; nonlinear	Experiences; better climate, irrespective of desired destination; nonlinear
Stakeholder accountability	Looking back; blame the previous part of the system	Looking forward; blame the subsequent part of the system	Looking around; blame the current part of the system
Policy implications	Supply side; recruitment, retention, outreach,	Demand side; placement, admission, enrollment	Internal; climate, culture, support, receptiveness, migration, and so forth

	school funding, and so forth	management, transfer, and so forth	

I now think of the LEEM prototype to be constructed so that engineers, engineering educators, and engineering education researchers can contextualize the ecosystem of their inquiry, name the pipelines/tunnels they've encountered along their paths toward liberation, and discuss how they interacted with the technologies sustaining those pipelines/tunnels. The pipelines as thin blue lines within the LEEM prototype reflect inhibitors to liberation that our own incommensurability laden inquiries leave intact or even strengthen, highlighting oppressive infrastructures to be abolished. This framing of the LEEM prototype positions it as an inquiry ecosystem desiring alignments toward liberation. The LEEM prototype allows for a longitudinal understanding of how alignments shift as the inquiry progresses. It also sets up the following structures shaping scholarship, praxis, and concientização that could shift such alignments:

- Theories of Change - "a theory of change refers to a belief or perspective about how a situation can be adjusted, corrected, or improved," (Tuck & Yang, 2014, p. 13) where "reflecting or imagining a theory of change is an ontological and epistemological activity, related to core questions of being and knowing," (Tuck & Yang, (Tuck & Yang, 2014, p. 126).
- Framing - framing reflects ideologies, systems of ideas and ideals, that contextualize conceptual frameworks and link theories of change to methodologies that seek to enact those theories of change.
- Methodologies - methodologies are practices of living or ways of being that shape engagement in inquiry (Liboiron, 2021a); (Simpson L. B., As We Have Always Done: Indigenous Freedom Through Radical Resistance, 2017).

- Actions/Learning Methods - actions taken by you and others engaged in the inquiry
- Context/Community Organizing - the contexts you and others engaged in the inquiry consider salient, which can include how communities are organized to connect learning methods to learning.
- Learning - what you and others engaged in the inquiry learn from acting in context
- Reflection/Assessment Methods - how you and others engaged in the inquiry reflect on the actions taken and what was learned from those actions.
- Positionality - How you and others engaged in the inquiry understand yourselves to relate to the contexts and framing of the inquiry.
- Assessment - what you and others engaged in the inquiry understand the significance of the inquiry to be (or to have been).

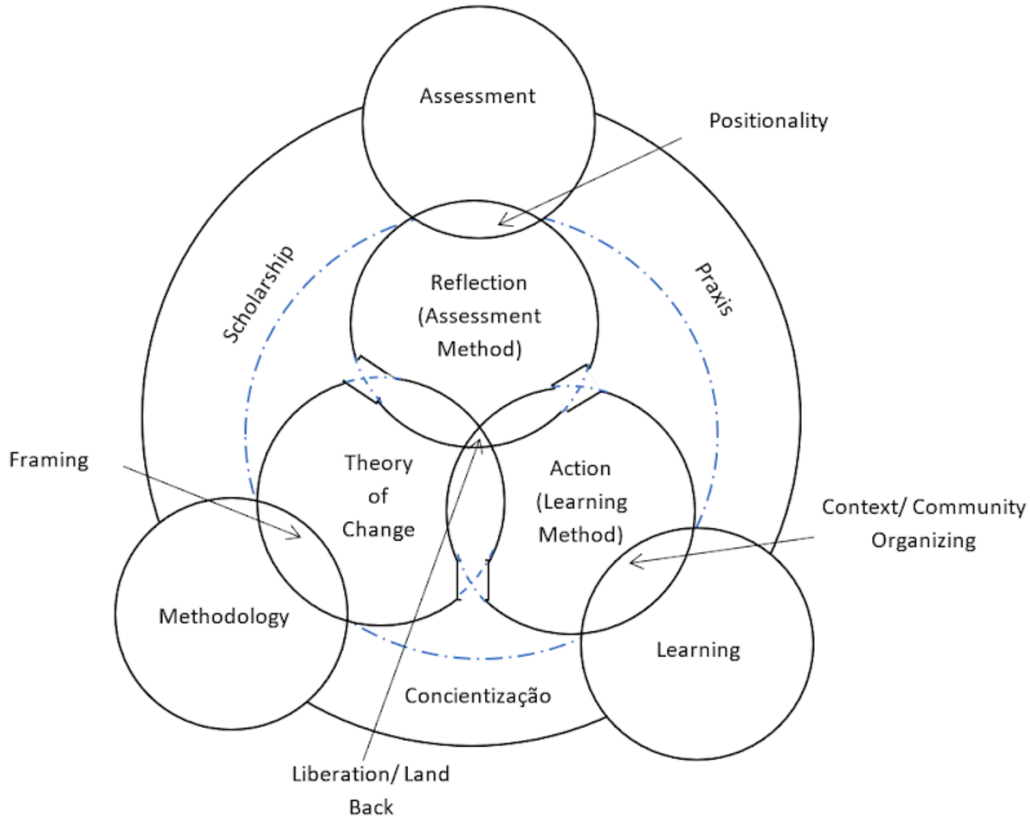


Figure 9: Updated LEEM, where locations of praxis and concientização are swapped and land back is co-located with liberation.

Two key shifts are made in the reconceptualization of the initial prototype, see Figure 9. First is a change to reflect how liberation is intertwined with land back through the double movements la paperson uses to describe decolonization: “anticolonialism and rematriation - restoring the futures that Indigenous land and life were meant to follow,” (la paperson, 2017, p. xxii). Explicitly situating land back as a central desire of inquiry within this LEEM obligates me to understand decolonization as material and not metaphor while seeking alignment with a third university mission of decolonization (Tuck & Yang, Decolonization is not a metaphor, 2012); (la paperson, 2017). This LEEM is a machine wired to guide engineering inquiry toward the abolition of the social institutions that “systematically erase certain socioecological contexts, or horizons, that are vital for members of another society to experience themselves in the world as having responsibilities to other humans, nonhumans and the environment," (Whyte, 2016). It might assist those of us who find ourselves already in the grasp of the academy Grande theorized as the arm of the settler state as we undo the fatal couplings of power and difference that maintain the settler state's grip; disarming and disassembling its structure, infrastructures, and superstructures (Grande, 2018); (Gilmore, 2002). It pushes for an unsettling of innocence through the acknowledgement of harms inherent to and arising in the inquiry as it was conducted in order to make space for discussing how those harms were addressed and assist inquirers in taking accountability for those harms.

Accountability is a critical mechanism and key principle in transformative justice (TJ), a powerful abolitionist framework for addressing harm. TJ was coined by Generation Five, a group working to end the sexual abuse of children within five generations, as "the term that best describes the dual process of securing individual justice while transforming structures of social injustice that perpetuate such abuse," (Generation Five, 2007, p. 6). While Generation Five focuses specifically on ending child sexual abuse, TJ is applicable to numerous forms of violence and systems of oppression enabled by that violence. As Mia Mingus names, many communities who are already targeted by the state have been practicing TJ for generations to create safety and reduce harms arising from oppressive conditions (Mingus, Transformative Justice: A Brief Description, 2018). Generation Five premises their TJ approach on three core beliefs:

- Individual justice and collective liberation are equally important, mutually supportive, and fundamentally intertwined - the achievement of one is impossible without the achievement of the other.
- The conditions that allow violence to occur must be transformed in order to achieve justice in individual instances of violence. Therefore, Transformative Justice is both a liberating politic and an approach for securing justice.

- State and systemic responses to violence, including the criminal legal system and child welfare agencies, not only fail to advance individual and collective justice but also condone and perpetuate cycles of violence (Generation Five, 2007, p. 5).

Liberation is a central principle in TJ, much as it is in the LEEM (Generation Five, 2007). Other principles Generation Five identifies in their TJ approach are shifting power, safety, accountability, collective action, honoring diversity, and sustainability. Shifting power moves power from individuals, institutions, and systems aiming to maintain oppression toward building and strengthening shared power based on equity, cooperation, and self-determination. This shared power builds capacity for sustainable, collective action. Safety is discussed as "liberation from violence, exploitation, and the threat of further acts of violence," (Generation Five, 2007, p. 28) manifesting on three intersecting and mutually reinforcing levels of the individual, the community, and across communities. Accountability makes space for a willingness to interrupt oppressive and abusive dynamics, transforming those dynamics to help us be in integrity with and realize liberatory visions of justice. Generation Five outlines that at minimum, accountability requires

- Acknowledging the harm done even if it is unintended;
- Acknowledging its negative impact on individuals and the community;
- Making appropriate reparations for this harm to individuals and the community;
- Transforming attitudes and behaviors to prevent further violence and contribute toward liberation;
- Engaging bystanders to hold individuals accountable, and toward shifting community institutions and conditions that perpetuate and allow violence; and

- Building movements that can shift social conditions to prevent further harm and promote liberation, including holding the State accountable for the violence it perpetuates and condones, (Generation Five, 2007, p. 29).

The second key shift in this reconceptualized prototype is a swapping of the locations of concientização and praxis from the initial prototype. Freire discusses concientização as learning to perceive contradictions in dominant systems and acting to undo the oppressive elements those contradictions represent, where a good alignment between the perception of contradictions and actions to undo them can create conditions of liberation (Freire, 1970). Here, framing still aligns a theory of change with methodologies across scales to form a paradigm. Framing reflects the shape of the tunnels/pipelines in the ecosystem, methodologies reflect pathways one takes (or hopes to take) in the ecosystem, and theories of change act to (re)shape the structures, infrastructures, and superstructures in the ecosystem. Also key to concientização are how context/community organizing aligns actions/learning methods with learning across scales. Learning is the socially situated path one takes in the context of the ecosystem, where action guides learning pathways based on how communities are organized. Actions can also re-organize communities, transforming the possibilities of what learning pathways can be taken and how, building capacity for sustainable, collective action through shared power (Generation Five, 2007). Freire discusses praxis as the intersection of action and reflection, where good alignment between the two can bring about conditions of liberation (Freire, 1970). Your reflection/assessment method is shaped by your positionality, which socially situates your assessment of the ecosystem. Those assessments are often turned into scholarship when they are performed in the context of the academy, where they become capital. Scholarship is the site of intersection for theories of change and reflection that can find alignment to create conditions of liberation.

To me, the LEEM is a map for structuring how I characterize inquiry, much in the way that the materials tetrahedron does in MSE. There is a directionality, where the aim with each inquiry is (toward) liberation/land back from the outside or margins toward the center. The degree of resonance or (mis)alignment amongst the components determines the forms of resistance to liberation/land back you can encounter or reproduce in inquiry. You shape your inquiry through how you holistically engage the components, similar to how structure, process, properties, and performance are engaged together in the materials tetrahedron. Liberation/land back is always the performance to aim towards in the LEEM. Your paradigm shapes the structures you pay attention to. Your process is your learning, situated in the context of how your community is organized and shaped by your learning actions and methods. Your properties come from your assessment, situated in your positionality and shaped by your reflection or method of analysis. This connection of the assemblages of the LEEM and the materials tetrahedron offers a way to deconstruct dominant engineering through materials science and engineering, which will be discussed in chapter 6.

Chapter 4 Methodologies and Methods

Methodologies are practices of living or ways of being that shape engagement in inquiry (Liboiron, 2021a); (Simpson L. B., As We Have Always Done: Indigenous Freedom Through Radical Resistance, 2017). Methodologies enact ethics, moral principles, through the methods employed in an inquiry. As Max Liboiron describes, "there are colonial ways to be in the world, whether intentionally or otherwise, and there are less colonial and anticolonial ways to be in the world," (Liboiron, 2021a, p. 36). Seeking the latter to cultivate relations of accountability as I moved through my graduate studies pushed and pushes me to reflect on the methodology I was professionalized to leverage as a materials scientist and engineer. That methodology is the scientific method. At the same time, it challenged me to better understand the methodologies underpinning my reflexivity and reflect on how those have shifted during my graduate studies. To grapple with that challenge, I chose to practice autoethnography.

4.1 The Scientific Method

The scientific method is a methodological hallmark of positivism (Harding, 1992); (Riley D. , 2008). A highly linear approach to inquiry, it guides knowledge acquisition primarily through six principles that lead to the production of outcomes considered falsifiable. These principles begin with some observation or formulation of a question. Following this, information related to that observation or question is gathered in order to form a hypothesis. A hypothesis is an explanation of underlying phenomena relevant to the observation or question that can be tested. With a hypothesis in hand, experiments to test the hypothesis are conducted in a way considered reproducible in order to generate data. That data is then analyzed and interpreted to draw conclusions. The conclusions are the outcomes of these interpretations that name how well the hypothesis explained the underlying phenomena, representing acquired, ‘objective’ knowledge. In dominant engineering, this methodology is often considered so commonplace by researchers that it goes unnamed within research papers.

4.2 Autoethnography

Autoethnography is a qualitative methodology combining elements of autobiography and ethnography designed to accommodate subjectivity, emotionality, and the researcher’s influence on research; all components that I found distinctly absent from the sorts of communications I was expected to give about engineering research I had conducted during my engineering education (Hughes & Pennington, 2017). Qualitative methodologies are attuned to answer questions relating to people’s lives, social, cultural, and political contexts people live in, and ways people understand the world and make meaning of their experiences (Merriam, 2009). Within engineering education research (EER), Slaton and Pawley demonstrate ways that prevailing standards are assembled from politics dominant within ‘evidence-based’ scientific and engineering fields (Slaton & Pawley, 2018). These standards run counter to and stigmatize qualitative and small-n studies, such as autoethnographic studies, instead forefronting more ‘objective’ methods of quantitative inquiry and large-n data sets to validate and verify claims.

Ellis and Adams discuss three interrelated conditions contributing to the emergence of autoethnography within the academy: 1) a growing appreciation for qualitative research and personal storytelling in academia, 2) a greater recognition of research ethics, and 3) the continued emergence and importance of identity politics as more systematically oppressed peoples entered into academia (Ellis & Adams, Ch. 13 The Purposes, Practices, and Principles of Autoethnographic Research, 2014). Hughes and Pennington describe autoethnography as “a *critical and reflexive way of writing or representing* (graphy) inherent *personal complications and possibilities* (auto) in relation to larger *cultural contexts* (ethno)," (Hughes & Pennington, 2017, p. xii). Whereas ethnography is often leveraged to observe and interpret the "other," autoethnography places a focus on the self. Rather than seeking to escape subjectivity as the positivist paradigm trains researchers to do, autoethnography allows you to write about how you grapple with your own subjectivity as a researcher, factors that have shaped it, and how it links to the broader means of situating yourself in context. As Starr describes, "the process of self-exploration and interrogation aids individuals in locating themselves within their own history and culture allowing them to broaden their understanding of their own values in relation to others," (Starr, 2010, p. 1).

Connecting to Kaba's point that an abolitionist journey entails understanding yourself, including ways you have internalized and replicate logics of domination and oppression, the reflexive element inherent to autoethnography can find good alignment with an abolitionist praxis (Kaba, 2021). Autoethnography allows for a systematic analysis of the personal to understand the cultural, situating research as a political, socially-just act (Ellis, Adams, & Bochner, 2011). As Chávez explains,

> "An important reason to do autoethnographic research is to help uncover relations of domination in the "ordinary" fabric of educational contexts. One way to do this is by problematizing how we live our daily lives, for it is in the social, political, and cultural practices that our perceptions of the "common sense" are formed that, in turn, affect how we live our lives," (Chávez, 2012, pp. 338-339).

Chávez's explanation, that autoethnography assists in uncovering and problematizing domination, aligns with the goal of autoethnography "to produce analytical, accessible texts that change us and the world we live in for the better," (Ellis, Adams, & Bochner, 2011, p. 273). Part of the (re/dis)orientation that autoethnography as a methodology allows for is that it can shift and challenge your own understanding and representation of self and the meaning-making arising from the conditions you are embedded within, making space for new understandings to grow. A component of this shifting and challenging is how an autoethnographer views "themselves as complicit (at least partially) in the problems they perceive. Discussing such complicity can place scholars in quite a vulnerable position. It is the crucial consideration of unveiling the vulnerable self with regard to sharing sensitive information with others as they grapple with the complications of their educational positions," (Hughes & Pennington, 2017, p. 22).

Many critical and post+ frameworks understand the centrality of personal narrative and experience denied within a positivist paradigm, and autoethnography allows researchers to hone our narrative agency. In her autoethnographic accounting as "an anomaly in higher education: a working-class, Chicana, first-generation college student with a Ph.D," conducting research, Chávez drew from *testimonios* in a critical race theoretical framework to "interrogate the role that educational institutions play in the creation of particular ideologies in working-class students of color," (Chávez, 2012, p. 334). Perez Huber discusses *testimonios* as autobiographical educational experiences developed in the field of Latin American studies that validate experiential knowledge and reveal exploitative and oppressive conditions toward healing and empowerment (Huber, 2009). Chávez describes how in her higher education studies, she was unwilling and unable to create the sort of "academic distance" that is coveted to maintain a false notion of objectivity (Chávez, 2012). She tells stories to recreate instances where she collided with hegemonic ideological constructs, superstructures, embedded in the dominant educational practices she experienced.

LeFrançois used an autoethnographic narrative methodology to unpack how ‘benevolent’ institutions perpetuate Indigenous genocide (LeFrançois, 2013). Leveraging the fluidity of identities within queer theory, they ground in their own identities as a white colonizer adult, storytelling of normalized connections between psychiatrization, colonialism, racialization, and adultism. They discuss their shifting complicity, (in)actions, and relationships with power when working at a child protective agency through a series of visits to an Indigenous mother and her teenage daughter alongside a white social worker. They write about how in personal storytelling, the storyteller is often crafted as ‘good’ in comparison to others. To depart from this, they queer their own complicity to disrupt narratives of goodness and rightness in social work stemming from whiteness as an organizing principle.

Moffat leveraged autoethnography using grounded theory to unpack the significant disconnect and epistemological differences between engineering education and practice he observed in his thirty year trajectory “as a factory worker, who became a motor mechanic, an electronics technician, process engineer, university course director, associate dean and more recently a PhD student in education,” (Moffat, 2017, p. 77). By engaging grounded theory, autoethnography was used to generate data that then led to the generation of theories from that data. Upon theory generation, he engaged in a literature review and connected the theories he generated to literature. A component of his questioning was “how many potential engineering students were being discouraged by the association with mathematics, when in my experience I never used anything more complex than I had learned in high school,” (Moffat, 2017, p. 80). He noted the discontinuity between the prioritization of the objective and quantitative in dominant engineering education compared to social science methods and concepts emphasizing the subjective and qualitative that better reflected his engineering practice.

Holly Jr. leveraged critical autoethnography in a framework of Black Critical Theory (BlackCrit) and African American Male Theory to shed light on how his experiences as a Black male engineering student and educator shaped how he taught engineering to Black boys (Holly Jr., 2018). Teaching engineering to Black boys in a culturally relevant manner through the Curriculum on Repurposing Engineering and Teaching Equity (C.R.E.A.T.E) he developed, he pushed back on the absence of sociopolitical teaching practices in K-12 engineering education. He used autoethnography as a tool for self-study to teach more effectively and grapple with racial injustice in engineering education. In doing so, he drew from semi-structured interviews of himself before, during, and after delivering the CREATE curriculum, artifacts from his own work and the work of students, his own reflective and reflexive journaling, and videotapes of CREATE courses as data. His positioning as a community-engaged scholar reflected his sociopolitical teaching practices and allowed for significant interactions with the students who participated in CREATE outside of the course.

Haverkamp et al. engaged collaborative autoethnography in a resiliency framework as a means of highlighting processes transgender and gender nonconforming (TGNC) engineering undergrads used to navigate the gendered field of engineering (Haverkamp, et al., 2019). In doing so, two autoethnographers, Ava Butler and Naya Pelzl identifying as white, transgender, and queer women, investigated their experiences with social support inside and outside the classroom and perceptions of gender and engineering. Commonalities between their autoethnographies revealed that dominant engineering and trans culture are separate or incompatible, that online social landscapes constructed affirming spaces that may not have existed in person, and that their support systems existed primarily outside of engineering contexts. They name that TGNC students in engineering exist in liminal spaces, sites of transition between two worlds, where in one world outside of engineering we are affirmed and supported and in another we are met with discrimination or misgendering.

Through my graduate educational studies at the University of Michigan, the ways that I have understood myself and the context of my labor as a grad student worker in materials science and engineering have shifted dramatically. The sort of technological optimism that carried me through undergrad has thoroughly worn off as I have accepted more invitations to reflect on the sociopolitical facets of my work and my personhood. My acceptance of these invitations has stood in opposition to the nominal trend within dominant engineering education, where engineers become less attuned to social justice concerns as we/they are professionalized (Cech E. A., 2014). Cech discusses depoliticization, technical/social dualism, and meritocracy as key ideologies underpinning this trend (Cech E. A., 2013). My acceptance of these invitations also contextualizes the role of this dissertation as an attempt toward reducing the harm of my institutional location, taking responsibility for the constructed privileges and precarities I receive as a graduate student worker in materials science and engineering at UM.

Ellis and Adams offer seven principles to consider when writing and reading autoethnography:

- An emphasis on personal experience - embracing dual identities of academic and personal selves to tell stories about some aspect of experiences
- Familiarity with existing research - having a sense of what other researchers have said on the topic(s) of the autoethnography
- Using personal experience to describe and critique cultural experience - working to change culture through telling and unpacking stories connecting the personal and the cultural

- Taking advantage of and valuing insider knowledge - embracing existence within (or closely related to) the groups and cultures described, recognizing this offers different kinds of knowledge than outsiders have and impacts how the groups and cultures described are represented
- Breaking silence, (re)claiming voice - telling and justifying telling personal stories that can add nuanced personal perspectives to and fill experiential gaps in research that often disregards emotions, perpetuates canonical narratives, and promotes hegemonic beliefs and practices
- Healing and maneuvering through pain, confusion, anger, and uncertainty - making sense of “a repetitive or problematic cultural experience and [having] the possibility of venting our frustrations or at least making these frustrations known to others,” (Ellis & Adams, 2014, p. 263)
- And writing accessible prose - making “meaning and knowledge available to more than a select, academically trained few,” (p. 264) by refusing highly abstract and jargonistic writing (Ellis & Adams, 2014).

I have found these principles to be helpful guides as I moved through this autoethnography, where the methodology allowed me to sit with my experiences in grad school specifically and engineering more broadly as I made meaning of them. In particular, as a ‘small-n,’ qualitative study methodology it allowed me to discuss difficulties I faced in organizing engineers arising from systemic inequities that are broadly ignored, misunderstood, or otherwise upheld through (in)actions within dominant engineering. The magnitude and scope of the tensions and difficulties I experienced increased with my involvement in organizing, particularly seeing how engineering faculty and peers engaged with and responded to calls to action around environmental justice, labor, and issues the academy shoehorns into the catchall of 'DEI.' Autoethnography and the overlapping settings of materials science and engineering with engineering education research offered me a way to make these tensions studyable, leverage the power and expectations of my position as a researcher to bolster and better contextualize my organizing labor both for myself and others. The review of literature that I conducted with Corey and Donna on intersections of engineering and labor alongside discussions with friends in EER showed me that research on engineering labor, TGNC experiences in engineering, and anticolonialism in engineering and engineering education was scarce, offering an opportunity to gather and synthesize interconnections across a variety of academic disciplines and broader discourses while expanding my/the horizon of hope for what EER could be. Because the discourses from within dominant engineering seemed so disparate and externalized, synthesizing my understandings of them through my experiences and research trajectory as a dissertation in materials science and engineering offered an important political motivation to refuse the prevailing norms of a discipline to be abolished. At the same time, given that I branched into EER during my fourth of five years in grad school while maintaining technical materials science and engineering research obligations, autoethnography as a means of reflection allowed me to bring in shaping experiences from those first four years that were not captured through more standard qualitative methods (e.g. interviews, journaling, field notes, focus groups, etc.) as they occurred, yet were invaluable to the shaping of this inquiry. Rather than designing a study to recollect the essence of that data in some other form with more standard qualitative methods and recruit other participants with time I did not have and could not extend (as my funding sources expired at the end of my fifth year), autoethnography allowed me to leverage stories as data bolstered by the context of published research papers as well as other informational sources that shaped how I understood myself, my research, and my organizing. This methodological choice allowed for discussing topics I had been unable to find in MSE literature (e.g. abolition, colonialism, labor organizing) while shifting the primary form of data validation from one of the consistency and reproducibility strived for in quantitative studies toward one more deeply rooted in lived experience. Since this is rooted in the lived experience of one person the degree to which the understandings conveyed here can be claimed to be held widely and deeply across engineering is low and a substantial limitation to the methodology, however this tradeoff is made to allow for an expanded imaginary/characterization and performance of what MSE and EER could be.

At the same time, it allowed me to maintain an ethical validity within self-study by having a sense of what details and facets of stories I could and should disclose or generalize without violating the trust of any friends, colleagues, or organizations implicated in the stories. Sochacka, Walther, and Pawley frame validation as focusing on the question “do the findings appropriately capture & represent relevant aspects of the social reality observed?” (Sochacka, Walther, & Pawley, 2018, p. 376), helping me hone in on research questions and stories that aligned in scale and scope without pushing me to tell stories or details that felt inappropriate to share in a research context (e.g. internal deliberations on union strategies and campaign designs might be relevant to connections between engineers and labor unions in the context of engineering education, however that would constitute a significant breach of trust that I have no interest in doing). Inherently, these inquiry decisions are subjective, opening up questions of rigor and bias that autoethnographers have contended with for decades. Ellis, Adams, and Bochner describe how prevailing social scientific standards open autoethnographers up to critique “for doing too little fieldwork, for observing too few cultural members, for not spending enough time with (different) others," (Ellis, Adams, & Bochner, 2011, p. 283) while biasing data by using personal experience. Simultaneously, autoethnography is dismissed for being insufficiently aesthetic, literary, and artful. These criticisms construct a friction between art and science, whereas Ellis, Adams, and Bochner describe how "autoethnography, as method, attempts to disrupt the binary of science and art," (Ellis, Adams, & Bochner, 2011, p. 283). The primary learning method I engaged this autoethnographic methodology of disrupting this and other binaries was that of embracing existence in *Nepantla*.

4.2.1 Learning method: Embracing Existence in Nepantla

Through autoethnography, data can take the form of stories from my experiences while holding the complexity and fluidity of salient identity and shifting community and cultural meanings. I found this particularly compelling since I have often felt myself sitting at a confluence of multiple liminal spaces; at a point of tension between multiple figured worlds. Mejia et al. draw from the work of Chicana Feminist theorists to discuss the concept of *Nepantla* as a way Latinx youth participate in social change in engineering (Mejia, Wilson-Lopez, Robledo, & Revelo, 2017). *Nepantla*, stemming from the Nahuatl word meaning "tierra entre medio" (land in between), represents the place where people straddle multiple worlds, realities, and systems of knowledge (Gutiérrez, 2012). While I no longer consider myself a youth per-say, I found the state of *Nepantla* as a third space helpful in describing a number of my experiences, including those of being mixed Mexican-Puerto Rican and white Jewish, being non-binary, coming from the working-class and being indoctrinated/professionalized into the professional class, being a union organizer in engineering, and generally living through and writing this whole thesis within materials science and engineering at UM. *Nepantla* is described by Gloria Anzaldúa as

"… The site of transformation, the place where different perspectives come into conflict and where you question the basic ideas, tenets, and identities inherited from your family, your education, and your different cultures. *Nepantla* is the zone between changes where you struggle to find equilibrium between the outer expression of change and your inner relationship to it," (Anzaldúa & Keating, 2013, p. 548) in (Mejia, Wilson-Lopez, Robledo, & Revelo, 2017, p. 2).

In *Embracing Nepantla: Rethinking "Knowledge" and its Use in Mathematics Teaching*, Rochelle Gutiérrez further describes concepts introduced in Anzaldúa's writings connecting *Nepantla* to *conocimiento* (Gutiérrez, 2012). Gutiérrez discusses how *conocimiento* carries multiple meanings in Anzaldúa's writings, including "connection with others," "in solidarity," "being receptive to others," "that aspect of consciousness urging you to act on the knowledge gained," and developing ways of knowing unaccepted or not recognized in dominant conditions that Anzaldúa calls "outlawed" knowledges. *Conocimiento* situates *Nepantla* as an uncomfortable space without solid ground or official recognition that can give rise to "new ways of asking questions, new theories, and more interdisciplinary approaches to understanding the world around us," (Gutiérrez, 2012, p. 35). Gutiérrez offers a visualization of the cycle of *conocimiento*, our framing of the world and consciousness, and *Nepantla*, the multiple realities we understand ourselves to occupy, in Figure 10. I think of this cycle as a critical consciousness raising process, concientização (Freire, 1970). Nos/Otras allows us to see ourselves as connected to or alongside others while recognizing and being cognizant of differences (Gutiérrez, 2012). A rejection of this recognition and connection is an active state of distancing or choosing not to know, represented through the ignorant stance of *desconocimiento*. An embrace of this recognition gives rise to new *conocimiento*. This framing of two directions (refusing to know and embracing connected knowledge, technology and spirituality, death and life, decolonization and extinction) reflects a foundational struggle of our times (Simpson L. B., 2011); (Benton-Benai, 1988); (The Red Nation, 2021); (Estes, 2019). I think of this in the context of the liberatory engineering education model (LEEM) discussed in chapter 3, where *desconocimiento* can act to reinforce thin blue lines, undermining movements toward liberation/land back, while new *conocimiento* can make visible emergent lines of power that hold potential to abolish thin blue lines.

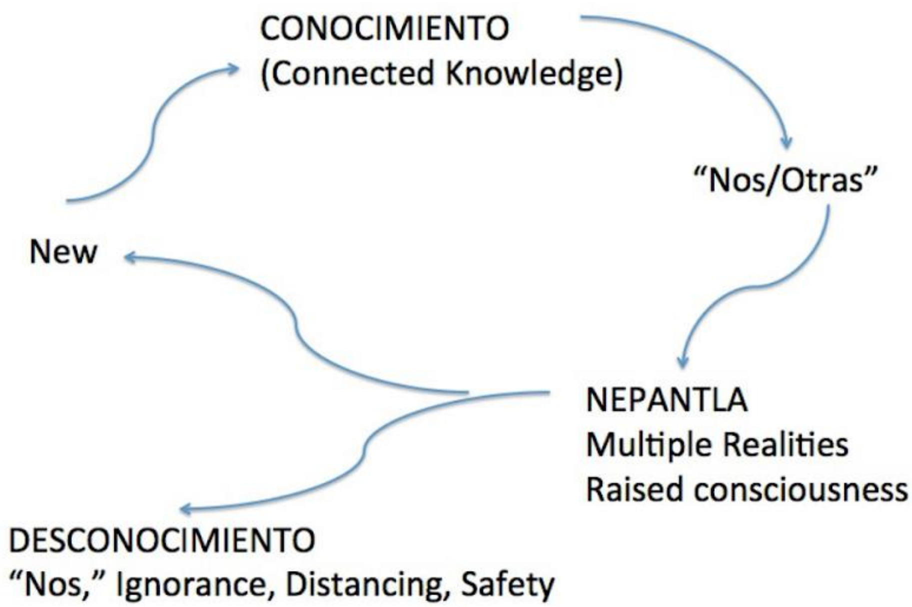


Figure 10: "The path of conocimiento," reproduced from (Gutiérrez, 2012).

4.2.2 Assessment Methods

The assessment methods I connected to this learning method in my autoethnographic praxis were reflecting on the papers I published during my time in graduate school and a public narrative storytelling method I had learned and used as an organizer. To navigate answering the three questions my dissertation centers on, I use the existing scholarship of published papers I contributed to during my graduate studies as a first or second author as opportunities for reflection. These papers are:

- Valle, J., Riley, D. M., Slaton, A. E. (2022) A Third University is Possible? A Collaborative Inquiry within Engineering Education. 2022 ASEE Annual Conference.
- Modak, S., Valle, J., Tseng, K.T., Sakamoto, J., Kwabi, D. G. (2022) Correlating Stability and Performance of NaSICON Membranes for Aqueous Redox Flow Batteries. ACS Appl. Mater. Interfaces, 14, pp. 19332-19341.
- Bond-Trittipo, B., Valle, J., Secules, S., & Green, A. (2022) Challenging the hegemonic culture of engineering: Curricular and co-curricular methodologies. 2022 Collaborative Network for Engineering and Computing Diversity (CoNECD).
- Bowen, C. L., Valle, J. M., Mondisa, J. L., Johnson, A. W., Sakamoto, J., Powell, K. G. (2021) "The Undergraduate Engineering Collaborative Growth Series": a Diversity, Equity, and Inclusion Program Supporting the Empowerment of Marginalized Students. 2021 Frontiers in Education Annual Conference.
- Valle, J., Huang, C., Tatke, D., Wolfenstine, J., Go, W., Kim, Y., Sakamoto, J. (2021) Characterization of hot-pressed von Alpen type NASICON ceramic electrolytes. Solid State Ionics, 369, 115712.
- Valle, J., Bowen, C. L., Riley, D. M. (2021) Liberatory Potentials of Labor Organizing in Engineering Education. 2021 ASEE Annual Conference and Exposition, 33603.
- Valle, J., Ali, I., Bowen, C. L., Riley, D. M. (2021) Experiences of Engineering Students Participating in an Abolitionist Labor Strike. 2021 ASEE Virtual Annual Conference and Exposition, 33614.

- Valle, J. M., Sakamoto, J. (2020) The effect of lanthanoid defects on anionic solvation of Li in Li6.5La2+xZr1.5Ta0.5O12 from x=0 to x=1.2 garnet. Solid State Ionics, 345, 115170.

Each of these papers leveraged their own methodologies and methods, which will be further discussed in the reflections. To guide these reflections I use the updated LEEM prototype from chapter 3 as an analytic tool to discuss 1) my professionalization in materials science and engineering, 2) how I have characterized and recharacterized the role of materials science and engineering (and dominant engineering more broadly) in settler society, and 3) how those recharacterizations relate to my engagement with an abolitionist praxis within materials science and engineering.

Alongside this analytic tool, I use the public narrative storytelling method "originally adapted from the works of Marshall Ganz of Harvard University" to add relevant context that I understand to have shifted my *conocimiento* (We The People Michigan, 2018). I first learned of this method as an organizer in the Graduate Employees' Organization (GEO), and my participation in a two day 'Leadership, Organizing, and Action' workshop put on by We The People, Michigan (WTPMI) gave me a greater depth of understanding how to work with this method. There, organizers with WTPMI used a four-stage pedagogy to explain how story works, model the storytelling practice, provide us workshop participants with space to come up with and practice our own story, and debrief our practice with others.

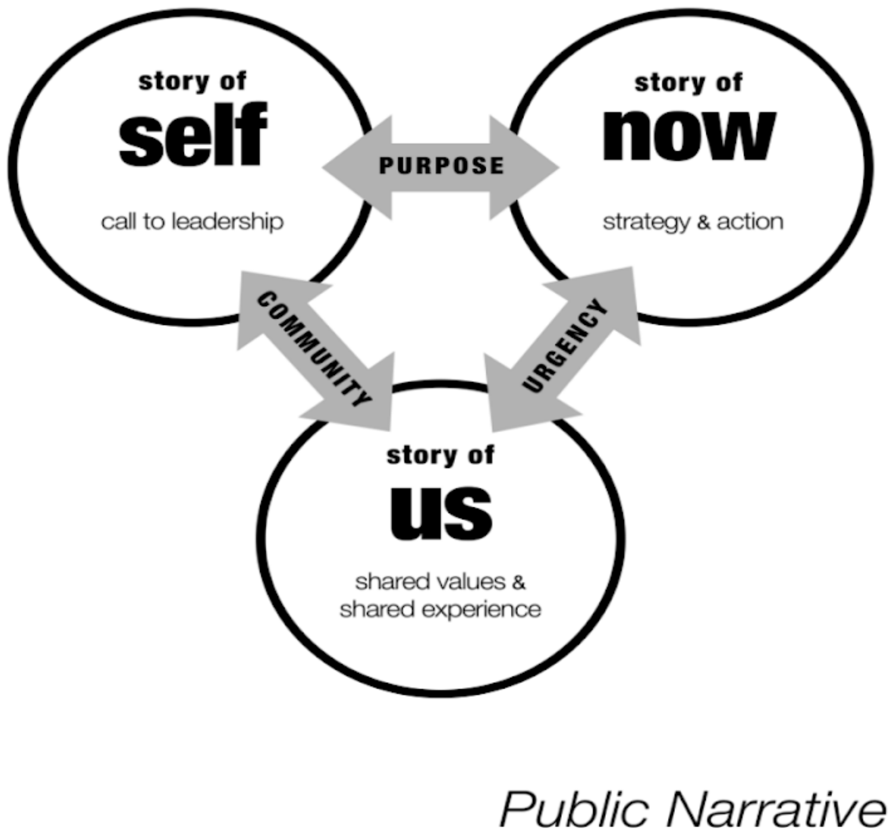


Figure 11: Public narrative as a combination of a story of self, a story of us, and a story of now (We The People Michigan, 2018).

Ganz describes three key elements of this public narrative structure as challenge, choice, and outcome (We The People Michigan, 2018). As unexpected challenges arise, people are presented with choices and draw on values in order to guide how they choose to act, where the choice leads to an outcome and teaches a moral. In this method, a public narrative is a combination of a story of self, a story of us, and a story of now, see Figure 11. A story of self communicates the values that called you to take action, the component of conocimiento discussed as "that aspect of consciousness urging you to act on the knowledge gained," (Gutiérrez, 2012) that allows people to connect with who you are and why you do the work you do. Key to a story of self is a focus on choice points, "those moments in our lives when we experienced the influence of our values on the choices we made that have shaped who we have become," (We The People Michigan, 2018, p. 35). A story of us connects those values and choices to shared values that anchor communities we are a part of and shared experiences within those communities that we can connect to. In this way, a story of us links to the component of *conocimiento* of connecting to and being receptive to others. A story of now communicates an urgent choice faced by your community, one which frames an opportunity to act. A story of now sits at an intersection of a challenging vision that could come if we as a community do not act and a hopeful vision of what may come from taking action. A story of now bridges a story of why we should act to a strategy of how we can act effectively, rooting in the values from the story of self and story of us.

Chapter 5 Batteries

This chapter describes how I came to research batteries coming into my graduate studies, my research on lithium-based solid electrolytes for batteries, ethical conflicts I encountered around lithium sourcing, navigating those conflicts within the confines of dominant engineering by switching to research on sodium-based solid electrolytes for batteries, incommensurabilities of that navigation that led me to see it inadequately addressed the ethical conflicts I encountered, and how those persisting ethical conflicts led me to a deconstruction and transform my relationship with dominant engineering. Coming from Miami, FL, in the so-called sunshine state, I could count on one hand the number of solar arrays I'd seen at home despite hearing for years how big of an issue climate change was. Since high school I'd come to understand batteries, a more common name for a wide set of electrochemical energy storage systems, as a key technological limitation to the widespread propagation of renewable energy technologies. With the batteries and other renewable energy technologies would come the transition away from fossil fuels and the damage they cause to ecosystems. It was that environmentalist drive to halt climate change that moved me to get involved in electrochemical research in undergrad. During those years, I bounced around a number of labs picking up research experience and a sense of experimental design along the way. It also gave me a sense that while the day to day of research was not particularly enthralling, I was making a small contribution to the meaningful and larger project of making the systems that support human life more sustainable as a way to make the world a better place.

The conviction that batteries were this good, key technological solution to the societal need to combat climate change was one I left largely unquestioned despite many opportunities to do so in undergrad. For instance, my participation in Fossil Free MIT showed me that fossil fuel companies were major funders of the MIT Energy Initiative that many campus renewable energy projects ran through. Yet I focused on the renewable energy projects themselves rather than also considering the conditions they were embedded in, reflective of my engineering education to focus on the technical and externalize sociopolitcal considerations. Particularly I remember a conversation I had with my high school U.S. history teacher Mr. Hernandez when I had gone back to visit a couple years into undergrad. I talked with him about how excited I was to be researching battery technologies and the sorts of vehicles I got to build as part of the MIT Electric Vehicle Team (EVT). After listening to me, I remember him bringing up the poor Chilean lithium miners and the further difficulties they'd face as electric vehicle production ramped up. While this was the sort of comment I should have come to expect from the man who'd given me the foundation of my understanding of U.S. imperialism through our class discussions on the Banana Wars, I just shrugged it off. I did not value their lives, my focus was too narrow to see them, a focus continually affirmed in my engineering education. Mr. Hernandez was speaking of another sort of 'doing good' outside of the technological solutions that my conviction and engineering education centered on (Lambrinidou, 2018).

In undergrad it was normal for the engineers and natural scientists to devalue and disregard the work of humanities, arts, and social science (HASS) majors and that majorism helped me disregard the additional layers of complexity his comments raised (Carrigan & Bardini, 2021). I chose *desconocimiento* over understanding why or how that connected to the battery research I was doing, since those questions seemed like they'd muddy the waters of my conviction and leave me unsure whether or not what I was doing was actually good. That wasn't something I was prepared to grapple with both in terms of the skillsets my engineering professionalization trained me in and the support systems that could help me process those questions along with any changes I might need to make as a result. So my conviction remained in place despite those seeds of an understanding otherwise having been planted within me.

As my time in undergrad came to a close, I knew I still wanted to work on batteries and grad school offered a clear path to continue doing so. My last research advisor in my undergraduate studies, Prof. Chiang, had told me Prof. Sakamoto was one of the leading battery researchers in the U.S., making it so that when I applied to UM I named him as the professor I'd like to study with. After I chose UM for graduate school we connected over electric vehicles and the need to transition from fossil fuels making it so that I was fortunate enough for him to accept me into his lab. I came in excited to continue contributing to the development of electrochemical energy storage systems.

5.1 LLZO

In the Sakamoto lab the project I worked on all the way through to my candidacy exam was looking at lanthanum site defects in the solid electrolyte lithium lanthanum zirconium oxide (LLZO). Lithium-ion batteries have been the standard rechargeable batteries found in cell phones, laptops, electric cars, and many other electronic devices for over twenty years now. They have been engineered to the point where their achieved ability to store and deliver energy has nearly matched their theoretical potential to do so, setting up a need for new configurations and materials to be developed that expand this theoretical ceiling. One of the ideas of how to do so that has been well resourced is swapping out the anode, one of the two electrodes where energy in the form of bonded lithium is stored and transferred to the other electrode on demand in a highly controlled and reversible process.

The current anode in lithium-ion batteries is a porous graphite electrode that allows lithium to be stored in between graphite layers, limiting the amount of energy per unit mass (specific energy with units of Wh/kg) and amount of energy per unit volume (energy density with units of Wh/L), see Figure 12 (Albertus, Babinec, Litzelman, & Newman, 2018). Swapping this graphite anode out with one that is just lithium would result in a higher specific energy and energy density, however this has largely been prevented by the safety issues (aka explosions and fires) stemming from the reactivity of lithium with the liquid electrolytes used to shuttle the lithium ions between electrodes. Solid electrolytes are considered a means of resolving these safety issues owing to their greater stability with lithium compared to liquid electrolytes, and investigating one facet of one of those solid electrolytes using the scientific method was the focus of my first first author paper *The Effect of Lanthanoid defects on Anionic Solvation of Li in Li6.5La2+xZr1.5Ta0.5O12 from x =0 to x=1.2 Garnet* (Valle & Sakamoto, 2020).

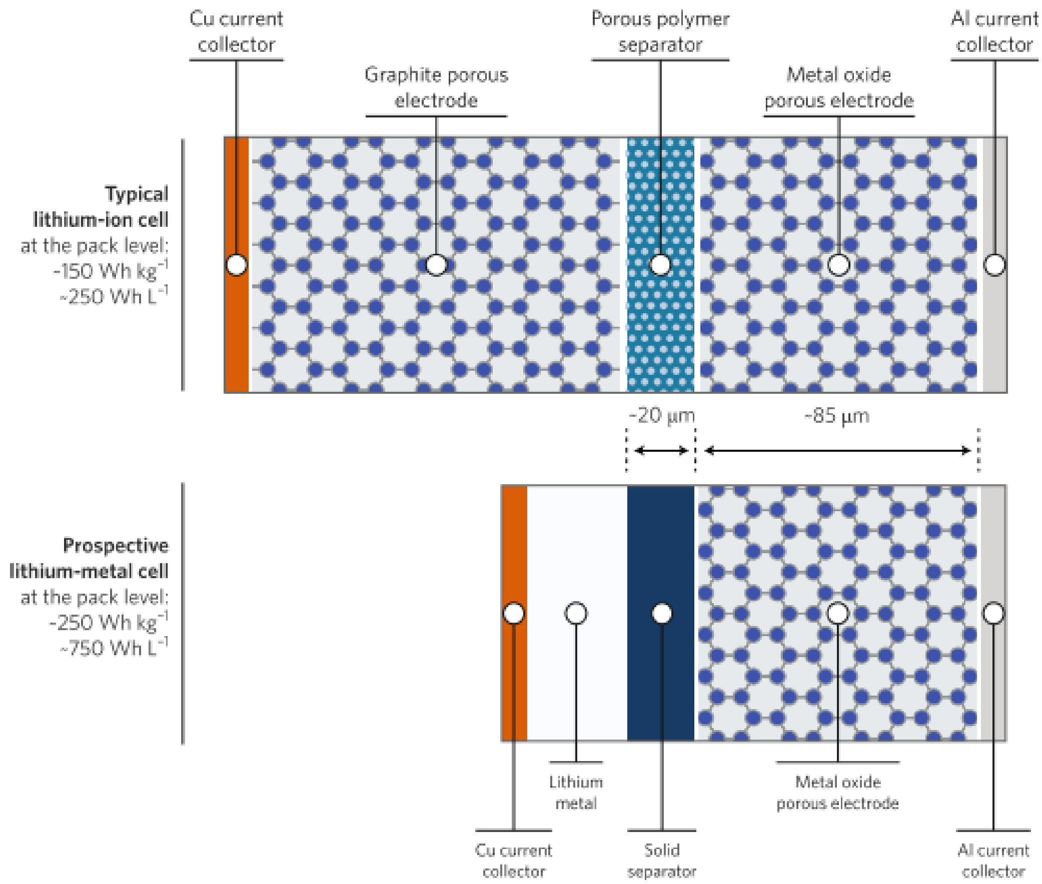


Figure 12: "A typical Li-ion cell (top) and one conception of a lithium metal cell (bottom), containing a solid separator and a dense layer of metallic lithium. … Layer thicknesses are shown to scale. The reduction in volume and mass associated with replacing the graphite electrode with lithium metal is evident," (Albertus, Babinec, Litzelman, & Newman, 2018, p. 17).

5.1.1 Introduction

Energy density and battery safety are important factors for electric vehicle (EV) commercialization (Tarascon & Armand, 2001). The use of lithium metal anodes could enable batteries with higher energy densities. As a result, significant interest has developed around solid state electrolytes (SSE) as materials which can enable lithium metal anodes and serve as a means to improve safety (Murugan, Thangadurai, & Weppner, 2007); (Sun, Liu, Gong, & al., 2017). Lithium lanthanum zirconium oxide (LLZO) has shown promise as a solid electrolyte, due to its high Li+ conductivity (~1mS/cm at room temperature), its good stability against metallic lithium, and a wide electrochemical window (~6eV) to accommodate high voltage cathodes (Murugan, Thangadurai, & Weppner, 2007). While the tetragonal polymorph of LLZO is stable at room temperature, it exhibits a lower conductivity (~10-2 mS/cm lower) than the cubic LLZO polymorph. Significant work has been done to investigate dopants which stabilize the cubic LLZO polymorph at room temperature by creating Li vacancies (0.5 moles per formula unit LLZO to stabilize the cubic phase – Ia3d) (Thompson, Sharafi, Johannes, & al., 2015); (Thompson, Wolfenstine, Allen, & al., 2014); (Rangasamy, Wolfenstine, & Sakamoto, The role of Al and Li concentration on the formation of cubic garnet solid electrolyte of nominal composition Li7La3Zr2O12, 2012); (Geiger, Alekseev, Lazic, & al., 2011); (Miara, Ong, Mo, & al., 2013); (Rettenwander, Redhammer, Preishuber-Pflügl, & al., 2016). Much attention has been paid in correlating lithium vacancies in LLZO with ionic conductivity, however comparatively little research has focused on the effects of other cation vacancies that can be present in LLZO. For example, Shimonishi et al. used a combination of chemical analysis (inductively couple plasma ICP) and atomic structural characterization (X-ray diffraction XRD) to indicate the presence of a nominal La deficiency in Al doped LLZO samples in addition to claiming LLZO should have oxygen deficient sites (Shimonishi, Toda, Zhang, & al., 2011). This claim was confirmed by recent studies which indicate the presence of oxygen vacancies in LLZO (Kubicek, Wachter-Welzl, Rettenawnder, & al., 2017); (Zhan, Lai, Gobet, & al., 2018); (Mukhopadhyay, Thompson, Sakamoto, & al., 2015). Kubieck et al. proposed that oxygen vacancies can affect Li+ conductivity by reducing the stoichiometry of Li as they act as a donor, by elastically deforming the LLZO lattice which impacts phase formation and stability, and by affecting the migration barriers and Li+ conduction pathways (Kubicek, Wachter-Welzl, Rettenawnder, & al., 2017). Wagner et al. also found an indication of a La deficiency relative to Zr content in Fe doped LLZO samples with the acentric $I\bar{4}3d$ crystal structure and others have showed a small amount of La defects that were found to decrease with increasing Ga content in LLZO (Rettenwander, Redhammer, Preishuber-Pflügl, & al., 2016); (Wagner, Redhammer, Rettenwander, & al., 2016); (Rettenwander, Geiger, Tribus, & al., 2014); (Wanger, Redhammer, Rettenwander, & al., 2016). Density functional theory studies by Moradabadi et al. and Squires et al. indicated that defects involving La and Zr sites are thermodynamically favorable under various conditions (Moradabadi & Kaghazchi, 2019); (Squires, Scanlon, & Morgan, 2019). As La is the largest cation present in LLZO, La defects should show a dramatic effect on lattice parameter, which has implications on bottleneck size for Li+ diffusion as well as Li+ conductivity. The experimental studies which reported La deficiencies do so as a secondary factor to studies of various doping strategies, which convolute any effects a La deficiency may have. A study of La deficiency in LLZO has yet to be undertaken.

To this end, powder XRD, powder Neutron diffraction (ND), Raman spectroscopy, scanning electron microscopy (SEM), electrochemical impedance spectroscopy (EIS), and DC cycling were used to investigate the role of La deficiency in tantalum doped LLZO (LLZTO). La was varied stoichiometrically from x=0.2 to x=1.2 in Li6.5La2+xZr1.5Ta0.5O12. The effect of sub and supercritical addition of La on the lattice parameter, formation of impurities, microstructure, and conductivity are investigated. A defect mechanism and a decomposition method of LLZO are proposed.

5.1.2 Methods

Materials Synthesis and Processing

Li2CO3 (1 µm, Alfa Aesar, Ward Hill, MA), La(OH)3 (99.95%, Alfa Aesar, Ward Hill, MA), ZrO2 (30-60nm, Inframat, Advanced Materials, Manchester, CT), and Ta2O5 (99.99% Inframat, Advanced Materials, Manchester, CT) were used as starting precursors to synthesize

LLZTO compounds with compositions $Li_{6.5}La_{2+x}Zr_{1.5}Ta_{0.5}O_{12}$ with La compositions x=0.2, 0.4, 0.5, 0.6, 0.8, 1.0, 1.1, and 1.2 via a solid-state synthesis process. The precursors were weighed in stoichiometric amounts and ball milled in ethanol for 20 hours. An excess of 5-6 wt% of Li_2CO_3 was added to account for Li volatilization during calcination. The resulting mixture was dried, cold pressed into pellets, and calcined at 1000˚C in air for 4 hours. The calcined pellets were then reground, cold pressed into pellets, placed in a graphite die and hot pressed using a custom rapid induction hot pressing technique at 1200˚C for 40 min under flowing argon at a pressure of 47MPa. The resulting billet was then cut into to 1.0 ± .2 mm thickness pellets using a diamond saw, and the pellets were polished down to a final 0.1μm final polish with diamond paste. Samples which underwent electrochemical testing were then heat treated at 400˚C in Ar for 3 hours, then freshly scraped Li was applied to the LLZTO surface and compressed with Ni foil current collectors using previously established methodology (Sharafi, Haslam, Kerns, & al., 2017). The Li|LLZTO|Li symmetric cells were then conditioned for 12 hours at 170˚C to ensure good surface contact between the Li and the LLZTO.

Materials Characterization

Powder XRD of post hot pressed samples was performed on a Rigaku Miniflex 600 using Cu Kα radiation over 2θ range of 15˚ to 65˚ with a 0.02˚ step size. Time of flight neutron powder diffraction data was collected at the POWGEN beamline at the Spallation Neutron Source (SNS), Oak Ridge National Laboratory (ORNL) with a center wavelength of 0.8Å at 300 K to obtain diffraction patterns spanning d- spacings of 0.2-5.0 Å. Rietveld structural refinements of powder XRD and powder ND were performed using Jade 2010 and GSAS-II, respectively. Relative density was obtained from taking average from both geometric and buoyancy methods. The Buoyancy method utilized Archimedes' Principle in cyclohexane at 21˚C. Raman spectroscopy was performed on a Horiba Micro Raman Spectrometer using a 532nm laser and a 1200 grating over Raman shifts from -10 to 900 cm-1. Microstructural analysis was performed on a JEOL IT500 SEM. Electrochemical impedance spectroscopy (EIS) and DC cycling were performed on a Biologic VMP-300 galvanostat/potentiostat. EIS was conducted from 50mHz to 1Mhz with a perturbation of 10mV in Li|LLZTO|Li symmetric cells. Temperature dependent EIS was performed over a range of 10˚C to 25˚C. Critical current density was measured under galvanostatic cycling using 0.25 mAh cm-2 per cycle under a constant uniaxial pressure of 3.5MPa, as in (Sharafi, Haslam, Kerns, & al., 2017). Current densities tested ranged from between 0.25 and 1mA cm-2, with the current density being stepped from 0.25 mA cm-2 to 0.5 mA cm-2, from 0.5 mA cm-2 to 0.6 mA cm-2, and subsequently increased 0.05 mA cm-2 per cycle until cell failure.

5.1.3 Results and Discussion

X-Ray and Neutron Diffraction

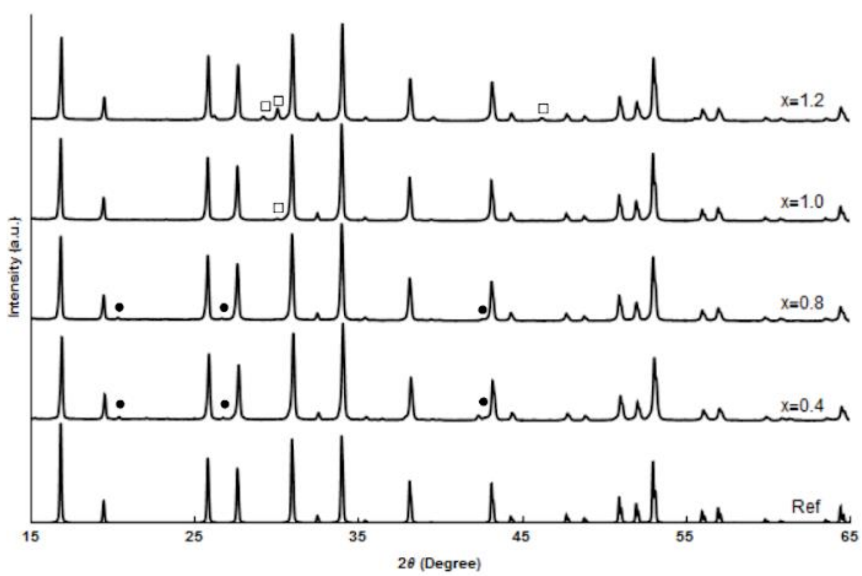


Figure 13: XRD spectra of samples x=0.4, x=0.8, x=1.0, and x=1.2 in $Li_{6.5}La_{2+x}Zr_{1.5}Ta_{0.5}O_{12}$; garnet reference (Thompson, Sharafi, Johannes, & al., 2015). • Correspond to Li_2ZrO_3 and $Li_6Zr_2O_7$ peaks and □ corresponds to La_2O_3.

X-ray diffraction was conducted for eight different values of stoichiometric La. Fig. 13 shows the x-ray spectra for x=0.4, 0.8, 1.0, and 1.2. All of the samples examined clearly showed the presence of LLZTO, as shown in the reference in Fig. 13 and Table 6. The LLZTO phase purity of all samples remained above 87.5 wt%, values of RBragg for LLZTO remained below 6.5% in each sample, and the Rwp values for each sample remained below 7.25%, indicating that the Ta doping was successful in stabilizing the cubic garnet phase (Logéat, Köhler, Eisele, & al., 2012). Additionally, the presence of pyrochlore ($La_2Zr_2O_7$) could not be detected, indicating enough of an excess of Li_2CO_3 was added to account for the volatilization of lithium during the synthesis process (Rangasamy, Wolfenstine, & Sakamoto, The role of Al and Li concentration on the formation of cubic garnet solid electrolyte of nominal composition $Li_7La_3Zr_2O_{12}$, 2012). Fig. 13 also shows that at subcritical La compositions x=0.4 and =0.8 lithium zirconates (Li_2ZrO_3 and $Li_6Zr_2O_7$) are present. The weight percent of the lithium zirconates at each composition are indicated in Table 6. A decrease in the presence of lithium zirconates can be observed as La deficiency is decreased from x=0.2 to x=1.0, indicating that Li_2ZrO_3 and $Li_6Zr_2O_7$ could be decomposition products of LLZO. Miara et al. and Canepa et al. have both performed DFT calculations indicating the products of LLZO decomposition to be Li_8ZrO_6, $Li_6Zr_2O_7$, and La_2O_3 (Miara, Ong, Mo, & al., 2013); (Canepa, Dawson, Sai Gautam, & al., 2018). However, Canepa et al. also indicates a metastability of Li_8ZrO_6 and Neubert et al. has outlined thermal decomposition reactions of Li_8ZrO_6 into Li_2ZrO_3 (Canepa, Dawson, Sai Gautam, & al., 2018); (Neubert & Guggi, 1978). The high energy environments of the synthesis process could have promoted the decomposition of Li_8ZrO_6 into Li_2ZrO_3. The lattice parameter of the samples showed a linear increase from 12.923 Å at x=0.2 to 12.936 Å at x=1.2, as shown in Fig. 14 a) and Table 6. The lattice parameter at x=1.0 was observed to be 12.9298 Å, which shows good agreement with the literature value of 12.9307Å and 12.9305Å (Thompson, Sharafi, Johannes, & al., 2015); (Mukhopadhyay, Thompson, Sakamoto, & al., 2015). The change in lattice parameter is indicative of a change in the La concentration within the LLZTO crystal structure, which may be the result of a complex defect type consisting of VLa, VLi, and VO or cation-antisite defects such as LiLa and ZrLa. The increase in lattice parameter at La values above x=1.0 could represent further uptake of La by the LLZTO structure, indicating a presence of La site defects even at the stoichiometric composition, which is in agreement with theoretical calculations (Squires, Scanlon, & Morgan, 2019). Table 1 also shows the increase in the presence of La2O3 from x=1.0 to x=1.2, indicating that some of the excess La goes unreacted. Changes in lattice parameter and formation of impurities indicate that changes to La concentration can elastically deform the LLZTO lattice and affect phase formation and stabilization, which was one of the influences Kubieck et al. proposed oxygen vacancies could have on LLZO (Kubicek, Wachter-Welzl, Rettenawnder, & al., 2017).

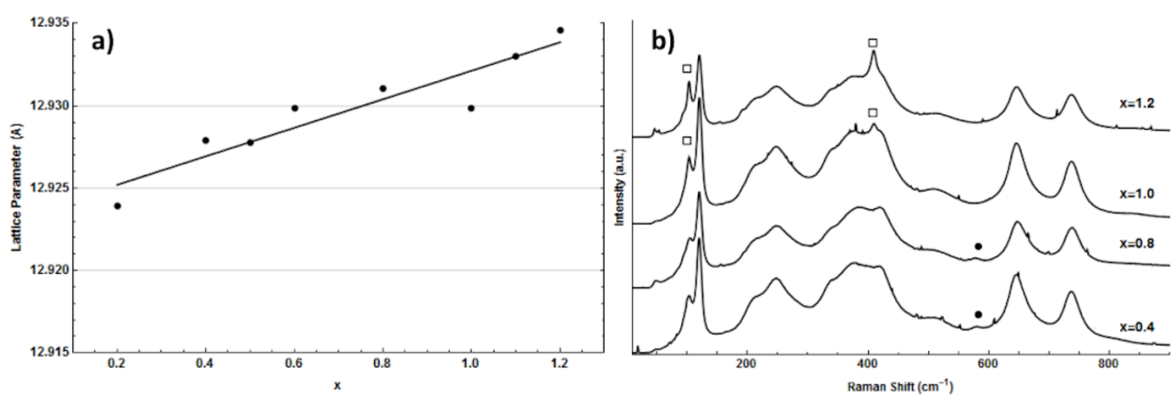


Figure 14: a) Lattice parameters of samples from x=0.2 to x=1.2 as determined by Rietveld refinement of XRD spectra, b) Average Raman Spectra for samples x=0.4, x=0.8, x=1.0, and x=1.2 in $Li_{6.5}La_{2+x}Zr_{1.5}Ta_{0.5}O_{12}$. • Correspond to Li_2ZrO_3 and □ corresponds to La_2O_3.

Table 6: Summary of physical properties of samples of LLZTO $Li_{6.5}La_{2+x}Zr_{1.5}Ta_{0.5}O_{12}$ as x is varied.

Sample	Lattice Parameter (Å)	Relative Density (%)	$Li_{6.5}La_{2+x}Zr_{1.5}Ta_{0.5}O_{12}$ (wt%)	R_{Bragg} (%)	R_{wp} (%)	$Li_2ZrO_3 + Li_6Zr_2O_7$ (wt%)	La_2O_3 (wt%)
X=0.2	12.923	97.0 ± 0.5	88.4	6.41	7.08	9.3	0.0
X=0.4	12.926	97.4 ± 0.5	87.9	6.23	6.92	9.8	0.0
X=0.5	12.928	98.1 ± 0.5	93.2	5.68	5.62	5.7	0.0
X=0.6	12.930	98.0 ± 0.5	88.4	5.41	7.07	1.8	0.0
X=0.8	12.931	98.2 ± 0.5	97.4	5.47	5.25	1.9	0.0
X=1.0	12.930	98.9 ± 0.5	96.2	5.81	5.66	0.0	0.5
X=1.1	12.933	97.2 ± 0.5	96.8	4.76	4.69	0.0	2.3
X=1.2	12.936	96.4 ± 0.5	91.5	5.47	5.44	0.0	4.7

Analysis of Neutron Diffraction data at x=0.8 and x=1.0 showed the relative occupancy of La to resemble values anticipated from synthesis, see Table 7. Results from the Neutron diffraction data indicate x=1.0 and x=0.8 samples show stoichiometries of Li6.533La2.976Zr1.5Ta0.5O11.964 and Li6.399La2.852Zr1.5Ta0.5O11.792, respectively. This indicated the presence of La site defects, even at stoichiometric composition. It was also indicated that the 24d site Li ions and O ions depopulate moving from x=1.0 to 0.8, suggesting the potential for a complex defect mechanism, such as the one proposed by Moradabadi [17].

Table 7: Summary of results of Neutron Diffraction.

Sample	Lattice Parameter [Å]	Atom Name	Site	Site Occupancy	X	Y	Z	100 x U_{iso} [$Å^2$]
X=1.0	12.92725	Li1	24d	0.4205	0.3750	0.0000	0.2500	0.516
		Li2	96h	0.4393	0.0972	0.6868	0.5790	1.793
		La	24c	0.9919	0.1250	0.0000	0.2500	0.558
		Zr	16a	0.7500	0.0000	0.0000	0.0000	1.171
		Ta	16a	0.2500	0.0000	0.0000	0.0000	-0.807
		O	96h	0.9970	-0.03170	0.0536	0.1488	1.235
X=0.8	12.92876	Li1	24d	0.3738	0.3750	0.0000	0.2500	0.744
		Li2	96h	0.4398	0.0972	0.6868	0.5790	1.795
		La	24c	0.9507	0.1250	0.0000	0.2500	0.638
		Zr	16a	0.7500	0.0000	0.0000	0.0000	0.604
		Ta	16a	0.2500	0.0000	0.0000	0.0000	1.000
		O	96h	0.9827	-0.03170	0.0536	0.1488	1.539

Raman Spectroscopy

The Raman spectra shown in Fig. 14 b) were collected for samples x=0.4, x=0.8, x=1.0, and x=1.2. The spectra collected confirmed the presence of La2O3 in samples x=1.0 and above, as indicated by the bands at 107 cm-1 and 410 cm-1 (Boldish & White, 1979). Li2ZrO3 can also be observed at sub-stoichiometric compositions, as indicated by the band at 577 cm-1 (Ma, Fu, Liu, & al., 2016). The Raman spectra collected also indicated no presence of tetragonal LLZO, as no splitting of vibrational modes near bands at 100 cm-1 or 120 cm-1 could be observed (Thompson, Sharafi, Johannes, & al., 2015); (Tietz, Wegener, Gerhards, & al., 2013).

Density

The hot-pressed samples showed a slight increase in relative density as x was increased until x=1.0, where it reached a maximum value at 98.9%, as seen in Table 1. The relative density then decreased as additional La was added. Thompson et al. observed a relative density of 97.8% for LLZTO when samples were hot pressed at 1025˚C for 1 hour (Thompson, Sharafi, Johannes, & al., 2015). It has also been shown that increasing hot pressing temperature increases relative density, so the value obtained for x=1.0 is in line with literature (Sharafi, Haslam, Kerns, & al., 2017); (David, Thompson, Wolfenstine, & al., 2015). Since the same RIHP conditions were used in the synthesis of each of the samples, the changes in relative density could be due to the presence of impurities altering the porosity of the sample.

SEM Analysis

The fracture surfaces of LLZTO were investigated for each of the samples. Figure 15 shows the fracture images of samples x=0.2, x=0.8, x=1.0, and x=1.2. Two different fracture types were observed in the samples. Intergranular, fracture between the grains, can be observed as the primary fracture type for samples below x=0.8. At the x=0.8 sample, a mixture of intergranular and intragranular, fracture through the grains, can be observed. At and above x=1.0, primarily intragranular fracture can be observed. This may be an indication that the presence of zirconates work to decrease the grain boundary adhesion of the under lanthanated samples, causing fracture along the grains instead of through them. This may also be due to a decreased La concentration near the grain boundaries, as LLZO exhibits normal grain growth which is rate-limited by lanthanum diffusion (Sharafi, Haslam, Kerns, & al., 2017). The mix of inter and intragranular fracture observed in the x=0.8 sample is likely due to the decreased presence of zirconates in the sample, allowing for a greater grain boundary adhesion. Intergranular fracture observed in samples at and above x=1.0 is an indication of relatively strong bonding between grains (Rangasamy, Wolfenstine, J., & al., 2013).

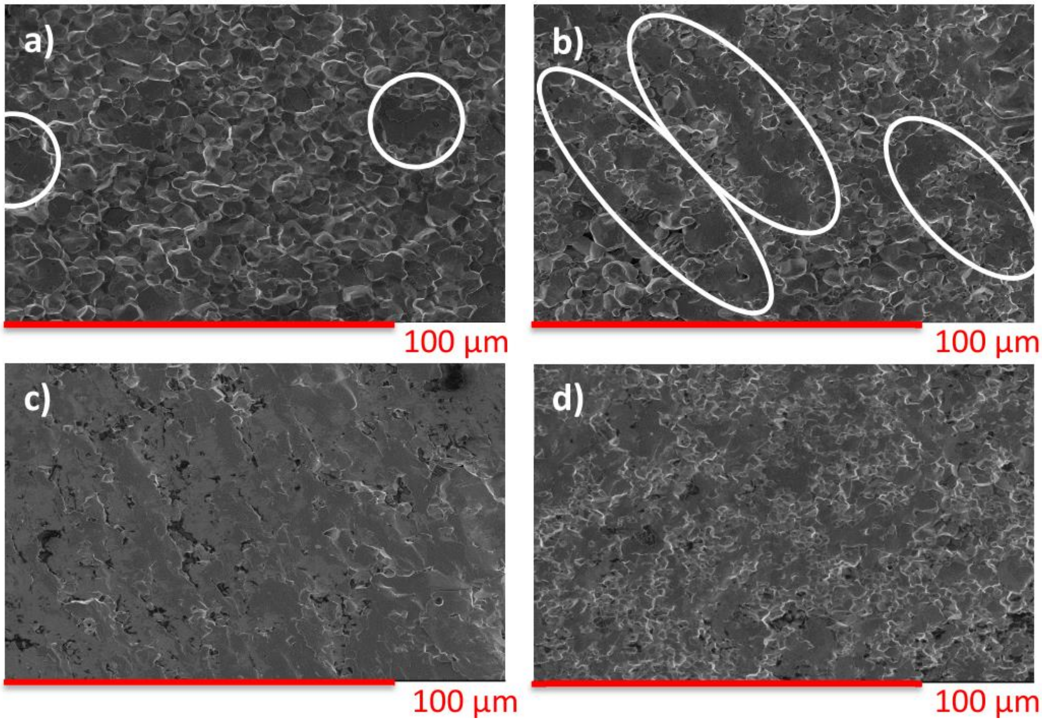


Figure 15: SEM Fracture surface images for samples a) x=0.2, b) x=0.8, c) x=1.0, and d) x=1.2 in $Li_{6.5}La_{2+x}Zr_{1.5}Ta_{0.5}O_{12}$. Regions of intragranular fracture are circled in a) and b).

Electrochemical Impedance Spectroscopy

EIS was conducted on each of the samples. A modified version of the equivalent circuit proposed by Huggins was used to determine the ionic conductivity of the samples, see Fig. 16 a) (Huggins, 2002). To account for variations in the time constants, the capacitive elements were replaced by constant phase elements (CPEs), and resistive elements were used to represent the uncompensated impedance of the system, the bulk material, the grain boundaries, and the interface between LLZTO and the Li electrode (Wang & Sakamoto, 2018). Nyquist plots from samples x=0.4, x=0.8, x=1.0, and x=1.2 are shown in Fig. 16 b). It can be observed that the total impedance of the cells decreases as the samples become less La deficient, and increase once excess La was added. Fig. 16 c) shows the conductivities obtained from fitting to the equivalent circuit. The bulk and grain boundary contributions showed an increase in conductivity as the samples became less La deficient, then a decrease as excess La was added. The slight changes in bulk conductivity is in line with the minimal change to 96h Li site occupancy, which were determined to be primarily responsible for the high ionic conductivity of Li garnets, observed in neutron diffraction, see Table 7 (Thompson, Sharafi, Johannes, & al., 2015). At room temperature, Li2ZrO3 (.1mS/cm at 598K reported) and Li6Zr2O7 (9.4*10-3 mS/cm at 573K reported) exhibits comparatively low conductivities ~10-7 to 10-9 mS/cm, indicating their presence should lower the conductivity of the samples below x=1.0 (Sherstobitova, Gubkin, Bobrikova, & al., 2016); (Liao, Singh, Park, & al., 2013). The conductivities obtained do not follow the rule of mixtures, in which the conductivities of LLZTO and each of the lithium zirconates are multiplied by their phase fraction present in each sample, for samples at and below x=1.0, indicating that changes in conductivity cannot solely be attributed to the presence of the zirconate phases. The presence of lanthanum oxide in the samples above x=1.0 likely results in the conductivity decrease as x exceeds 1.0, owing to the poor conductivity of lithium in the lanthanum oxide. An Arrhenius plot of the conductivity of the bulk contribution as a function of temperature was constructed for temperatures from 283K to 298K, see Fig. 4 d). The resulting activation energies can be seen in Table 8. The activation energy at x=1.0 was found to be 0.54eV in the present study, which is slightly higher than previously reported (Thompson, Sharafi, Johannes, & al., 2015); (Inada, Kusakabe, Tanaka, T., & al., 2014); (Buschmann, Berendts, Mogwitz, & al., 2012). A general increase in activation energy could be observed until x=1.0 is reached, after which a general decrease in activation energy can be observed. The presence of La defects in the samples could work to decrease the activation energy by changing the lithium ion conduction pathways in LLZO, while ultimately lower sample conductivity could result from other deleterious mechanisms such as the formation of lower conductivity impurities and presence of grain boundaries.

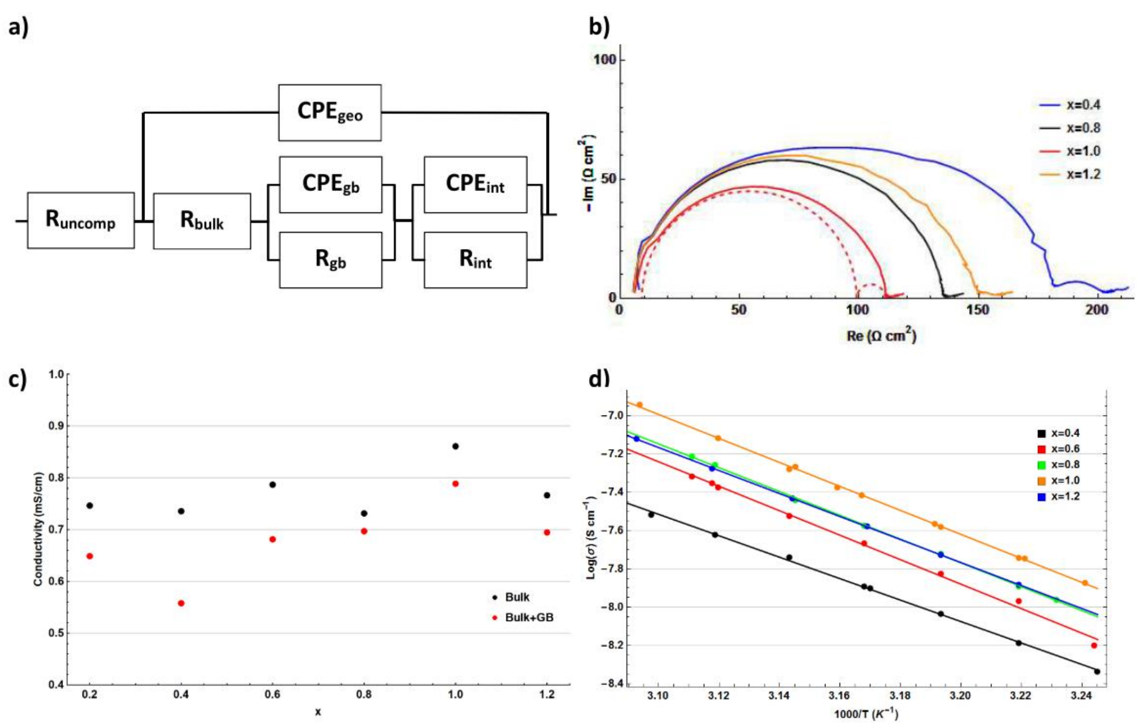


Figure 16: a) Equivalent circuit model used to analyze EIS results, b) Nyquist Plots of x=0.4, x=0.8, x=1.0, and x=1.2, dashed red lines indicate fitting of bulk and grain boundary contributions for x=1.0, c) Conductivity results

of bulk and bulk + grain boundary contributions for samples x=0.2 to x=1.2, d) Arrhenius plot of bulk conductivities for samples x=0.4, x=0.6, x=0.8, x=1.0, and x=1.2.

Table 8: Summary of electrochemical properties of samples of LLZTO $Li_{6.5}La_{2+x}Zr_{1.5}Ta_{0.5}O_{12}$ as x is varied.

Sample	σ_{Bulk} (mS/cm)	σ_{Total} (mS/cm)	Q_{geo} (F) 10^{-10}	$E_{a,Bulk}$ (eV)	ASR (Ω cm^2)	CCD (mA/cm^2)
X=0.2	0.747 ± 0.051	0.649 ± 0.077	7.931 ± 0.127	0.523	3.7	0.5
X=0.4	0.736 ± 0.106	0.563 ± 0.028	8.243 ± 0.212	0.483	21.2	0.58
X=0.6	0.787 ± 0.029	0.682 ± 0.098	7.949 ± 0.041	0.551	2.7	0.65
X=0.8	0.732 ± 0.019	0.697 ± 0.010	7.920 ± 0.046	0.536	2.4	0.75
X=1.0	0.861 ± 0.068	0.789 ± 0.087	7.933 ± 0.218	0.540	2.4	0.8
X=1.2	0.766 ± 0.039	0.695 ± 0.055	7.965 ± 0.002	0.518	6.7	0.55

Critical Current Density

Critical current density (CCD) measurements were taken of the samples using DC cycling. CCD measurements are used to indicate the maximum current density that a solid electrolyte sample can withstand before experiencing short circuit. This information can provide an indication of the effects of different compositions and processing techniques on the overall susceptibility of a solid electrolyte to penetration by metallic Li. A representative DC cycling voltage profile of the Li|LLZTO|Li symmetric cell for an x=1.0 sample can be seen in Fig. 17. The cell showed a sudden drop in polarization voltage at a current density of 0.75 mA/cm2, indicating that shorting occurred at that current density. As a result, the CCD of that cell was determined to be 0.75 mA/cm2. The area specific resistance (ASR) of each of the cells was below 22 Ω cm2, indicating interfacial resistance for the cells was not a large contribution to the critical current density (Sharafi, Kazyak, Davis, & al., 2017). An increase in critical current density could be seen as samples became less lanthanum deficient, spanning from 0.5mA/cm2 at x=0.2 to 0.8mA/cm2 at x=1.0, see Table 8. This could be due to the lower grain boundary adhesion in the samples with low La concentration, as dendrites have been shown to grow along grain boundaries in LLZO, and the increased presence of the less conductive lithium zirconate secondary phases (Cheng, Sharafi, & Sakamoto, 2017). The samples with excess La showed a lower CCD than the x=1.0 sample, which could be due to the lower relative density of the over lanthanated samples in addition to the presence of excess lanthanum oxide.

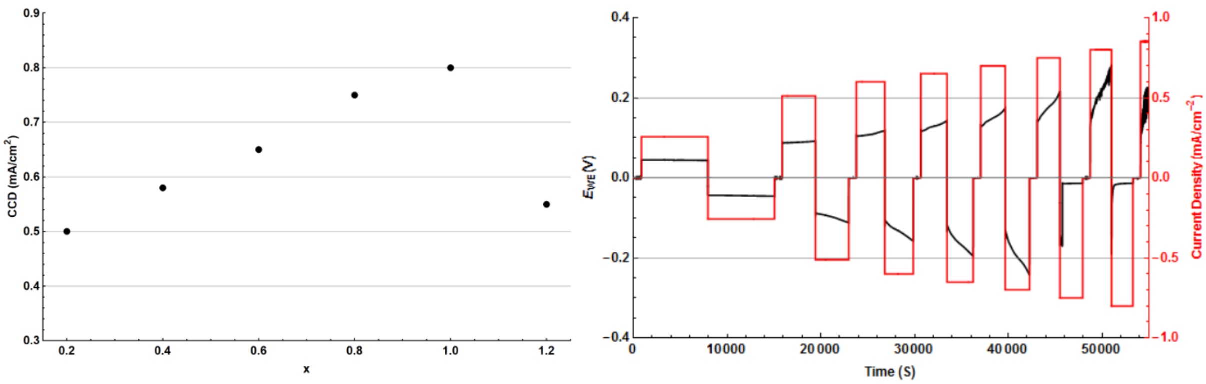


Figure 17: a) Critical current density of samples from x=0.2 to x=1.2, b) DC cycling of x=1.0 sample in Li|LLZTO|Li symmetric cell, stepping current density from 0.25 to 0.8 mA/cm2.

5.1.4 Conclusions

In this study, the effect of La deficiency on LLZTO was investigated. Analysis of XRD and Raman spectroscopy showed that LLZTO exhibits two methods of accommodating a deficiency of lanthanum. A decrease in lattice parameter with a decrease in La concentration is indicative of the formation of La defects in the lattice. The minimal change in conductivity is indicative that if the La defect formation is directly coupled with Li vacancy formation, it takes place via a complex defect mechanism involving 24d site Li and O. The change in conductivity is more likely to be accounted for by the formation of secondary phases. The formation of lithium zirconate impurity phases as samples became more La deficient indicate that the LLZO structure decomposes to Li2ZrO3 and Li6Zr2O7 under La deficiency, and that the predicted product Li8ZrO6 likely decomposes to Li2ZrO3 during synthesis. SEM imaging showed that La deficient samples exhibited mainly intergranular fracture, while samples which were close to fully lanthanated exhibited mainly intragranular fracture. The presence of lithium zirconates likely decreases the grain boundary adhesion in the La deficient samples, resulting in intergranular fracture. The increase in total conductivity and CCD, from 0.649 mS/cm and 0.5 mA/cm2 at x=0.2 to 0.789 mS/cm and 0.8 mA/cm2 at x=1.0 may be caused by the improved density and grain boundary adhesion of the samples.

5.2 Turning from Li toward Na

During the time I was conducting that research on LLZO, the seeds of doubt sown during undergrad about how much good I was doing researching batteries began to sprout. In undergrad I could see climate change as an issue, but it was an issue largely disconnected from other societal issues because the sort of understanding I held of the problem was a technical one focused on reducing carbon dioxide emissions. That is a rather common understanding within neoliberal environmentalist spaces that I'd internalized over the years, one that renders the problem as a universalized technical abstraction to forefront solutions devoid of sociopolitical contexts. One where we just have to make the tech to get off of fossil fuels and we'll be good. As I read more and more papers on electrochemical energy storage systems this was the narrative I would see consistently repeated; a narrative linking batteries, especially through the commercialization of electric vehicles, to CO2 reduction as a way to curb or stop climate change. By and large I think of this as the story we tell ourselves in the battery community that helps us justify why we research what we research; unless of course someone is just looking to make money in the very lucrative, speculative battery industry. Looking back on it now, I realize I'd seen this narrative so much that I'd even dropped the pretext of climate change and CO2 reduction in my first paper, assuming it to be common sense and instead focusing the story on its relevance for electric vehicle commercialization.

In my classes, research, internships, seminars, informal talks with engineering colleagues, etc. batteries were always framed as this sort of universal good, aligning well with and upholding the same conviction I'd held since high school. This framing made it so that even on the rare occasion when issues about materials sourcing and disposal were brought up, they were largely discussed in a way that was either external to the problem batteries were supposed to solve or a necessary evil of advancing this necessary solution (Lynch, 2021). One of the things that participating in groups like Science for the People (SFTP), the Collective Against White Supremacy (CAWS), and the Graduate Employees' Organization (GEO) helped me see and do was actually question that narrative, see it in conversation with other narratives that held a more systemic, interconnected analysis of climate change. As city anti-policing campaigns telescoped into school climate strikes and union organizing drives, learning and organizing in groups like these gave me ample opportunities to work through an intersectional analysis and practice different theories of change from those engineering exposed me to. While they led to many late nights, long hours, difficult conversations, and bitter losses, the emphasis on people power and relationship building as the foundation of the work was enlivening in a way that kept me wanting, needing to come back and continue learning. These were affirming spaces I felt I could actually be present and vulnerable in, bringing the messiness and curiosities of my whole self into them as I learned more of what my whole self really meant.

I remember one day going to a small event in the law school with Vincent Warren, executive director of the Center for Constitutional Rights, that I had heard about from some fellow organizers. Given the small event size, it became a pretty intimate affair and I was the only engineering student worker there amongst maybe 7 lawyers and law students in a large, wood paneled lecture hall in the Law Quad on central campus. I remember he posed questions like ‘who are your people?’ ‘Who are you working for?’ that pushed me to reflect deeply on the research I was doing. These were not the sort of questions I was ever asked in my engineering education. As the law students listed off personal connections to causes like immigrant rights and racial justice, I realized that the people my work was benefitting were the Elon Musks of the world and the folks rich enough to buy a Tesla to say they’re helping the environment. As I named that, it did not sit well. Those were not the sort of people with whom I’d grown up nor really enjoyed spending time around, yet it was their theories of change and comfortable futures my labor was propping up. I’d come into grad school and researching batteries with the desire to halt climate change, yet broadening my scope to reflect on who my battery work benefitted opened me up to exist in *Nepantla*.

The organizing spaces I frequented and questions like those highlighted a void that had been growing for years because of how much I actually needed to set aside for the battery narrative to make sense and how little room there was in dominant engineering to work through concerns challenging that narrative, especially because those concerns were not read as technical. One of the main points of conflict that arose for me came from sitting with what Mr. Hernandez had brought up years ago about lithium mining. Lithium was the basis of my research and also became a trigger for the moments of vertiginous consciousness that gave me a sense of the violence holding my settler-colonial privilege in place (la paperson, 2017); (Burelle, 2015). I remember my undergraduate academic advisor Prof. Elsa Olivetti came to give a talk at UM about lithium availability and anticipated demand for vehicle electrification. She emphasized that the supply of lithium existed, but that the limiting factor was more so the rate that lithium could be extracted (Olivetti, Ceder, Gaustad, & Fu, 2017). Having heard about extraction as one of the key rate limiting steps to electric vehicle commercialization, I started getting curious about how lithium was extracted. Seeing that much of it came from a water intensive process of concentrating brine pools in a region known as the Lithium Triangle situated between Chile, Argentina, and Bolivia, I wondered whether LLZO as a technology for selectively, rapidly shuttling lithium ions might be usable as a membrane for lithium extraction.

Part of the dissonance that line of research brought up in me was that it more directly put into conflict the technical research and narratives of batteries as good with the experiences I'd had of seeing how communities are systematically and violently disregarded to maintain the status quo. Reading articles like *Tossed Aside In The 'White Gold' Rush: Indigenous people are left poor as tech world takes lithium from under their feet in* the Washington Post (Frankel & Whoriskey, 2016) and particularly *No Comemos Baterías: Solidarity Science Against False Climate Change Solutions* in the SFTP magazine (Center for Interdisciplinary Environmental Justice, 2019) rather directly connected the research I was doing and narratives I was advancing to the undermining of the Indigenous sovereignty of the peoples of the Altiplano basin. The framing of lithium as 'white gold' connected it to the histories of dispossession, destruction of ecosystems, and the killing and displacing of Indigenous peoples through the gold rush in the U.S. and the 'black gold' fossil fuel rush that lithium is supposed to bring an end to. Seeing the U.S. backed coup in Bolivia oust their first Indigenous President Evo Morales, install a right wing government that immediately went about trying to privatize Bolivian lithium, and Tesla CEO Elon Musk tweet out 'We will coup whoever we want! Deal with it.' made the connections that much more obvious to me (teleSUR, 2020). The new *conocimiento* coming from the small glimpse of what lithium mining entailed telescoped into colonial, imperial, and racial capitalist structures that left me feeling that I could not live in my integrity if I continued doing this work.

The set of incommensurabilities from working in materials science and engineering felt further complicated by my being white Latinx and how Latinidad is constructed. Maya Ch'orti' and Zapotec environmental scientist Jessica Hernandez names how Latinx people in the United States

> "often move toward navigating their own oppression within the United States while forgetting that they are sometimes our oppressors back in our native lands … [where] Latinidad is a duality between the oppressed and the oppressor as settler colonialism frameworks exist in Latin America that continue to harm Indigenous, Afro-Latino, and Afro-Indigenous peoples," (Hernandez, 2022, pp. 5-6).

It was this duality I found myself in as well, where the career I was building toward as a Latinx materials scientist and engineer and part of the first generation on that side of the family to go to college was being constructed from the destruction of other Latinx folks' homes and ecosystems. I did not come here to "*systematically erase* certain socioecological contexts, or horizons, that are *vital for members of another society to experience themselves in the world as having responsibilities to other humans, nonhumans and the environment,*" (Whyte, 2016) however I can't understand my research on batteries in any other way. The academy as an arm of the settler state repositions this as the desired performance; a desired property in the process of turning land into property that dominant engineering is structured to uphold and systematically deny (Grande, 2018). And I couldn't do it anymore; that was not where my solidarity lied. I'd heard too many stories of displacement within my own family to claim that as a path forward in any solution to climate change. McGee and Bentley discuss an equity ethic amongst Black and Latinx undergrad students in engineering that signifies "students' principled concern for social justice and for the well-being of people who are suffering from various inequities," (McGee &

Bentley, The Equity Ethic: Black and Latinx College Students Reengineering Their STEM Careers toward Justice, 2017, p. 6).

I wanted to return to my sense of integrity with that new *conocimiento*, but was unsure of how. I considered dropping out, but I could only see that as self-defeating resistance since it would just center my own distress and shift my own complicity within the structures maintaining these injustices rather than changing the infrastructures keeping them in place (Solórzano & Delgado Bernal, 2001). I brought up the dissonance I was feeling with other folks in the lab, trying to highlight connections between Indigenous water protectors resisting oil pipelines and extraction at places like Standing Rock and lithium mining in the Altiplano basin (Estes, 2019); (Center for Interdisciplinary Environmental Justice, 2019). However, in the same way I'd brushed off Mr. Hernandez all those years ago because the concerns he raised were unintelligible in the paradigm I operated in, these connections were quickly brushed off. I considered changing labs, but I didn't see the problem as lying with the people in my lab group as much as the structures, superstructures, and infrastructures we'd been trained into. As a white Latinx person working primarily alongside other researchers of color, part of existing in *Nepantla* was questioning whether I was just enacting white saviorism. As Pawley describes, white saviorism "occurs when White people act as though they alone have the solution to social problems, even though, first, they may be a large part of the problems, and second, people of color are already working to solve them," (Pawley A. , 2019a, p. 447). Talking it over with other organizers of color that held anti-imperialist understandings helped reassure me this wasn't the case, and that staying in and enacting changes was about the best I could do since there was really no out of this system, pushing me instead to aim for transformational resistance and harm reduction (Solórzano & Delgado Bernal, 2001).

The shape I could see that transformational resistance taking was in bringing the learning and relationships that had been sustaining me in the spaces where I'd felt affirmed into the engineering spaces that I'd felt ignored much of what my affirmation was predicated upon; trying to bridge these worlds. I figured I could at least start conversations that had been largely absent from my own engineering education and the engineering spaces I existed in. The vague nature of DEI in the department often led to events like ice cream socials rather than discussions on navigating moral and ethical conundrums of our research and its relationships to systems of oppression, which I thought offered space for transformation. One of the more immediate ways this took shape was when I worked with the lead instructor of the MSE lab class I was a graduate student instructor for to offer a module on lithium ion-batteries and imperialism. In it I used life cycle analysis to discuss connections between the sort of electric vehicles my research was supposed to be bringing closer to a reality, the ecosystem destruction lithium mining brings, and legacies of colonialism and U.S. government intervention on global lithium production.

While I could bring these connections up in a class I was teaching, reconsidering my research given their implications felt like it operated on an entirely different scale. The research basis of our lab was and is still lithium based solid state electrolytes explicitly through a technical lens in the positivist paradigm. What Alice Pawley calls the moral infrastructure needed to address equity and the climate crisis has not been built, and I don't think it can be built within a positivist paradigm since it requires grappling with subjectivity (Pawley A. , 2019a). I felt connected to that infrastructure through years of concientização that affirming organizing spaces had allowed me to develop, however the invitations I extended to connect to these infrastructures often went unaccepted. Prof. Sakamoto admitted that he couldn't offer guidance on the elements of my grad school experience that extended beyond the technical battery research, however his commitment to DEI did make it so that when I asked, I got the space I needed to process how to move forward.

That reassurance from him and embracing the uncomfortable existence in *Nepantla* left staying in lab seem like the best option and as the opportunity presented itself Prof. Sakamoto helped me shift toward a sodium ion project. The structural, economic aspects of being a grad student made it so that I still needed funding to continue and the only funding he had available was sticking with the Joint Center for Energy Storage Research (JCESR) grant I'd done the LLZO research through. While a shift to sodium ion and its horizons for success wouldn't alter the vast majority of infrastructures needed for lithium ion, it did offer a small crack through which lithium could be critiqued beyond purely techno-economic considerations. The sodium ion project was a collaboration he'd set up with researchers at the Ulsan National Institute of Science and Technology (UNIST) who were focusing on the sodium solid electrolyte NASICON. He even brought two undergrads onto the project and helped train them in mechanical characterizations I was unfamiliar with. It was out of those collaborations that my second first author paper, *Characterization of hot-pressed von Alpen type NASICON ceramic electrolytes,* came about (Valle, et al., 2021).

5.3 NaSICON

5.3.1 NaSICON Introduction

Li-ion conducting solid state electrolytes (SSE) have garnered much interest as a possible solution to limits faced by liquid electrolytes traditionally used in Li ion batteries. Much of this interest for Li based SSE stems from the improved safety solid electrolytes offer compared to non-aqueous liquid electrolytes as well as their ability to be used in higher energy density cells when paired with Li metal anodes (Tarascon & Armand, 2001); (Manthiram, Yu, & Wang, 2017); (Albertus, Babinec, Litzelman, & Newman, 2018). **While there have been a number of Li based SSE systems which have shown promise in enabling the use of Li metal anodes, serious concerns remain around the quantity of available Li and conflict associated with accessing remaining sources of available Li** (Romero, Mendez, & Smith, 2012); (McManus, 2012); (Agusdinata, Liu, Eakin, & al., 2018); (Liu & Agusdinata, 2020). Na based SSEs offer the same form of improvements to safety and energy density that Li based SSEs do compared to Li ion batteries, while having the added benefit of allowing for pairing with Na metal anodes (Zhao, Liu, Qi, & al., 2018). Na metal has a higher propensity to creep than Li, which can result in higher charge rate capabilities when compared to Li (Wang, Chang, Woldenstine, & al., 2020); (Fincher, Zhang, Pharr, & al., 2020); (Bay, Wang, Grissa, & al., 2020). While Li- based battery technology has significantly advanced in recent decades, the cost and availability of Li could be potential issues for application such as grid storage (Olivetti, Ceder, Gaustad, & Fu, 2017). Sodium has a higher abundance than Li, is more affordable, and presents a possibility for fewer conflicts in sourcing (Slater, Kim, Lee, & al., 2013).

Alongside the need for higher performance batteries for electric vehicles comes a need for improved grid energy storage. Flow cells are one format of electrochemical cells which show promise as grid energy storage systems, however a need remains for effective, low-cost single-ion conducting membranes to prevent cross contamination (Prifti, Parasuraman, Winardi, & al., 2012). SSEs also show promise as membranes for flow cells, as there is much overlap between the engineering requirements for SSEs and flow cell membranes. One of the most promising Na based SSEs have been the Na super-ion conductor (NASICON) materials of the form NaxM2(XO4)3. NASICON materials, particularly variations of Na3Zr2Si2PO12 (NSZP), have long been investigated as solid electrolytes due to their high ionic conductivity (Hong, 1976); (Von Alpen, Bell, & Hofer, 1981); (Bayard & Barna, 1978). These NASICON materials have been used commercially in molten sodium batteries, such as sodium sulfur and ZEBRA cells operating near 300 ◦C (Ellis & Nazar, 2012). Hong originally described NASICON formulations based on Na1+xZr2SixP3-xO12 consisting of a solid-solution series between NaZr2P3O12 and Na4Zr2Si3O12 in 1976 (Hong, 1976). Due to the presence of zirconia formation upon sintering, von Alpen suggested a zirconia-deficient form of NASICON with the general formula Na1+xZr2−x/3SixP3−xO12−2x/3 with end members of NaZr2P3O12 and Na4ZrSi3O10 [16]. Kuriakose et al. and Ahmad et al. analyzed the effects of sintering both Hong and von Alpen type NASICON samples, observing that von Alpen samples typically did not form the secondary phase zirconia upon sintering, while Hong samples did contain zirconia (Ahmad, Wheat, Kuriakose, & al., 1987); (Kuriakose, Wheat, Ahmad, & al., 1984).

NASICON materials also have demonstrated effectiveness at operating as membranes in aqueous flow cells (Allcorn, Nagsubramanian, & Pratt III, 2018). However, the ability to densify and manufacture thin films of NASICON remains a challenge. The processing methods used to create NASICON have been shown to have drastic impacts on the microstructure, mechanical, and electrochemical properties of NASICON (Anatharamulu, Rao, Rambabu, & al., 2011); (Perthuis & Colomban, 1984); (Gordon, Miller, McEntire, & al., 1981). While much work has been done to investigate the effects of various NASICON synthesis methods (Ahmad, Wheat, Kuriakose, & al., 1987); (Perthuis & Colomban, 1984); (Gordon, Miller, McEntire, & al., 1981); (Colomban, 1986); (Naqash, Ma, Tietz, & al., 2017) and various sintering conditions (Kuriakose, Wheat, Ahmad, & al., 1984); (Gordon, Miller, McEntire, & al., 1981); (McEntire, Bartlett, Miller, & al., 1982); (Fuentes, Figueriredo, Marques, & Franco, 2001); (Gasmi, Gharbi, Zarrouk,

& al., 1995), comparatively few studies have been performed on the effects of hot pressing on NASICON NZSP samples. Perthuis observed that hot pressing Hong-type NASICON at 1250C resulted in highly dense (98% theoretical density) and conductive (1mS/cm at room temperature) NASICON samples, however the effects of hot pressing on phase purity, microstructural evolution, and mechanical properties were not described (Perthuis & Colomban, 1984). Yde-Andersen hot pressed varied NASICON compositions prepared from gel-derived raw materials and obtained high densities (~95–99% theoretical density) and varied conductivities (~0.30–2.94 mS/cm at room temperature), however the effects on mechanical properties and phase purity, including the presence of a glassy phase, were only minimally described and effects on microstructural evolution were not described (Yde-Andersen, Lundsgaard, Moller, & al., 1984). Moreover, the presence of the glassy impurity phase has been believed to affect the NASICON bulk phase composition and therefore the bulk properties (Kuriakose, Wheat, Ahmad, & al., 1984); (Colomban, 1986). In addition, the glassy phase has been observed to be present at grain boundaries, which likely affects ionic transport, stability, and perhaps mechanical properties. Comparatively few studies have also investigated mechanical properties of NASICON samples. Nonemacher investigated the elastic modulus (72–88 GPa), hardness (5.6–7.6 GPa), and fracture toughness (1.30–1.58 MPa m0.5) of Al and Y substituted NASICON solid electrolytes (Nonemacher, Naqash, Tietz, & al., 2019). Fracture strengths ranging from 55 to 212 MPa have been found using three point bend, four point bend, and diametral strength tests (Gordon, Miller, McEntire, & al., 1981); (McEntire, Bartlett, Miller, & al., 1982); (Yde-Andersen, Lundsgaard, Moller, & al., 1984); (Kim J. , Jo, Bhavaraju, & al., 2015).

In this study, we hypothesize that a combination of optimized hot-pressing conditions and powder processing could enable a processing route to produce a dense NASICON with a reduced glass content compared to conventional sintering. Furthermore, there is very limited information on the mechanical properties of VA NASICON. Hot-pressing has previously been shown to produce ceramic samples enabling reliable testing of mechanical properties such as elastic modulus, hardness, and fracture toughness (Wolfenstine, Allen, Sumner, & al., 2009); (Smith, Thompson, Sakamoto, & al., 2017); (Ni, Case, Sakamoto, & al., 2012); (Kim Y. , Jo, Allen, & al., 2016). Thus, we hypothesize that hot-pressing can be used to prepare dense NASICON samples that allow for increased understanding of the mechanical properties of VA NASICON. Powder x- ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive x-ray spectroscopy (EDS), impulse excitation, Vickers hardness, indentation fracture toughness, and electrochemical impedance spectroscopy (EIS) were used to investigate the effects of hot-pressing von Alpen type NASICON powders. Von-Alpen type NASICON was selected due to its lower propensity to form zirconia as compared to Hong type NASICON, which leads to higher conductivity and fracture strength (Go, Wolfenstine, & Kim, 2020). Von Alpen NASICON powder synthesis was varied to alter particle morphologies to see how this effects the microstructure and properties of the hot-pressed samples.

5.3.2 NaSICON Methods

Materials Synthesis and Processing

Von Alpen (VA) type NASICON ($Na_{3.1}Zr_{1.55}Si_{2.3}P_{0.7}O_{11}$) powders were prepared through the following process. Reagent grade $Na_3PO_4·12H_2O$, Na_2CO_3, ZrO_2 and SiO_2 were used as starting materials. The starting materials were mixed into ethanol. The resulting mixture was ball milled (Pulverisette 5, Fritsch) at 400 rpm for 0.5 h. After ball milling it mixture was dried at 80 ◦C in an oven for 24 h. After drying, the resulting powder was calcined at 1100 ◦C for 10 h. The calcined powder was ball milled in ethanol at 400 rpm for 0.5 h. With the resulting mixture, 3 types of powder were prepared. For the first case, the mixture was fully dried in oven at 80 ◦C for 24h, but was not spray dried; labeled as ‘NS' for no spray. For the second case, organic additives including ~1 wt% binder and dispersant agents were added into the mixture. Then the mixture was spray dried (B-290, Buchi) at 90 ◦C labeled as ‘S’ for spray. For the third case, the S samples were heat treated at 450 ◦C for 5 h followed by additional heating to 900 ◦C for 3 h; labeled as ‘S900C’ for sprayed and heat treated at 900 ◦C. Heat treatments were performed on the S900C to remove binder and dispersing agent additives in S powders. The resulting powders were cold pressed into pellets, placed into a graphite die and hot-pressed using a custom rapid induction hot pressing (RIHP) technique at 1150 ◦C for 40 min under flowing argon at a pressure of 23.5 MPa. The resulting billet was then cut into 1.1 ± 0.3mm thickness pellets using a diamond saw, and the pellets were polished down to a final 0.1um polish with diamond paste. Samples which underwent electrochemical testing were then sputtered with Au to act as blocking electrodes.

X-Ray Diffraction and Density

Powder XRD of pre and post RIHP samples was performed on a Rigaku Miniflex 600 using Cu Ka radiation over a 2theta range of 10 deg. to 40 deg. with a 0.02 deg. step size. Density was obtained from geometric measurements of post RIHP billets.

Microstructure

Microstructural analysis and Energy-dispersive X-ray spectroscopy (EDS) of fracture surfaces and polished sample surfaces were performed on a JEOL IT500 SEM. Both secondary electron detection (SED) and backscatter electron composition (BEC) modes were used. SED mode allows for topographical information of an image surface that is more independent of sample material, while BEC has a dependence on the atomic number of a given sample, allowing for more clarity in distinguishing between phases with dissimilar densities. SEM images of polished sample surfaces were analyzed using ImageJ image processing software to determine area percentage of phase fractions. EDS point scan data was used to determine compositions of various regions within the samples.

Elastic Modulus

The elastic modulus of the samples was determined via impulse excitation measurements of ultrasonic velocities in the samples, using a pulser-receiver 5073 PR-15-U, Olympus M110 and V156 transducers (operating at 5 MHz), couplant SWC, Olympus NDT INC, Waltham MA. Shear and longitudinal velocities, vs and vl respectively, were calculated using Eqs. (1) and (2),

Equation 1: $v_s = \frac{2\, n_s\, t}{t_{d,s}}$

Equation 2: $v_l = \frac{2\, n_l\, t}{t_{d,l}}$

where ns and nl are the number of measured shear and longitudinal waves, respectively, and td,s and td,l represent the time delay between the first and last shear and longitudinal echoes, respectively. The thickness of the sample is represented by t. The elastic modulus, E, was subsequently calculated using Eq. (3) (ASTM Standard E494: Standard Practice for Measuring Ultrasonic Velocity in Materials, 2015),

Equation 3: $E = \frac{\rho\, v_s^2\, (3\, v_l^2 - 4 v_s^2)}{v_l^2 - v_s^2}$

where ρ is the density of the sample, and vs and vl are the shear and longitudinal velocities previously defined.

Hardness

The hardness of the samples was determined using Vickers indentation (HM122V/K Series 810 Micro, Mitutoyo Corporation Vickers hardness tester). Vickers hardness tests were conducted three times at each load of 1.96 N, 2.94 N, and 4.90 N for a duration of 10 s, totaling 9 indentations per sample. The Vickers hardness was calculated using Eq. (4),

Equation 4: $H_v = \frac{1.854\,F}{d^2}$

where Hv is the Vickers hardness, F is the applied load, and d is the average diagonal length.

Fracture Toughness

The fracture toughness of the samples was determined using the same Vickers indentations as were used to determine hardness. The indentations were imaged using a scanning electron microscope (SEM; JEOL IT500), and the crack lengths were measured using ImageJ. Fracture toughness, KlC, was calculated using Eq. (5) (Niihara, 1983), valid for Palmqvist-type cracks,

Equation 5: $K_{IC} = 0.035\,(\frac{Ha^{\frac{1}{2}}}{\phi})(\frac{E\phi}{H})^{\frac{2}{5}}(\frac{l}{a})^{\frac{-1}{2}}$

where H is the hardness, E is the elastic modulus, a is the length of the indentation half-diagonal, l is the crack length, and Φ is a constraint factor (Φ ≃ 3). The cracks were determined to be Palmqvist cracks, as the ratio of the crack length l and the indentation half-diagonal a was between 0.25 and 2.5 for all measured cracks.

Grain Size

Grain size was determined using the linear intercept method (Yamai & Ota, 1993). The average grain size was calculated using Eq. (6),

Equation 6: $GS_{avg} = \frac{1.56\,C}{M\,N}$

where GSavg is the average grain size, C is the total length of test lines used, M is the magnification of the image, and N is the number of intercepts between grains. Transitions between grain and glass phase were counted as one intercept, unless the section of glass phase was comparable in size to the grains.

Electrochemical Analysis

Electrochemical impedance spectroscopy (EIS) was performed on a Biologic VMP-300 galvanostat/potentiostat. EIS was conducted from 50 mHz to 7 Mhz with a perturbation of 10 mV in Au|NASICON|Au symmetric cells.

5.3.3 NaSICON Results and Discussion

Materials Characterization

SEM images of NASICON powders were taken for the three different powders used prior to hot pressing. Fig. 19 shows the particle morphology for NS, S, and S900C powders. A significant difference in particle morphology can be observed between NS and S powders prior to hot pressing. The NS particles consisted of irregular and larger particles while the S powders had a more consistent spherical morphology, in line with (Hwang, Park, Kim, & al., 2019). After undergoing heat treatment, S900C samples did not undergo any significant changes to particle morphology in comparison to S sample. Fig. 19 shows images of hot pressed NS, S, and S900C pellets. NS pellets exhibited a gray color while S pellets exhibited a black color, likely due to the trapping and pyrolization of binder and dispersive additives within the S samples during hot pressing. After the addition of heat treatment steps, the S900C samples exhibited a comparable coloration to the NS pellets, indicating that the heat treatment steps were successful in removing the binder and dispersive additives from the S samples prior to hot pressing.

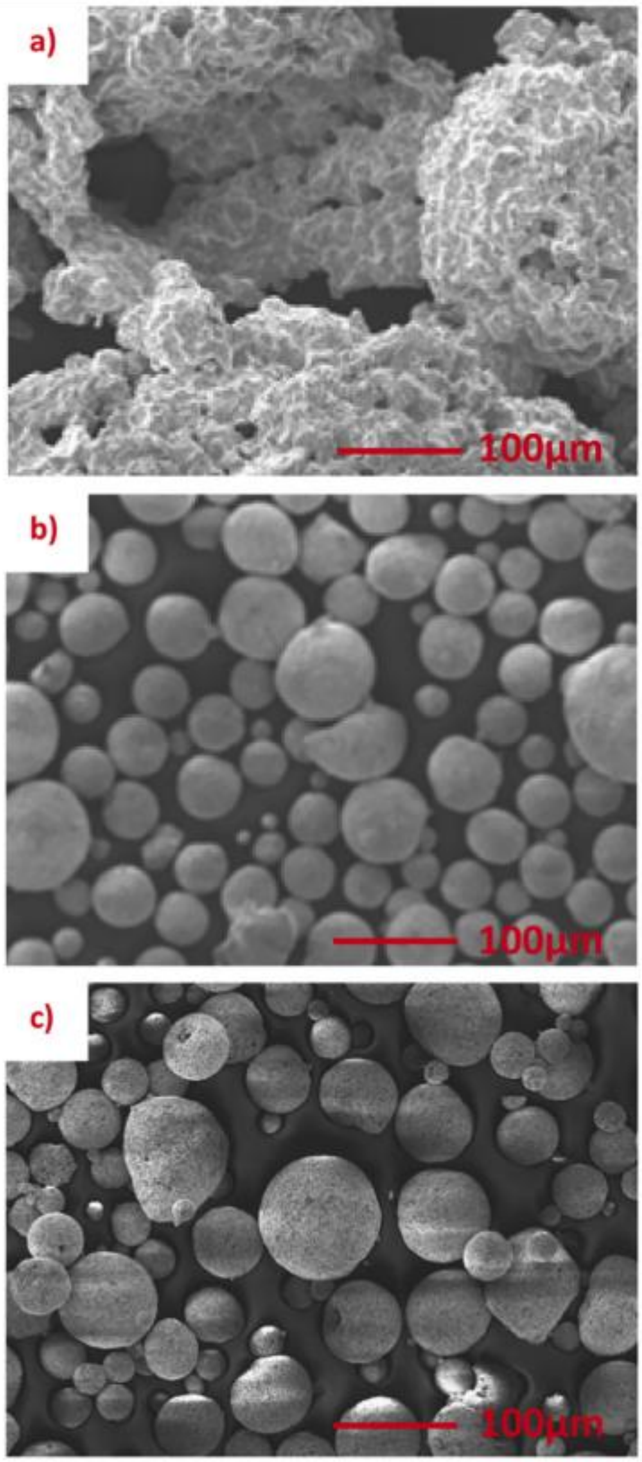


Figure 18: SEM images of NASICON powders prior to rapid induction hot pressing, a) NS, b) S, c) S900C.

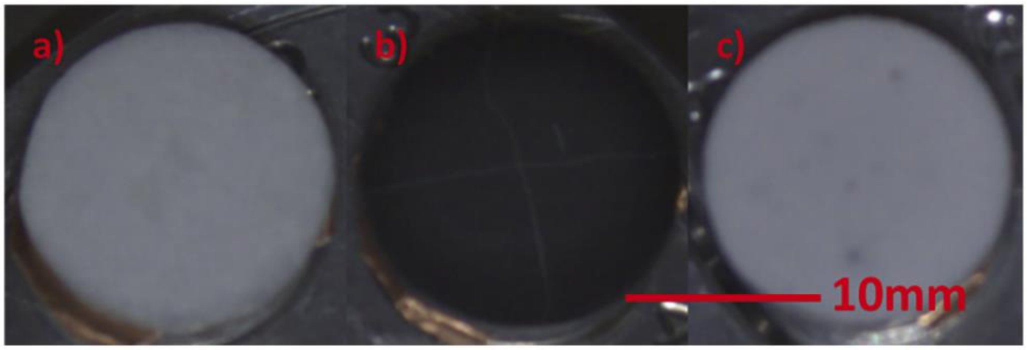


Figure 19: Images of NASICON pellets a) NS, b) S, c) S900C.

XRD was conducted on NASICON powders prior to Fig. 20a), b), and c) and after hot pressing Fig. 20d), e), and f). Each of the samples examined clearly showed the presence of NASICON, as shown in the reference in Fig. 20g) for Monoclinic NASICON. Peak triplets between 19 and 20 degrees are indicative primarily of the presence of monoclinic phase NASICON, with a shoulder peak appearing at roughly 19.3 degrees indicating the presence of rhombohedral phase NASICON. Powder samples prior to hot pressing showed a presence of ZrO_2, one of the constituents used in synthesizing the NASICON powder as well as $Na_2ZrSi_2O_7$. Powder samples prior to hot pressing gave comparable XRD patterns, indicating that neither spray processing nor heat treatment significantly altered the chemical composition of the powders. Significant decreases in peak intensity corresponding to ZrO_2 and $Na_2ZrSi_2O_7$ can be observed in S and S900C samples after hot pressing, while NS samples did not show significant changes in XRD patterns as a result of hot pressing. This may be due to the difference in particle morphology between NS and S samples, in which the spray step assisted in more evenly distributing secondary phases within the powder to be reacted during hot pressing. This may also be the result of a larger particle size in the NS samples as compared to the S and S900C samples, as larger, more irregular particles result in a longer diffusion path and thus are less able to react in the same time frame as the spray dried particles.

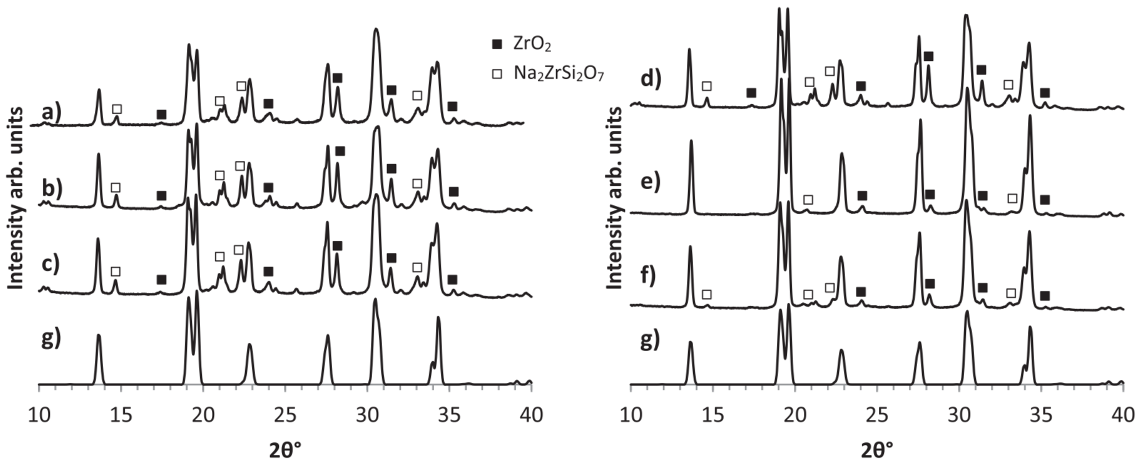


Figure 20: The XRD patterns of NASICON powder samples before RIHP; a) NS, b) S, c) S900C and after RIHP at 1150 ◦C; d) NS, e) S, f) S900C, g) reference peaks for Monoclinic NASICON (Baur, Dygas, Whitmore, & al., 1986). Impurities ZrO2 (black boxes (Kudoh, Takeda, & Arashi, 1986)) and Na2ZrSi2O7 (white boxes (Voronkov, Shumyatskaya, & Pyatenko Yu, 1970)) are also indicated for each NASICON powder sample.

The polished pellet surfaces and fracture surfaces of NASICON were investigated for each of the samples. Fig. 21 a), b), and c) show polished pellet surfaces of NS, S, and S900C surfaces, respectively. Polished pellet surfaces showed lighter regions which were representative of NASICON grains (A) and darker regions which were representative of a glass phase (B), and white regions representative of ZrO2 (C), for example, the NS sample shown in Fig. 21 d). The changes in brightness observed in backscatter images (BEC) indicate that the different regions are reflective of different phases, see Fig. 21 h). The white surfaces observed in Fig. 21 d) are indicative of ZrO2 (Colomban, 1986); (Naqash, Sebold, Tietz, & al., 2018). The glassy darker regions are Zr poor, which is related to the formation of zirconia and is in line with literature (Kuriakose, Wheat, Ahmad, & al., 1984); (Colomban, 1986); (Naqash, Tietz, Yazhenskikh, & al., 2019). The glass phase appeared to only be present at grain boundaries, and has been observed in other NASICON samples in literature (Ahmad, Wheat, Kuriakose, & al., 1987); (Kuriakose, Wheat, Ahmad, & al., 1984); (Colomban, 1986); (Nonemacher, Naqash, Tietz, & al., 2019); (Naqash, Sebold, Tietz, & al., 2018); (Naqash, Tietz, Yazhenskikh, & al., 2019). It has been reported that the glass phase promotes sinterability, but acts as an electrical barrier toward

Na^+ conduction (Kuriakose, Wheat, Ahmad, & al., 1984); (Naqash, Tietz, Yazhenskikh, & al., 2019).

Fracture surfaces of each of the NASICON samples were mainly flat (intragranular) with a few protrusions, see Fig. 21e), f), and g). NASICON structures tend to fracture in an intragranular mode when density reaches high fractions of theoretical density due to high grain boundary strength when porosity is low (Wolfenstine, Allen, Sakamoto, & al., 2018); (Rice, 1977). Protrusions present on the fracture surface are likely clusters of NASICON grains which experienced intergranular fracture, as they are slightly larger in size than grains observed in Fig. 21a), b), and c) (Baur, Dygas, Whitmore, & al., 1986).

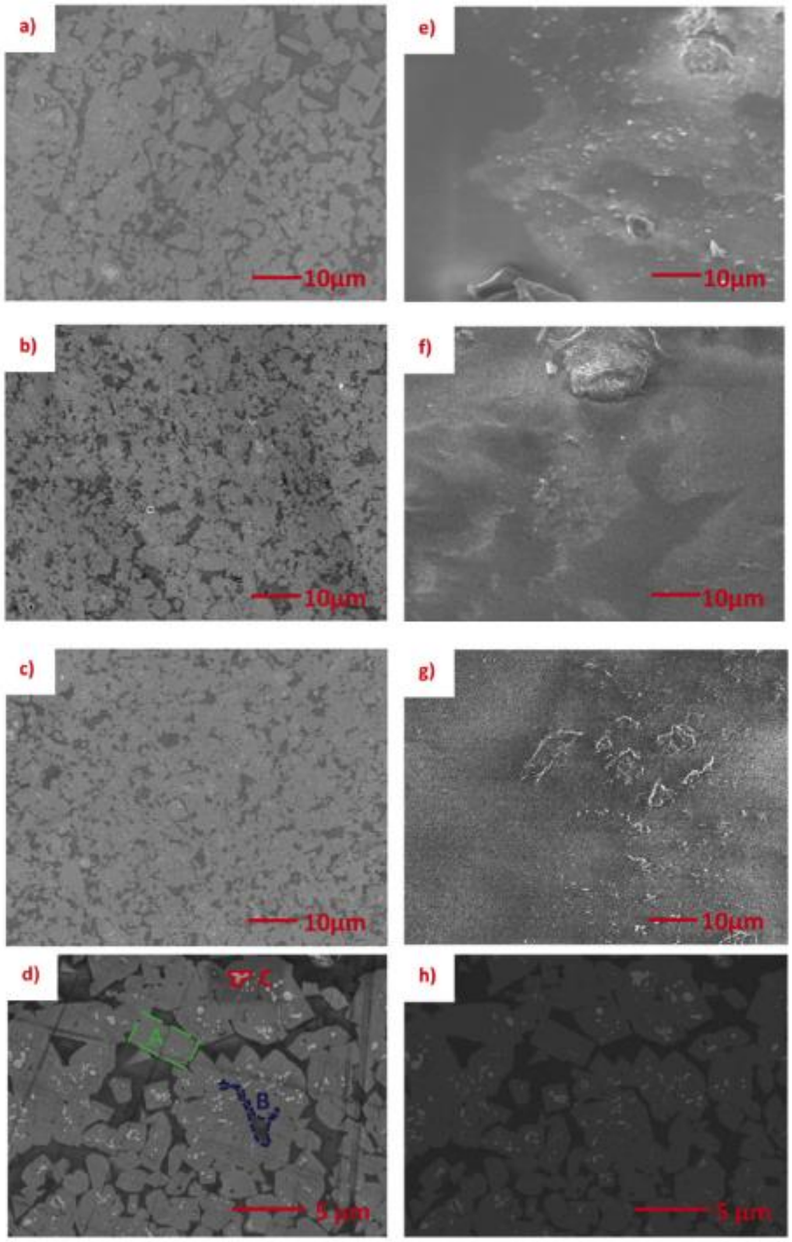


Figure 21: SEM images of polished surfaces of NASICON pellet samples after RIHP at 1150 ◦C a) NS, b) S, c) S900C. SEM images of fracture surfaces of NASICON pellet samples after RIHP at 1150 ◦C e) NS, f) S, g) S900C. Regions representative of protrusions (red solid) are indicated. SEM SED d) and SEM BEC h) images of NS sample. Regions representative of grains (A, green dashed), glassy phase (B, dark blue dotted), and zirconia (C, red solid) are indicated in d).

Table 9 shows the sample densities as well as the area percent phase fractions and average grain sizes taken from SEM images of polished surfaces. Measured densities were consistent with densities reported in literature in all samples (Gordon, Miller, McEntire, & al., 1981); (Colomban, 1986); (McEntire, Bartlett, Miller, & al., 1982). The glass phase, which exists at grain boundaries, was high for each sample compared to values reported by Naqash for Hong type NASICON samples, but appeared comparable to the amount of glass phase observed by Ahmad on von Alpen type NASICON samples (Ahmad, Wheat, Kuriakose, & al., 1987); (Naqash, Sebold, Tietz, & al., 2018).

Table 9: Density of NASICON pellets after RIHP at 1150 ∘C and area fractions of different phases obtained by image analysis.

Sample	Density (g/cm^3)	Grain size (μm)	NASICON (Area %)	Glassy (Area %)	Pores (Area %)	ZrO_2 (Area %)
NS	3.118	4.49 ± 1.15	67.90 ± 3.66	28.23 ± 5.15	0.36 ± 0.26	3.51 ± 0.82
S	3.102	3.08 ± 0.42	77.49 ± 3.68	21.48 ± 3.62	0.57 ± 0.51	0.46 ± 0.35
S900C	3.126	3.08 ± 0.27	79.03 ± 3.90	19.08 ± 3.64	0.19 ± 0.15	1.70 ± 0.16

The high density and low porosity of the samples may be due to the function of the glassy phase acting as a sintering aid. The increased presence of the glass phase in NS samples may correspond to the increased presence of Na2ZrSi2O7 observed in Fig. 20d) and ZrO2 observed in Fig. 20d) and Table 9 (Niyompan & Holland, 2001). The trend observed in the area % of ZrO2 present in each of the samples, of NS containing the most ZrO2 and S containing the least, is corroborated by the trend observed in the relative heights of the ZrO2 peaks in the XRD data. Table 9 shows that NS samples had a larger average grain size than S and S900C samples, 4.49 um compared to 3.08 um and 3.08 um respectively, however significantly more varied grain sizes were also seen in NS samples compared to S and S900C samples. This is likely due to the difference in particle morphology prior to hot pressing, as the NS particles had a more randomized morphology and appeared to have a larger initial powder granule size.

Mechanical Properties

Elastic Modulus

The elastic constants were measured using acoustic impulse excitation. The measured elastic modulus E was lower and ranged between 83.65 ± 4% and 97.65 ± 4%, see Table 2. Measured E values are comparable to a previously reported E value for Hong NASICON made through pressureless sintering (88 ± 3 GPa) (Nonemacher, Naqash, Tietz, & al., 2019). Deng et al. used first principle calculations to determine the elastic modulus for NaZr2P3O12, an end member composition for both Hong and Von Alpen NASICON with a rhombohedral structure, to be 120.9 GPa (Deng, Wang, Chu, & al., 2016). In alignment with discussion from Nonemacher et al., this value is higher than what was obtained experimentally in this work, likely owing to the polycrystalline nature of samples, presence and distribution of secondary phases, values obtained by Deng et al. being calculated at a temperature of 0 K, and a difference in investigated composition (Nonemacher, Naqash, Tietz, & al., 2019); (Deng, Wang, Chu, & al., 2016). For S and S900C, the E was approximately 10% higher than for the NS. It has generally been observed that the elastic modulus of glasses is lower than that of crystalline oxides, partly owing to the inversely proportional relationship of molar volume to elastic modulus, where glasses tend to have higher molar volumes than their corresponding crystalline materials (Barsoum, 1997); (Chiang, Birnie, & Kingery, 1996).

This phenomenon may contribute to the lower E observed in NS samples compared to the S and S900C samples, which had more similar amounts of glassy phase and similar E. While the effect of the glass on E could be further analyzed using a rule-of-mixtures analysis, since the precise composition and therefore E of the glass is unknown, it is not possible to do so. Further study is needed on the impacts of the glass phase on mechanical properties of NASICON.

Table 10: Mechanical properties of NASICON pellets.

Sample	Elastic modulus (GPa)	Poisson's ratio	Shear modulus (GPa)	Vickers hardness (GPa)	Fracture toughness (MPa $m^{1/2}$)
NS	83.65 ± 3.35	0.23 ± 0.01	33.87 ± 0.34	4.30 ± 0.63	N/A
S	97.65 ± 3.91	0.26 ± 0.01	38.79 ± 0.39	4.68 ± 0.14	1.05 ± 0.04
S900C	96.33 ± 3.85	0.25 ± 0.01	38.54 ± 0.39	4.68 ± 0.11	1.09 ± 0.09

The shear modulus G also measured using acoustic impulse excitation, see Table 10. The values for the S and S900C samples were in good agreement, (38.79 ± 0.39 GPa and 38.54 ± 0.39 GPa, respectively) while the NS was approximately 5 GPa lower than the S and S900C samples (33.87 ± 0.34 GPa). It is likely that if the presence of more glass phase in the NS reduced the elastic modulus, the same is true for the shear modulus. Deng et al. calculated the shear modulus of NaZr2P3O12 to be 47.7 GPa (Deng, Wang, Chu, & al., 2016). Using the experimentally determined elastic and shear moduli, Poisson's ratio was calculated to be 0.23 ± 0.01 for the NS, 0.26 ± 0.01 for the S, and 0.25 ± 0.01 for the S900C samples, see Table 10. These values show good agreement with the Poisson's ratio of 0.27 calculated from first principles by Deng et al. (Deng, Wang, Chu, & al., 2016). We believe these are the first experimentally determined values reported for shear and Poisson's ratio, thus there is no experimental comparison in literature.

Hardness

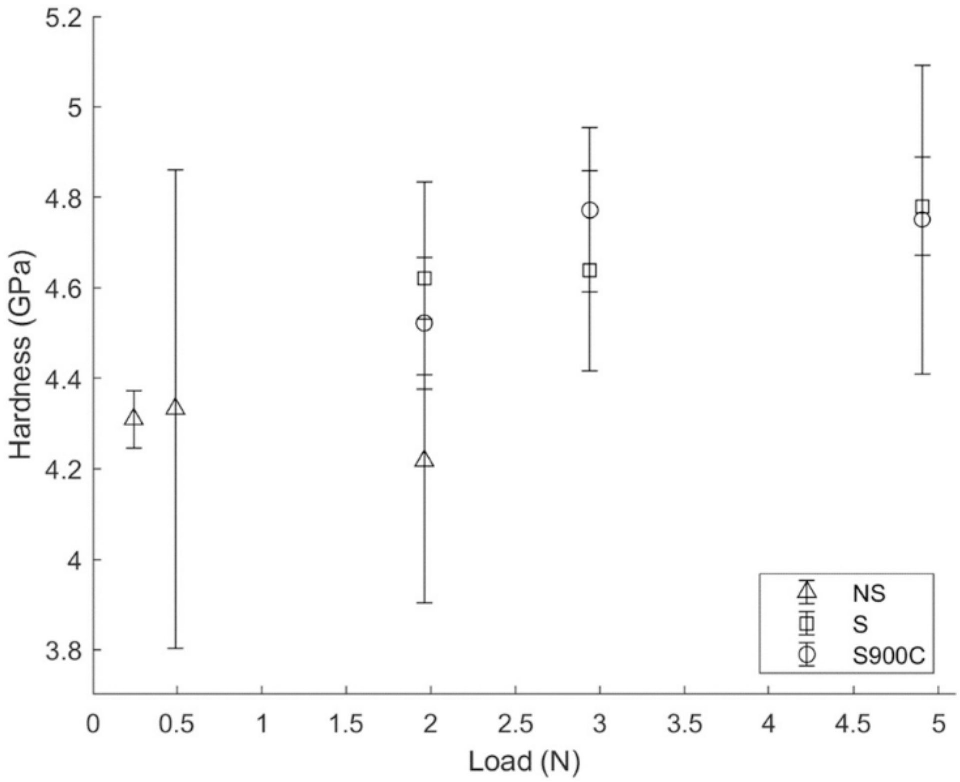


Figure 22: Hardness at loads ranging between 0.24 and 1.96 N for NS samples, and between 1.96 and 4.90 N for S and S900C samples. In general, hardness increased with increasing load, but remains relatively constant regardless of load.

The hardness was measured using Vickers indentation at loads ranging from 0.245 N to 4.90 N, see Fig. 22. The loads used depended on the material type. For example, higher loads were used for the S and S900C samples (2–5 N) while lower loads were used for the NS (0.25–2 N). The NS samples consisted of multiple phases, thus cracks formed at relatively low loads. Thus, to prevent the formation of cracks that would complicate analysis, lower loads were used. Higher loads were required to create sufficiently large, crack-free indents in the S and S900C, likely owing to the more homogenous microstructure. The hardness within experimental error is constant with load. Hardness values for the three samples (NS, S, and S900C) were similar and ranged between 4.05 and 4.68 GPa. The values are in very good agreement with literature values for comparable formulation and density: ~4.9 GPa for $Na_{3.2}Zr_2$- $Si_{3.2}P_{0.8}O_{12}$ and ~ 4.5 GPa for $Na_3Zr_2Si_2PO_{12}$ (Bogusz, Kroh, & Jakubowski, 1983); (Bouquin, Perthuis, & Colomban, 1985). The hardness of the S samples was slightly higher than that for the NS samples. This is likely a result of the smaller grain size and lower amount of glass phase in the S samples (Han, Kinzer, Garcia-Mendez, & al., 2020). Nonemacher et al. measured hardness values of 7.5 (at 50 mN load)-6 (at 1N load) for $Na_3Zr_2Si_2PO_{12}$ on samples with relative densities between 85 and 93%. The amount of the phases and the grain sizes were not reported by Nonemacher et al. (Nonemacher, Naqash, Tietz, & al., 2019). In principle, hardness should be independent of load and taken under conditions in which cracking is minimized (Li, Ghosh, Kobayashi, & al., 1989). The values in this study reached a steady-state, however some cracking occurred at higher loads, especially in the NS samples. If cracking occurred it is expected that this would result in smaller indent size and yield a higher hardness (Li & Bradt, 1996), however the values in this study were lower than those of Nonemacher et al. (Nonemacher, Naqash, Tietz, & al., 2019). This requires further study.

Fracture Toughness

Fracture toughness was determined for the S and S900C materials using the relationship derived by Niihara for Palmqvist cracks, as the ratio of crack lengths l to half-diagonal a were generally in the range of 0.25–2.5 (Niihara, 1983). Because the NS material was inhomogeneous containing substantial secondary phases, it was difficult to create cracks of homogenous length and that did not traverse across what appeared to be the presence of glass phase, see Fig. 23 a). Sometimes the crack propagated from a NASICON grain and into the glass phase and other times cracks propagated along the interface between NASICON grains and the glass phase. It was because of this inhomogeneity, which led to erratic crack propagation, that the fracture toughness was not determined for the NS samples. For the S samples, the crack lengths were more uniform and the microstructure was more homogeneous compared to the NS samples, see Fig. 23 b). Fig. 23 b) shows a representative SEM image of a typical indent with cracks radiating from each corner. Owing to the consistent crack propagation, it was possible to determine the fracture toughness of the two S samples. The fracture toughness for the two S samples were determined to be 1.05 and 1.09 (MPa m½), respectively. These values are lower than those reported by Nonemacher, who reported fracture toughness values in the 1.3–1.58 MPa m½ range for samples of compositions ranging from $Na_{3+2x}Al_xY_xZr_{2-2x}(SiO_4)_2(PO_4)$, for x values from 0 to 0.3 (Nonemacher, Naqash, Tietz, & al., 2019). The discrepancy could result from differences in NASICON composition, microstructural aspects such as grain size, and the fraction and distribution of glass phase at grain boundaries or ZrO_2 content.

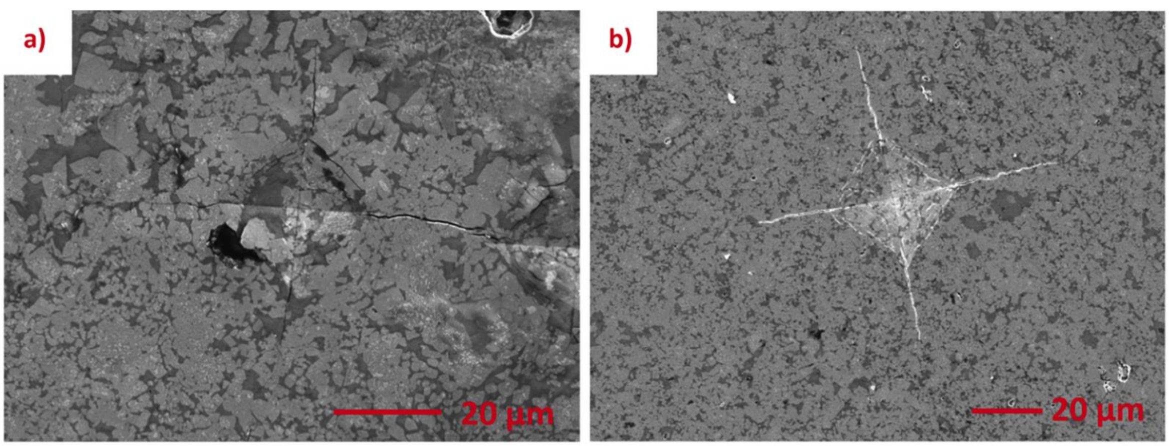


Figure 23: Fracture toughness indentation marks for a) NS and b) S at 4.9N load.

Electrical Properties

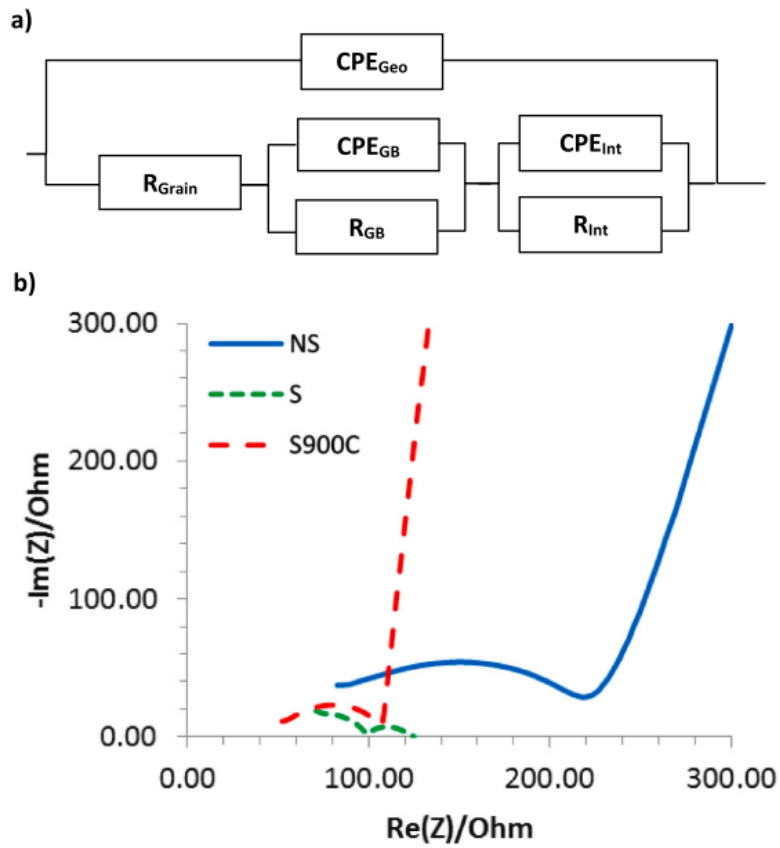


Figure 24: a) A schematic of the equivalent circuit used for fitting the impedance spectra, b) Nyquist plot for hot pressed NASICON samples NS (blue continuous), S (green short dashes), and S900C (red long dashes).

Table 11: Summary of electrochemical properties of NASICON samples.

Sample	Grain conductivity (mS/cm)	%GB	Grain boundary capacitance	Alpha grain boundary	Total conductivity (mS/cm)
NS	1.023 ± 0.152	73.22 ± 5.39	3.88E-9	0.735	0.292 ± 0.059
S	1.090 ± 0.053	43.89 ± 8.51	1.37E-8	0.816	0.612 ± 0.098
S900C	1.287 ± 0.094	53.65 ± 0.98	3.09E-8	0.836	0.596 ± 0.031

EIS was conducted on each of the samples. The ionic conductivity of the NS and S900C samples was determined by using a modified version of the equivalent circuit proposed by Huggins, see Fig. 24a) (Huggins, 2002). Resistive elements were used to represent impedance in the bulk material, the grain boundaries, and the interface between NASICON and Au for the NS and S900C samples. The capacitive elements were replaced by constant phase elements (CPEs) to account for variations in the time constants (Wang & Sakamoto, 2018). Fig. 24b) shows the Nyquist plots for representative NS, S, and S900C samples. It can be observed that the total impedance of the cells decreases in transitioning from NS to S and S900C powders. Table 3 shows the results of fitting to the equivalent circuit, including conductivities for each sample. No trend could be observed between grain conductivity and either grain size or NASICON area %. The decrease in impedance from NS to S and S900C is most significantly shown in the decrease in the % grain boundary contribution to the overall cell resistance. This is likely due to the decreased presence of the glassy phase, which accumulates at the grain boundaries, in the S and S900C samples compared to the NS samples and/or to the lower ZrO2 content, see Table 9. The S sample also exhibited a second semicircle as opposed to a characteristic blocking tail, indicating that the S sample was a mixed ionic and electronic conductor, rendering it unviable as a solid state electrolyte (Wang, Wolfenstine, & Sakamoto, 2020). This phenomenon is likely the result of electronically conductive carbon channels forming within the S sample as a result of trapped and pyrolyzed binder and dispersive additives within the sample. The total conductivities obtained for the NS and S900C samples, 0.292mS/cm and 0.596 mS/cm respectively, are in line with literature (Perthuis & Colomban, 1984); (Colomban, 1986); (Naqash, Sebold, Tietz, & al., 2018). The transference numbers calculated for S sample were an ionic transference number of 0.408 and an electronic transference number of 0.592. The transformation of the low impedance semicircle in the S sample into a blocking tail in the S900C samples indicates that the binder and dispersive additives were responsible for the non-blocking behavior of Au electrodes observed in EIS and that these additives were removed by the heat treatment, as observed by visual inspection in Fig. 18.

5.3.4 NaSICON Conclusions

A RIHP technique was used to synthesize dense von Alpen NASICON-type materials using three different precursor powders. Changes in particle morphology resulted in differences in phase purity, microstructure, mechanical properties, and electrochemical properties. The formation of a secondary, glassy phase impurity along the grain boundaries was more prevalent in NS precursor powders with larger, more irregular particles. The heightened presence of the glassy phase served to decrease the elastic modulus, 83.65 GPa and 96.33 GPa for NS and S900C samples respectively. The first measurements of Poisson's ratio and shear modulus for NASICON are reported for NS, 0.23 and 33.87 GPa respectively, and for S 900C samples, 0.25 and 38.54 GPa respectively. Vickers hardness and fracture toughness measurements showed Vickers hardness ranging from 4.30 to 4.68 GPa and fracture toughness ranging from 1.05 to 1.09 MPa m½. Ionic conductivity measurements generated total conductivities of 0.292 mS/cm for NS samples and 0.596 mS/cm for S900C samples, which are in line with conductivities obtained from samples synthesized through traditional pressureless densification sintering techniques. The decreased conductivity in NS samples was due to the higher % of the lower conductivity glassy phase along the grain boundaries and the higher ZrO2 content.

5.3.5 NaSICON and Aqueous Redox Flow Batteries

That NASICON research gave rise to a collaboration with Prof. Kwabi and one of his students to investigate how NASICON could be used in aqueous redox flow batteries (RFBs). In it I was tasked with making and characterizing NASICON pellets as well as looking at their degradation in various electrolytes for redox flow cells; the basis for my second author contribution to *Correlating Stability and Performance of NaSICON Membranes for Aqueous Redox Flow Batteries* summarized here (Modak, Valle, Tseng, Sakamoto, & Kwabi, 2022)

Introduction

… multiple studies have indicated that NaSICON membranes, for instance, show some reactivity with certain aqueous solutions resulting from degradation along their grain boundaries (Guin, et al., 2017); (Mauvy, Siebert, & Fabry, 1999); (Fuentes, Figueriredo, Marques, & Franco, 2001). This degradation has been attributed to dissolution of secondary phases, but the mechanism by which this dissolution occurs, its extent, and its implications for RFB performance are not well understood. It is therefore important to characterize the evolution of the resistance, microstructure, and chemical composition of these ceramic membranes while in contact with potential RFB electrolytes and understand how any observed changes ultimately affect RFB performance.

In this study, we examine the feasibility of von Alpen NaSICON with the chemical formula Na3.1Zr1.55Si2.3P0.7O11 as an RFB membrane material, by performing concurrent measurements of resistance, permeability, and interfacial morphology as a function of electrolyte composition and cell temperature.

NaSICON Pellet Synthesis and Characterization

Von Alpen type NaSICON (Na3.1Zr1.55Si2.3P0.7O11) powders were synthesized from reagent grade Na3PO4·12H2O, Na2CO3,ZrO2,and SiO2 precursors via calcination at 1100 °C for 10 h using the process outlined for S900C samples in ref. .31 NaSICON pellets were synthesized via a rapid induction hot pressing technique at 1200 °C for 40 min under flowing argon at a pressure of 47 MPa. The resulting billet with a 12.7 mm diameter and 6 mm height was then cut to desired thicknesses using a diamond saw, and pellets were polished down to a final 0.1 μm polish with diamond paste. Pellets were cut to thicknesses between 0.4 and 1.2 mm, and Au blocking electrodes were sputtered onto the pellets for electrochemical testing. Electrochemical impedance spectroscopy (EIS) on Au|NaSICON|Au symmetric cells with NaSICON pellets of varying thickness was performed on a Biologic VMP-300 galvanostat/ potentiostat. Frequencies from 50 mHz to 7 MHz were used with a perturbation voltage of 10 mV. Equivalent circuit modeling was used to determine grain resistance, grain boundary resistance, and total resistance for each pellet. Microstructural analysis of polished NaSICON sample surfaces before and after immersion in electrolytes was performed on a JEOL IT500 scanning electron microscope (SEM). Grayscale analysis ofSEM images to determine area percentages of identified phases was performed using ImageJ software.

Microstructural Stability and Conductance

To assess the microstructural stability of NaSICON in the presence of typical RFB reactants, the pellets were imaged after 7−9 and 30 days of immersion in select electrolyte compositions under neutral to strongly alkaline conditions. Acidic solutions were not examined, as NaSICON is well known to rapidly decompose at pH < 7 via glass phase dissolution (Fuentes, Figueriredo, Marques, & Franco, 2001); (Jing, 2017). The inorganic reactants tested included NaMnO4 and Na2S2, whereas organic/organo-metallic reactants included ferrocyanide and a proprionic acid-substituted phenazine (1,8-PFP) that has recently been shown to exhibit extraordinarily high chemical and thermal stability among molecules under consideration for aqueous organic RFBs (Xu, Pang, Wang, Wang, & Ji, 2021). In all cases, it was found that the glass phase in the pellets was etched over time, whether or not an RFB reactant was also present in solution. The severity of etching was found to be highly sensitive to the concentration of K+ ions in the electrolyte. Thus, the etching analysis was divided into two categories: (1) immersion of NaSICON in non-K+-containing electrolytes and (2) immersion of NaSICON in K+-containing electrolytes.

Immersion of NaSICON in Non-K+-Containing Electrolytes

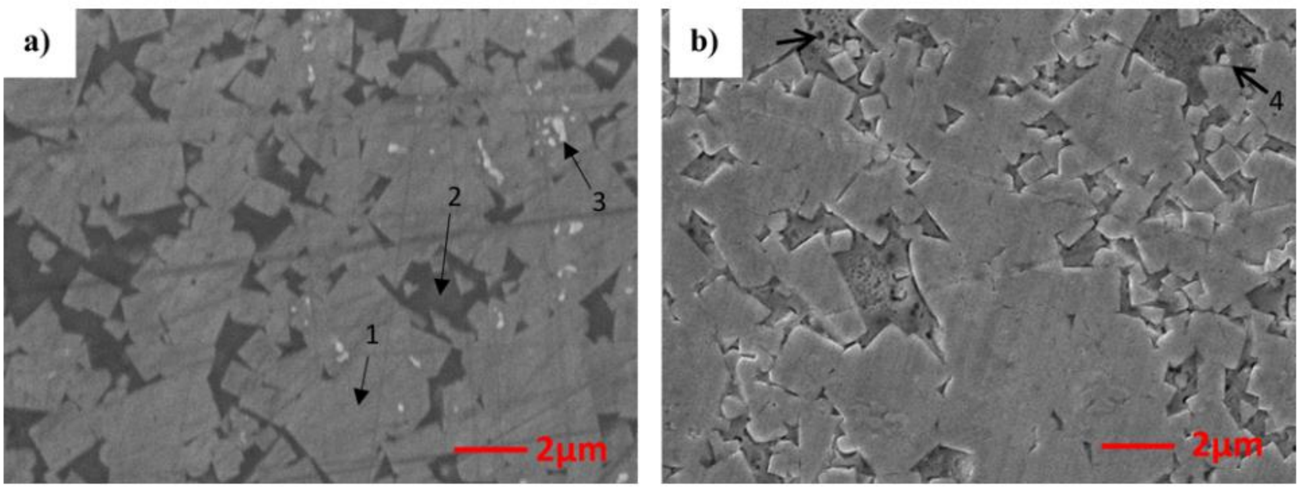


Figure 25: SEM images of (a) as-synthesized NaSICON pellet and (b) NaSICON sample immersed for 30 days in 100 mM NaMnO4 and 2M NaOH. Regions representative of grains (1), glass phase (2), and zirconia (3) are indicated in (a). Example regions of glass phase and grain boundary degradation (4) are indicated in (b).

To assess the microstructural stability of NaSICON in the presence of typical RFB reactants, the pellets were imaged after 7−9 and 30 days of immersion in select electrolyte compositions under neutral to strongly alkaline conditions (Xu, Pang, Wang, Wang, & Ji, 2021). Figure 25a shows the SEM image of a freshly synthesized NaSICON pellet, whereas the SEM image in Figure 25b shows such etching after 30 days of immersion in an electrolyte containing 100 mM NaMnO4 and 2 M NaOH, in the form of voids ∼100−300 nm in size; these voids were also evident after 7 days of immersion (Figure 26a). Similar degradation was observed in pellets immersed in electrolyte containing 100 mM Na4Fe- (CN)6 in 1 M NaOH (Figure 26b), 100 mM 1,8-PFP in 2 M NaOH (Figure 26c,d), and 100 mMNa2S2 in 2 MNaCl (Figure 26e,f) and reactant-free supporting electrolytes containing NaOH and NaCl only. No degradation of NaSICON grains was observed across all samples. Table 12 reports the apparent void area fraction of NaSICON as quantified by grayscale analysis after 7−9 and 30 days of immersion. In the reactant-containing electrolytes, the void area fraction increased from 0.7% in the pristine state to between 3.1 and 4.85% after 30 days of immersion; this represents an increase in the absolute value of void area fraction of between 2.4 and 4.15%. The pellet immersed in reactant-free 2 M NaCl had the smallest void area fraction increase (1.9%) after 30 days; for pellets immersed in reactant-free NaOH solution, the 30-day void area increase scaled with alkalinity, from 3.8% in 1 M NaOH to 4.6% in 2 M NaOH to 5.8% in 3 M NaOH.

It is worth noting that MnO4, which is the most oxidizing reactant tested here based on redox potential, did not etch the glass phase to a significantly greater extent than the other reactants and that the corresponding pellet was mechanically intact. The 30 day increase in void area fraction for the pellet soaked in 0.1 M NaMnO4 and 2 M NaOH was 3.44%, which is slightly lower than the 4.55% increase in reactant-free 2 M NaOH.

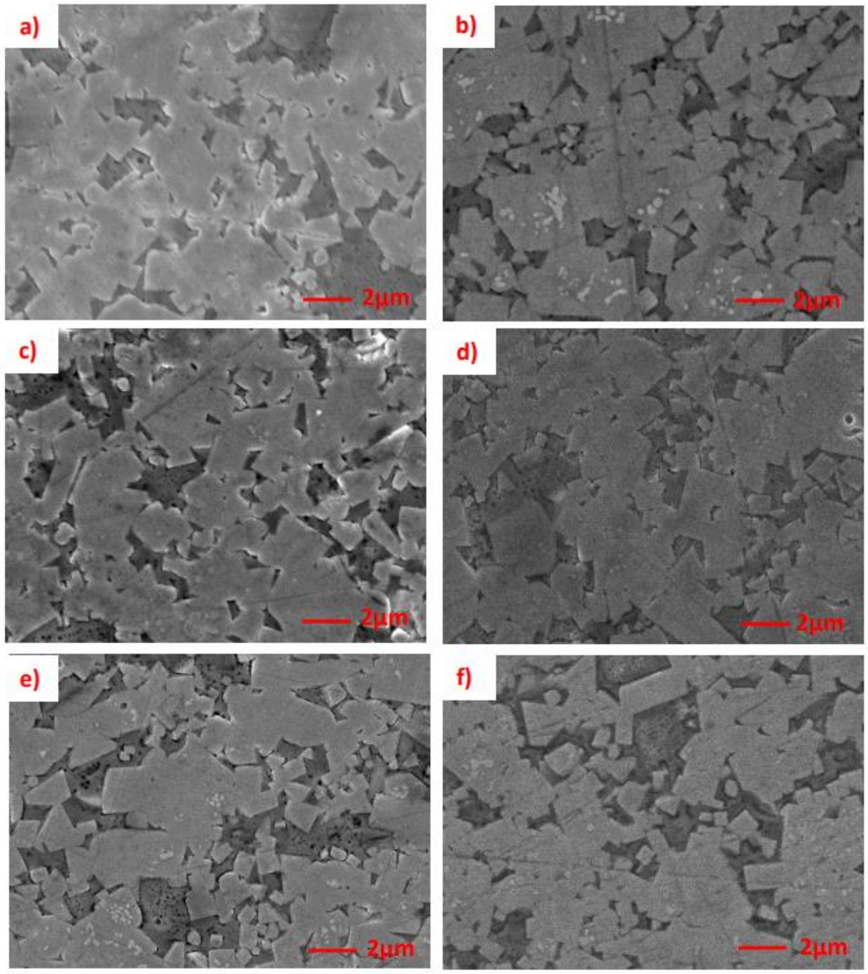


Figure 26: SEM images of NaSICON pellets after (a) 9 days immersion in 100 mM NaMnO4 in 2M NaOH, (b) 7 days of immersion in 100 mM Na4Fe(CN)6 in 1M NaOH, (c) 8 days immersion in 100 mM 1,8 PFP in 2M NaOH, (d) 30 days immersion in 100 mM 1,8 PFP in 2M NaOH, (e) 8 days immersion in 100 mM Na2S2 in 2 M NaCl, and (f) 30 days immersion in 100 mM Na2S2 in 2 M NaCl.

Table 12: Void area percentages from SEM images of NaSICON immersed in various electrolytes for different immersion times at 18 °C.

Electrolyte	Immersion Time	Void Area %
Pristine NaSICON	N/A	0.70 ± 0.31
1M NaOH	7 days	3.13 ± 0.24
	30 days	4.51 ± 0.28
2M NaOH	7 days	3.44 ± 0.93
	30 days	5.25 ± 0.32
3M NaOH	7 days	4.85 ± 0.88
	30 days	6.49 ± 0.50
2M NaCl	7 days	2.02 ± 0.50
	30 days	2.61 ± 0.27
100 mM PFP in 2 M NaOH	8 days	2.19 ± 0.21
	30 days	3.41 ± 0.61
100 mM $Na_4Fe(CN)_6$ in 1 M NaOH	7 days	3.24 ± 0.48
100 mM $NaMnO_4$ in 2 M NaOH	9 days	2.13 ± 0.57
	30 days	4.14 ± 0.56
100 mM Na_2S_2 in 2 M NaCl	8 days	3.14 ± 0.43
	30 days	4.85 ± 0.87

Immersion of NaSICON in Non-K+-Containing Electrolytes

Because supporting electrolytes containing potassium or a mixture of potassium and sodium ions have been shown to increase solubility of certain organic and inorganic RFB reactants (Esswein, Goeltz, & Amadeo, 2014), a pellet was also immersed in 1 M KCl. That pellet broke apart into granules within 7 days of immersion, and the SEM images of these granules (Figure 27a,b) indicated a much more severe and extensive degradation of the glass phase than was observed in non-K+- containing electrolytes. Close inspection of the images showed that the loss of structural integrity also involved the formation of extensive voids along grain boundaries, apparently due to glassy phase dissolution. The dissolution of the glassy phase is consistent with the behavior observed by Fuentes et al., who analyzed the stability of NaSICON in water (Fuentes, Figueriredo, Marques, & Franco, 2001), but the finding in this study that K+ ions accelerate this dissolution is novel.

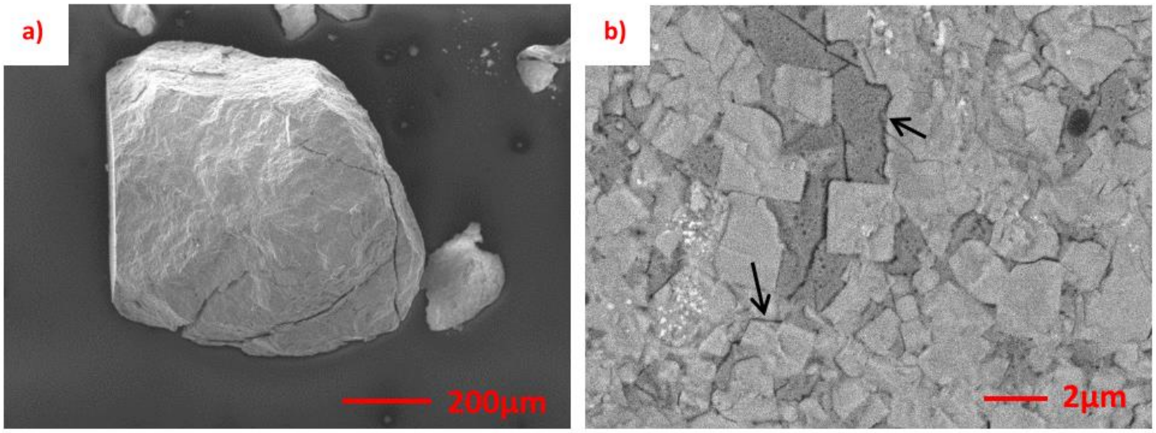


Figure 27: SEM images of remnants of a pellet immersed for 7 days in 100mMKCl at (a) low and (b) high magnification. Example regions of glass phase and grain boundary degradation are indicated in (b) with black arrows.

Conclusions

The glassy phase at the surface of NaSICON is susceptible to etching while in contact with aqueous electrolytes. In non-K+-containing electrolytes, the etching increases slightly with pH, but the overall grain and grain boundary resistance impedance of NaSICON is stable over time. In K+-containing electrolytes, the etching increases dramatically and leads to complete disintegration of the pellet. On the basis of these results, NaSICON pellets with very little to no glassy phase present are likely to be suitable as aqueous RFB membranes (Hwang, Park, Kim, & al., 2019).

Although I knew how to perform technical work to the standard expected of a PhD student in materials science and engineering, I no longer understood the methods I was expected to use as connected to solving climate change, much less addressing any systems of oppression that maintain it. It had become more difficult for me to stay present in the lab, embracing it as a job tracking me toward greenwashed corporate careers that I thought ought to be abolished rather than adored. This overlapped with the Rackham Merit Fellowship (RMF) I had been awarded for my fourth year to fund my studies, along with the onset of stay at home orders due to COVID-19. RMF offered an opportunity to shift my work toward engineering education research unpacking why and how sociopolitical components of engineering are systematically externalized. The time away from lab during COVID-19 gave me the space to do so. The issues with extraction still loom(ed) large over my head, but I'd found the conditions of dominant engineering offered virtually no space to discuss them, much less embrace ways of knowing and being that challenged these conditions and changed research trajectories. I felt the incommensurability of meritocratic and depoliticized ideologies in dominant engineering normalized through a positivist paradigm with my ways of knowing and being and sought a way to reconfigure my relationships to dominant engineering (Haverkamp, et al., 2019); (McGee & Bentley, The Equity Ethic: Black and Latinx College Students Reengineering Their STEM Careers toward Justice, 2017).

Chapter 6 A Deconstruction of Dominant Engineering

From within dominant engineering, the horizons for hope all seemed to veer towards transdisciplinary endeavors. I hoped engineering education research (EER) would offer more of a path to grow the nuclei of those existing spaces already restructuring engineering and its research trajectories from within. Figuring out what materializing that through my actions might look like led me to reflect on and unpack my understanding of harmful assemblages holding dominant engineering together. A first step in moving away from the dominant engineering paradigm is critiquing it and how I was educated within it, before stepping into other ways of knowing and being. The organizing work I was a part of offered the pedagogy I needed to take those steps, described in this chapter through a reflection on experiences in engineering education that lead me to a shift in characterization in and of the materials tetrahedron, a deeper context of dominant engineering than what my dominant engineering education had offered me, and ways I understand dominant engineering is enmeshed in the assemblage of industrial complexes.

6.1 A Reflection

A key component of accountability is self-reflection (Mingus, The Four Parts of Accountability: How To Give A Genuine Apology Part 1, 2019), the sort of reflection on harmful actions that leads to transformation and behavioral change. The framing of sustainability I internalized and was trained to replicate through my dominant engineering education is deeply entrenched in, reinforced by, and reinforces colonialism, imperialism, and racial capitalism. It was baked into the institution I attended for undergrad, MIT, grown through the Morrill Land

Grant Act (MIT Admissions, 2022). The Morrill Act turned land into capital to construct universities with the goal of growing industry (la paperson, 2017). As the act states,

> "The leading object shall be, without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts, … in order to promote the liberal and practical education of the industrial class," (Morrill Act, 1862).

This is discussed by la paperson, where

> "the prioritization of settler colonial technologies - agricultural and mechanical engineering, not to mention military tactics - reflects how land-grant universities were commissioned as part of the empire-self-making project of the United States," (la paperson, 2017, pp. 27-28).

To me, taking on the title of engineer, particularly in the context of the United States, is (unwittingly) choosing to inherit these settler colonial technologies along with the structures and the processes that have and continue to uphold them. This helped me understand why in my education as an engineer I was consistently and constantly taught to perform in ways that uncritically ignore just about everything that was not considered technical or reduce the non-technical into an abstract technicality. For so long I embraced that ignorance, that *desconocimiento*, as a way to dampen down and cover up much of the shame and self hate I had internalized and emotions I had not processed; the disconnection of subject and object helping me hide the need to work on myself. MIT offered an environment for that disconnection to flourish as I and just about everyone I knew piled on a bunch of clubs, research, and other activities on top of heavy course loads while stigmatizing and casting aside non-technical considerations into the umbrella of humanities, arts, and social sciences (HASS). That kept it so the gap between the sinking in my stomach from a sense that what I was doing, how I was being trained, professionalized, to perform was wrong and the tools of how to understand, name, unpack, and move through that wrong seemed so large that it was insurmountable. While I could commiserate with friends in engineering about climate change and inequities, we never really got past the commiserating stage toward seeing the tunnel our studies tracked us into and acting against it.

Even with a transition to a grad school considered well rounded, top 10 in just about every program it has, I couldn't find relief in dominant engineering. Rankings did not give way to transdisciplinarity and de-siloed paths through which the ways of knowing bounded outside of dominant engineering might make their way in from areas of the academy where they are more commonplace (Riley D. , 2017). That absence of relief within dominant engineering forced me to reflect and brought me back to Mr. Hernandez's U.S. history class in high school, where he pulled from Howard Zinn's A People's History of the United States (Zinn, 1999). It had been years since I'd dropped my practice of reading outside of coursework, focusing more on my studies, lab research, and work on the MIT Electric Vehicle Team (EVT) that landed me a spot in grad school. Picking up Zinn over my first winter break in grad school to restart that practice gave me a framing that engineering didn't: one where change happens by regular, unsuspecting people coming together to make it happen. That reframe lit a fire in me that being in dominant engineering had trained me to dampen down, spurring me to attend an Ann Arbor City Council meeting in January 2018 based on a facebook event from Transforming Justice Washtenaw (TJW). TJW was seeking support in holding the Ann Arbor Police Department (AAPD) accountable for the killing of Aura Rosser, a Black mother who was experiencing mental health issues, by officer David Reid over 3 years prior in 2014 (RAW, 2015). With no sense of how that meeting would shape my trajectory moving forward, I walked into the council chambers open and eager to learn more and get involved. I didn't know anyone there; a city council's chambers aren't a place you typically find engineers and those were the only sort of people I knew in Michigan at the time.

The main agenda item of note was the Hillard Heintz report, a ~$200,000 study run by a group consisting overwhelmingly of ex-police officers commissioned by city council after years of mounting pressure from community members to investigate AAPD's practices, which advocated for "co-produced policing" (Hillard Heintze, 2017). As the report came up and council started discussing next steps, a white member of the crowd started berating city council and particularly Mayor Taylor, who had gone on record saying Aura's murder was "not a tragedy of racism" (Abbey-Lambertz, 2015). They condemned the report as a waste of money advancing false solutions that served to strengthen police power. As they continued on, other white folks on council and in the crowd reacted more to the outburst as a break from civility than its content, with the meeting eventually continuing. After the council session wrapped up, I went up to them, amazed at what they'd done, realizing I'd gotten more context on the place I was living in an hour than I'd gotten in months of being in my engineering program. I wanted to learn more about what they had talked about, and asked how I could do so. That conversation got me set up to attend a Collective Against White Supremacy (CAWS) meeting later that week, introducing me to white anti-racist organizers and a sense that this was the sort of group that could help me cultivate the *conocimiento* my engineering mentors and program couldn't.

I remember a conversation with one of my BIPOC grad student peers in MSE one summer night walking home from downtown after the buses had stopped running. It was months after the city council meeting and I had been talking to them about the tensions I'd been experiencing. I talked about the fulfillment I got through my increasing engagement with CAWS and GEO organizing for a police oversight commission in Ann Arbor as well as the enjoyably difficult challenge of organizing engineers into our union. I contrasted it with the sorrow of how distant that all seemed from my research in dominant engineering. I still enjoyed the battery research, clinging to my same high school narrative that it was a way for me to do good, but there was a hollowness I felt with it that I couldn't shake. As we reached the dimly lit spot where our paths home diverged, after having patiently listened to what I was saying, they gave me what felt like an ultimatum of picking one or the other, because continuing with both wasn't something I could really do. It didn't necessarily help alleviate the internal tensions I was still having, but it did spark my curiosity. As I kept walking home, alone, I wondered why not. What prevented those paths from overlapping?

About a year later and well into my role as one of our union's department stewards, there had been a number of racist, xenophobic, and sexist incidents within our department that brought a number of the primarily BIPOC impacted folks together and one of them looped me in. I offered that these incidents weren't something these members could grieve through our union, since nearly a decade prior the unionization drive of graduate student research assistants (GSRAs) was busted through the lobbying efforts of the right wing think tank the Mackinac Center for Public Policy and then-UM President Mary Sue Coleman (Prusak, 2011). They'd seen to it that the Republican controlled state government passed a bill naming research assistants as students and not workers, making it so that as GSRAs we were excluded from accessing the anti-discrimination protections in our union contract (Woodhouse, 2012). While we couldn't rely on the GEO contract provisions, we could pull on the same sorts of union and community organizing methods that led to those provisions in the first place. In naming the harms stemming from those incidents, we began assembling a list of changes for the department to make that would shift the conditions that allowed harm to occur in the first place. The changes that group came up with included increased DEI programming, improved accountability structures rooted in restorative justice, transparency in advising expectations, reduced barriers to switching labs, and student decision making power in departmental faculty and chair hirings. From there, we secured support from the department grad student council (MSE GSC) and began collecting signatures of support from other grad students and faculty members.

As our signature list grew, departmental administrators caught wind of what was going on and pulled a couple of us into a meeting. There, we were chastised for a "UAW-style demands" list and were told to go back to our lab work since they alleged some of the professors were concerned about how this drive impacted our degree progress. The reminder of degree progress was a not so subtle hearkening back to justifications given for why a grad student labor organizer from our department that was heavily involved with the GSRA unionization drive was fired a few years prior (White, 2016). The students I'd known who have had this held over their heads here have overwhelmingly been BIPOC folks, queer folks and folks going through mental health struggles. It came as we were told the means by which we could uplift our communities was effectively through a conformist resistance strategy of keeping our heads down and getting out of here with a degree (Solórzano & Delgado Bernal, 2001). I remember the conversation flowing toward a practice of land acknowledgements the Ecology and Evolutionary Biology (EEB) department had been doing and asking whether that was something our department could move toward as well (LSA EEB, 2022). I brought up EEB specifically since EEB was also a STEM field. It surprised me when I was told to cut out the "LS&Play crap," an intentionally derogatory remark about the College of Literature, Science, and the Arts (LS&A) teeming with the same casual majorism dominant engineering had trained me to uphold in undergrad (Carrigan & Bardini, 2021). That was followed up with a reminder of how in engineering we just do things differently. While land acknowledgements themselves have tense relationships to privileged university spaces, especially when they function more to check a box than invite further learning about the territory we occupy and the jurisdictions of Indigenous nations, this response seemed more reflective of an outright denial of that learning as a way to maintain this construct of dominant engineering (CBC Radio, 2019).

There is a particular sort of indignity that comes from having a program gaslight you by saying diversity, equity, and inclusion are departmental priorities while seeing actual moves toward equity denied. Experiencing that meeting left me reflecting more deeply on the corporate meaning of DEI at a school with a history of intentionally upholding racial inequity (Johnson, 2020). It had given me a small glimpse of how settler colonialism structures our department and was definitely effective in grinding organizing to a halt. Out of that entire campaign the only discernible shift from the department's leadership came in the form of two DEI grad seminars. They would replace two technical seminars in the semesterly seminar series graduate students are required to attend their first 4 semesters in the department. Notably, this was a change that did not impact the departmental budget and land acknowledgements have still remained noticeably absent in departmental spaces. A disappointment compared to the set of changes we hoped to bring about, but it also represented a significant step in the ways the graduate students in MSE organized together. We saw that we could bring about some changes to the department while also recognizing the resistance departmental administrators would put up.

The first DEI seminar speaker ended up being Prof. Erin Cech, a queer white woman who gave me an introduction to EER that I will never forget. Prof. Cech presented on the depoliticized and meritocratic nature of dominant engineering, gender inequities in STEM, and covering and passing strategies of queer folks in engineering that had me bawling (Cech & Waidzunas, 2011); (Cech E. A., 2013); (Cech E. A., 2014). The combination of the folks attending who saw to it that grad student organizing in the department was halted, Prof. Cech putting words to phenomena that we had just had to bump up against in order to see this seminar exist, actually feeling seen in the content of the presentation for the first time as a queer person who had to do a whole lot of covering in departmental spaces … having that happen in a department space, the gravity of realizing how it took years to open up a crack in the thin blue lines for a moment was too much for me to be able to contain. I caught a glimpse of a way engineering could be different, one that could be aimed at challenging inequities rather than reinforcing them, and refused to let that go. After Prof. Cech's talk wrapped up, choking down tears, I made sure that it was known that grad student organizing led to this seminar being able to take place and was consoled by folks like my now committee member Dean Millunchick. That seminar and the follow up conversation between Prof. Cech and me a couple weeks later gave me an understanding that a miscibility gap could be found in EER that troubles the immiscibility framed to exist in dominant engineering between sociopolitical considerations and engineering. EER made space for me to envision how engineering could be done fundamentally differently, queerly, opening up a wider set of structures and processes that could be transformed, including how dominant engineering itself is constructed and maintained.

6.2 Shifting Characterization in the Materials Tetrahedron

I consider deconstruction akin to reverse engineering, getting a sense of why and how something was constructed the way it was without having been there as it was constructed. The materials tetrahedron is commonly understood to outline interconnections between the fundamental components of materials science and engineering, namely structure, properties, processing, performance, and characterization (see chapter 3). I think of it as a key technology of materials science and engineering in assemblage with technologies of settler supremacy, Indigenous erasure, and anti-Blackness. Recognizing the limitations of how the materials tetrahedron, as it is currently used, fails to adequately address beginning and end stages in the life cycle of a metal, Donahue proposed a reimagination of the materials tetrahedron into a materials square pyramid (Donahue, 2019). According to Donahue, the existing materials tetrahedron "completely ignores the energy and emissions costs involved in obtaining the metal to process and also totally ignores the fate of the product after its usefulness has ceased," (Donahue, 2019, p. 2684). In this transformation, sustainability/criticality functions as the base as a means to ensure the entire life cycle of a metal (sustainability), or any material, is adequately considered alongside supply and demand challenges (criticality). As this reimagination seeks to envelop structure, processing, properties, and performance in a sustainability/criticality component, it leverages sustainability/criticality as a key characterization lens for any material, see Figure 28.

While the addition of sustainability/criticality may represent a step toward a key layer of analysis that is currently inconsistently considered within dominant materials science and engineering education, I think this analysis may find a clearer connection to the characterization component of the existing tetrahedron. Donahue did not use a version of the tetrahedron that included characterization and did not address epistemological perspectives outside of positivism, which is why I think he focused primarily on the technoeconomic arguments related to supply chains. I think characterization offers a meaningful intervention point in MSE since it allows for the existing materials tetrahedron to be understood through paradigms more attuned to analyzing the power relations that shape notions of sustainability/criticality and much more. It is notoriously difficult to discuss power relations in positivist paradigms, owing to its construction of reality as objective, singular, and external to the researcher as well as its incommensurability with other paradigms (Guba & Lincoln, 2005), see Figure 29.

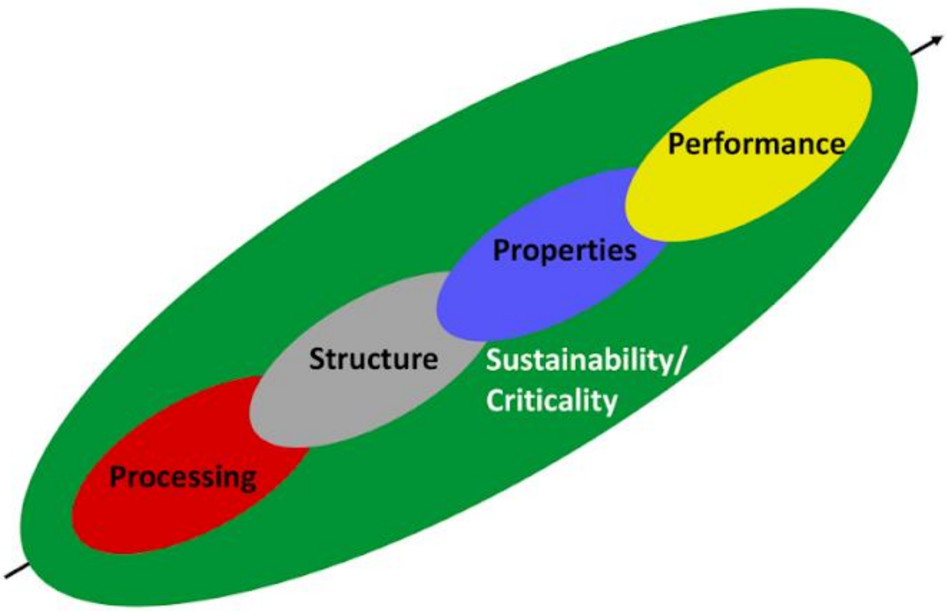


Figure 28: Linear approach to the materials tetrahedron with a sustainability/criticality component, reproduced from Donahue (2019).

In the *Prison Notebooks*, Marxist theorist Antonio Gramsci decried a "reductionism" or "economism" common when considering class within classical Marxism (Gramsci, 2011 [1929-1935]). Stuart Hall discussed this sort of "reductionism" or "economism" as:

> "a specific theoretical approach which tends to read the economic foundations of society as the *only* determining structure. This approach tends to see all other dimensions of social formation as simply mirroring 'the economic' on another level of articulation, and as having no other determining or structuring force in their own right. The approach, to put it simply, reduces everything in a social formation to the economic level, and

conceptualizes all other types of social relations as directly and immediately ‘corresponding’ to the economic,” (Hall, 1986, p. 10).

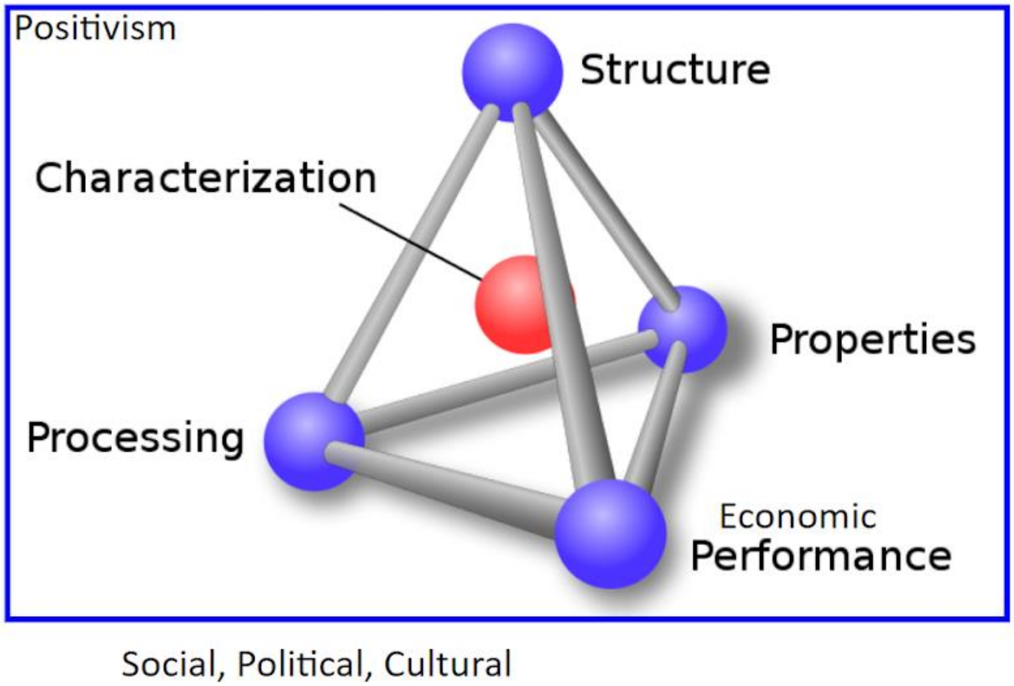


Figure 29: The materials science and engineering tetrahedron. The boundaries of a positivist epistemology are shown as a thin blue line to highlight how the social, political, and cultural are positioned external to and beneath the tetrahedron as well as the association of the economic with performance.

The “economism” approach Hall discusses is a theoretical reductionism endemic in dominant engineering today that typically anchors discussions of performance within the materials tetrahedron, see Figure 29 as compared to Figure 5. This “economism” considered commensurable within positivist paradigms, exemplified in the way the UM MSE department describes how “every part in technologies … are carefully designed to optimize performance and *cost effectiveness*,” (UM Materials Science and Engineering, 2022). Yet cost effectiveness does not show up in nominal constructions of the materials tetrahedron. As Gramsci discussed, the role of the economic in this context is to “create a terrain more favourable to the dissemination of certain modes of thought, and certain ways of posing and resolving questions involving the entire subsequent development of national life,” (Gramsci, 2011 [1929-1935], p. 184) cited in (Hall,

1986) which he linked to tendencies to positivism, empiricism, and objectivism. In this way, the economic acts like an activation energy, manipulating what pathways are favorable. The tendencies he discussed are central to what dominant engineering education teaches, where “economism” in engineering education obscures connections to what Gramsci discusses as complex superstructures: the political, social, cultural, and ideological formations that relate to and contextualize the economic structure. Gramsci discusses relationships between these superstructures to the structure of the economic base via the passage of historical movements through the social formation, which I consider to be infrastructures holding these relationships together. Dominant materials science and engineering education teaches structure, as understood through the materials tetrahedron, while maintaining technological infrastructures that hide the superstructures normalizing this sort of reductionism. This makes for a dominant materials science and engineering that makes bold claims that we are “creating how the world works” and are “designing how the future is made” (UM Materials Science and Engineering, 2022) while ignoring increasingly precarious material conditions people must operate in and crafting the infrastructures needed for “systematically eras[ing] certain socioecological contexts, or horizons, that are *vital for members of another society to experience themselves in the world as having responsibilities to other humans, nonhumans and the environment*," (Whyte, 2016). A tension that I believe infrastructural theories of change make space for this field to contend with is how positivism contorts epistemologies of ignorance to all but guarantee *desconocimiento*, rendering critical components of reflexivity central to many forms of *conocimiento* illegible to maintain “the empire-self-making project of the United States," (la paperson, 2017, p. 28).

One site of this tension is objectivity. Feminist scholar Sandra Harding discusses the ideological formation of objectivity endemic within dominant engineering and engineering education as laden with “culture-wide assumptions that have not been criticized within the scientific research process,” (Harding, 1992, p. 446). She names this “weak objectivity,” contrasting it with a “strong objectivity” which requires “the subject of knowledge be placed on the same critical, casual plane as the object of knowledge” (Harding, 1992, p. 458). In advancing this notion of “strong objectivity,” Harding claims

> “the subject of knowledge - the individual and the historically located social community whose unexamined beliefs its members are likely to hold “unknowingly,” so to speak - must be considered as part of the object of knowledge from the perspective of scientific method,” (Harding, 1992, pp. 458-459).

The ‘technical’ as well as dominant engineering itself are social constructs (Pawley A. , 2019a). With a more enveloping, expansive notion of the characterization in the materials tetrahedron offered by constructivist, critical, and post+ paradigms, the superstructures shaping subjectivities of materials scientists and engineers are no longer externalized from the object of materials science and engineering characterization, but instead become a central component. In this expanded characterization, Gramsci’s concept of hegemony where the political leadership of the ruling class is primarily derived from the consent of subjugated classes through manipulating ‘common sense’ rather than the overt use of force or coercion becomes hyper-relevant (Gramsci, 2011 [1929-1935]). In particular I’ve found post+ characterizations to offer an additional depth of analysis toward the interrogation of the hegemonic conditions underpinning dominant engineering; the superstructures functioning to invisibilize themselves within dominant engineering and being normalized as ‘common sense’ through weak objectivity.

One of the aspects of thinking through post+ characterizations is that it makes space for questions of validity. In their discussion of paradigmatic controversies, Guba and Lincoln consider validity to pose questions like “are these findings sufficiently authentic (isomorphic to some reality, trustworthy, related to the way others construct their social worlds) that I may trust myself in acting on their implications? More to the point, would I feel sufficiently secure about these findings to construct social policy or legislation based on them?” (Guba & Lincoln, 2005, p. 205). Part of the construction of validity within autoethnography is related to the care that goes into the stories told. Identification of the challenges, choices, outcomes, values, and morals conveyed, how autoethnographers assemble those together while being mindful of how others implicated in the stories are portrayed as well as how it might be received by its intended audience. How the story resonates with the readers and their subjectivity, what it drives them to feel, (re)consider, and/or do becomes a more substantive component of the research process. Such validation is felt and those feelings are shaped through experience.

I feel an uncanny connection to traditional materials science and engineering concepts in Guba and Lincoln’s discussion of validity as resistance and post+ transgression through Laurel Richardson’s work and a move from triangulation (Guba & Lincoln, 2005). Triangulation is a means of bolstering trustworthiness, particularly in narrative inquiries, by gathering at least three sources that address the same issue (Hughes & Pennington, 2017); (Polkinghorne, 1995). Triangulation has connections to positivism and I think of it as related to the notion of needing at least three points to make a more believable trendline. To quote extensively from Guba and Lincoln’s discussion:

> “Laurel Richardson (1994), (1997) has proposed another form of validity, a deliberately “transgressive” form, the crystalline. … In order to see “how transgression looks and how it feels,” it is necessary to “find and deploy methods that allow us to uncover the hidden

assumptions and life-denying repressions of [a discipline]; resee/refeel [that discipline]. Reseeing and retelling are inseparable" (1997, p. 167).

The way to achieve such validity is by examining the properties of a crystal in a metaphoric sense. Here [Guba and Lincoln] present an extended quotation to give some flavor of how such validity might be described and deployed:

> I propose that the central imaginary for "validity" for postmodernist texts is not the triangle - a rigid, fixed, two-dimensional object. Rather the central imaginary is the crystal, which combines symmetry and substance with an infinite variety of shapes, substances, transmutations, multidimensionalities, and angles of approach. Crystals grow, change, alter, but are not amorphous. Crystals and prisms that reflect externalities and refract within themselves, creating different colors, patterns, arrays, casting off in different directions. What we see depends upon our angle of repose. Not triangulation, crystallization. In postmodernist mixed-genre texts, we have moved from plane geometry to light theory, where light can be both waves and particles. Crystallization, without losing structure, deconstructs the traditional idea of "validity" (we feel how there is no single truth, we see how texts validate themselves); and crystallization provides us with a deepened, complex, thoroughly partial understanding of the topic. Paradoxically, we know more and doubt what we know (Richardson L. , 1997, p. 92).

The metaphoric "solid object" (crystal/text), which can be turned many ways, which reflects and refracts light (light/multiple layers of meaning), through which we can see both "wave" (light wave/human currents) and "particle" (light as "chunks" of energy/elements of truth, feeling, connection, processes of the research that "flow" together) is an attractive metaphor for validity. The properties of the crystal-as-metaphor help writers and readers alike see the interweaving of processes in the research: discovery, seeing, telling, storying, re-presentation" (Guba & Lincoln, 2005, p. 208).

6.2.1 The Materials Tetrahedron in the House Modernity Built

This construction of crystalline validity sits alongside the empirical validity demanded in dominant engineering contrasting with the ways of knowing deemed acceptable to contribute to universal reason. I feel like crystalline validity offers me a way to characterize superstructures through the conceptual framework of the materials tetrahedron. The metaphor of "the house modernity built" developed by the Gesturing Toward Decolonial Futures Collective has been particularly helpful for me to understand these superstructures and the infrastructures maintaining them (Gesturing Toward Decolonial Futures Collective, 2018). Collective member Sharon Stein described the metaphor as a pedagogical tool intended to "enable the possibility of interrupting and denaturalizing enduring frames of reference, making new connections and relationships, and enabling qualitatively different kinds of conversations and questions," (Stein S. , Navigating Different Theories of Change for Higher Education in Volatile Times, 2019, p. 670), see Figure 30. Post+ paradigms allow for a dissolution of at least parts of the thin blue line boundaries of positivism, opening up a multitude of angles of approach to understand dominant materials science and engineering and its associated lines of inquiry as situated within the house modernity built. This metaphor of the house modernity built allows for a naming of a foundation of separability, or a separation of "humans from "nature" and other-than human-beings, and institut[ing] a hierarchy that is premised on human domination/ownership," (Stein S. , Navigating Different Theories of Change for Higher Education in Volatile Times, 2019, p. 671). This separability is connected to the epistemology-ontology divide Vanessa Watts names, discussed in chapter 2 (Watts, 2013). The wall of universal reason connects to Enlightenment humanist knowledge, a notion of one universally relevant truth interrelated propped up in positivist paradigms (Stein S. , Navigating Different Theories of Change for Higher Education in Volatile Times, 2019). As Max Liboiron puts it, "the universal is never universal, but rather an argument to imperialistically expand a particular worldview as the worldview," (Liboiron, 2021a, p. 52). The wall of the nation-state acts as a means of protecting the house by restricting who is allowed in and protecting the property claims of those inside (Stein S. , Navigating Different Theories of Change for Higher Education in Volatile Times, 2019). Ruth Wilson Gilmore and Craig Gilmore describe that states seek “to maintain, through consent or coercion, supremacy over all other organizational forms in the social order. A key feature of that supremacy lies in the state's singular control over who may commit violence, how, and to what end,” (Gilmore & Gilmore, Restating the Obvious, 2008, p. 144). The roof of global capital acts as a “driving force of the house’s outsized environmental impact on the planet, through the consumption of “natural resources” and the production of toxic waste,” (Stein S. , Navigating Different Theories of Change for Higher Education in Volatile Times, 2019, p. 672).

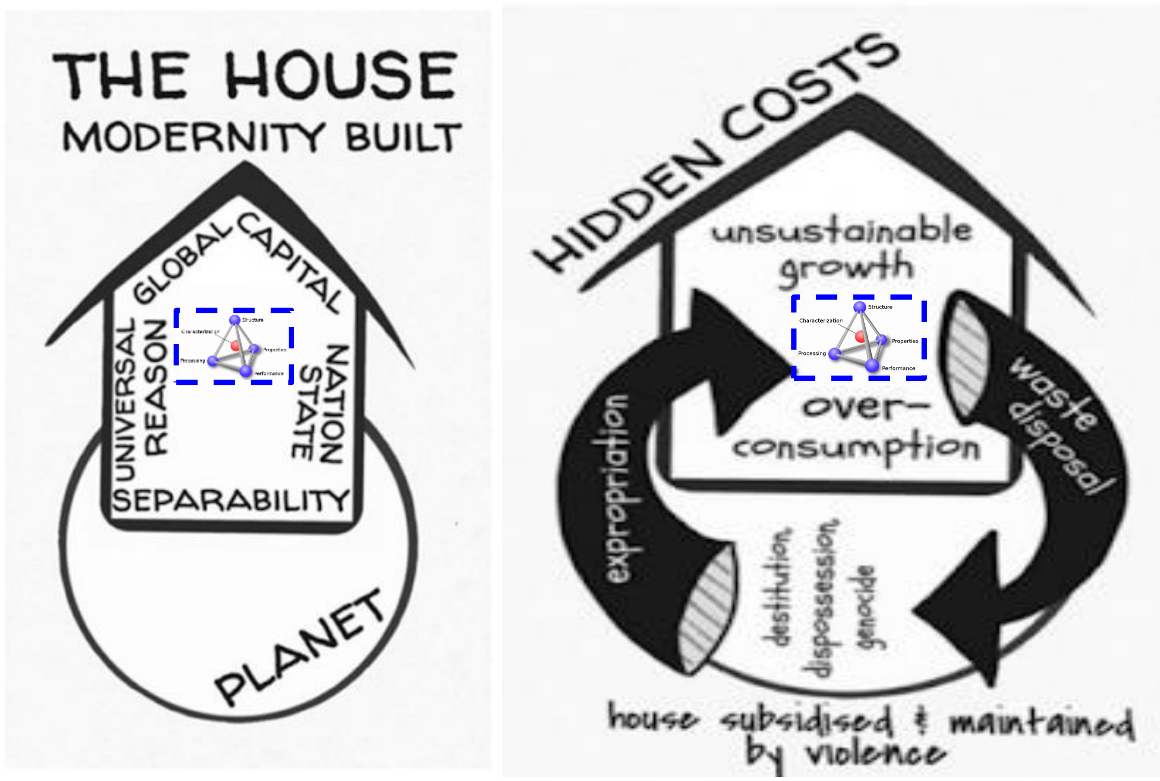


Figure 30: 1) situating the materials tetrahedron in the metaphor of "the house modernity built" by dissolving rigidly constructed boundaries through a shift from positivist paradigms, 2) invisibilized costs of maintaining the house modernity built (Stein S. , Navigating Different Theories of Change for Higher Education in Volatile Times, 2019).

Also obscured by the thin blue lines in dominant materials science and engineering education are the invisibilized costs of violently maintaining the house modernity built, see Figure 30 (Stein S. , Navigating Different Theories of Change for Higher Education in Volatile Times, 2019). Unsustainable growth and overconsumption drive waste disposal, fueling destitution, dispossession, and genocide toward further expropriation. Stein connects the infrastructures of these violent, colonial processes to the superstructures as systems maintaining the assemblage of the house modernity built through modern promises offered by the house, see Table 13 (Stein S. , 2021). Positivist paradigms do not situate action as a responsibility of the researcher, as action veers more toward subjectivity or "advocacy" that is incommensurable with the notions of validity and objectivity positivism upholds (Guba & Lincoln, 2005). This allows for uncritical adoption of the modern promises as conditions for engineering labor and maintenance of the fatal couplings of power and difference holding these assemblages of systems, promises, processes together. One way I've made sense of this as an abolitionist engineer in the context of both the electrochemical energy storage research and the engineering education research I've conducted is through the liberatory engineering education model (LEEM) discussed in chapter 3.

Table 13: Modern promises and the colonial processes that subsidize them, reproduced from (Stein S. , 2021).

Systems	Modern Promise	Colonial Process
Capitalism (Economic system)	Continuous economic growth and wealth accumulation	Racialized expropriation and exploitation of humans and other-than-human beings
Nation-state (political system)	Security and order; protection of people and property; cohesion through shared identity	State-sanctioned violence, including policing, prisons, borders, and global militarism
Universal reason (intellectual system)	A single, universally relevant knowledge system that offers certainty, predictability, consensus	Suppression and attempted obliteration of other knowledges (epistemicide); knowledge used to index and control the world
Extractivism (ecological system)	Infinite consumption of 'natural resources' for human use	Climate change; biodiversity loss; denial of the intrinsic worth of other-than-human beings
Separability (relational system)	Independence, individualism, and unrestricted autonomy	Refusal of interdependence and its related responsibilities

6.3 Dominant Engineering and the LEEM

Theories of change are shaped by how a problem is conceived of and proposed responses to the problem, in turn shaping critiques and horizons of possibility (Stein S. , 2019); (Tuck &

Yang, 2014). I see this as connected to the design dimension of engineering Figueiredo posits, discussed in chapter 2, since it guides decision making amidst uncertainty (Adams, Evangelou, English, & al., 2011). Continuing with the metaphor of the house modernity built, Stein discussed three theories of change as approaches to navigating the increasing instability of the house, see Table 13 (Stein S. , 2019). In collaboration with Bailey Bond-Trittipo, Prof. Stephen Secules, and Andrew Green at FIU, we considered these three theories of change in the context of curricular and co-curricular methodologies (Bond-Trittipo, Valle, Secules, & Green, 2022). We summarized them in Challenging the Hegemonic Culture of Engineering: Curricular and Co-Curricular Methodologies as:

> "Minor reform theories of change hold a notion that despite the historical and present-day imperfections of higher education, institutions can be refined to reclaim the purpose of higher education for the public good without disrupting existing power dynamics. As such, rather than dismantling the oppressive structures of education and society more broadly, this framing promotes the idea that individuals should change in order to improve the effectiveness, efficiency, and inclusivity of the current system (Stein S. , 2019).
>
> Major reform theories go beyond making revisions at the level of practice by connecting the production of knowledge with historical and systemic inequities, recognizing that dominant ways of knowing are favored to benefit a select few and sacrifice the quality of life for others. These theories of change open up conversations about who is in control of what constitutes valuable knowledge and viable change-making approaches and center oppressed people's experiences, perspectives, and ways of knowing (Stein S. , 2019). By doing so, they seek to learn "from alternative ways of

knowing in search of roadmaps that can lead toward more equitable, sustainable futures," enacting the "redistribution of resources within existing systems (Stein S. , 2019, p. 673).

Beyond reform theories of change recognize the problems in the system are of its own making. Oriented by a sense of disillusionment with the promises offered by the existing system, these theories of change invest "not in the university itself, but instead in learning how to become answerable for our complicity, engaging in collective experimentation with more viable less violent futures, and committing to learning from both the successes and failures of those experiments," (Stein S. , 2019, p. 678). They deemphasize and denaturalize the university in order to imagine other possibilities. Additionally, beyond reform theories of change adopt strategies of harm mitigation and resource redistribution as short-term responses to crises of higher education, aimed toward "viable but as-yet-undefined and unimaginable futures" (Stein S. , 2019, p. 673)" (Bond-Trittipo, Valle, Secules, & Green, 2022, pp. 2-3).

Table 14: Different theories of change, reproduced from (Stein S. , 2019).

	Minor reform	Major reform	Beyond reform
Emphasis of change	Doing differently	Knowing differently	Being differently
Theory of change	Improve the effectiveness, efficiency, and inclusiveness of the existing system	Pluralize knowledge and representation, and enact redistribution of resources within existing system	Learn from/at the limits of the existing system, experiment with and regenerate other possibilities
Horizon of hope	Perpetual expansion and improvement toward greater progress, and exporting the system to other countries	Learning from alternative ways of knowing in search of roadmaps that can lead toward more equitable, sustainable futures	Messy, collective process of learning/unlearning that might lead (non-linearly) to viable but as-yet-undefined and unimaginable futures

Response to the crumbling house	Maintain and operate the house more efficiently (e.g. install solar panels, improve insulation), invite in a few more people	Remodel and expand the house to invite many more, different people inside, democratize house governance, and use sustainable materials	Dismantle the house and/or witness its inevitable collapse, learn from its mistakes, and experiment with building other kinds of dwellings
Response to crises of higher education	Reclaim public good purposes, flatten the “playing field” for social mobility, toward a diversified (global) middle class	Radically transform existing institutions by redistributing material resources, opportunities, and epistemic authority to the most marginalized	Mitigate harm and redistribute in the short-term, and consider what might be possible beyond “the university as we know it” in the long-term

I find these three framings of reform connected to the three functionalities of the university in assemblage la paperson discusses (la paperson, 2017). Minor reforms relate to the first university, where the horizon of hope is limited to perpetual expansion of the academic-industrial complex through colonial accumulation and inclusion via student debt; how dominant MSE is “creating how the world works” and “designing how the future is made” (UM Materials Science and Engineering, 2022); (Stein S. , 2019). As a discipline MSE sits at a particular conjunction in relation to other engineering disciplines, performing and leveraging ‘basic’ or ‘fundamental’ research in the natural sciences toward reducing material constraints other engineering disciplines must operate within. The attention to relationships across scales, from subatomic to macro, that I’ve learned through my dominant MSE education offer powerful analytics into ways that small differences between atomic configurations can drastically impact material performance. However, without the critical self-reflection on the scale at which dominant MSE operates within the U.S. settler colony that might expand the horizon of hope, MSE students are trained to replicate the structures and processes rather than move beyond the shallow understandings which maintain these conditions.

Major reforms relate to the second university as a more participatory and democratic academy, a remodeled house modernity built. Beyond reforms relate to the third university through the dismantling of the house and use of its scrap material to further break it down and produce counters to it. Dominant engineering education all but eliminates the possibilities for major and beyond reform through an adherence to technocratic theories of change in a positivist paradigm, see Figure 31. Aspects of this technocratic theory of change are described by Alice Pawley in *"Asking questions, we walk": How should engineering education address equity, the climate crisis, and its own moral infrastructure?* (Pawley A. , 2019a). She names that often as engineers and engineering educators, "we tell ourselves that through techno-rational arguments we can persuade people in power to make whatever limited changes are needed to excise discrimination and marginalization without touching the rest of the system," (Pawley A. , 2019a, p. 450). This narrow, technocratic theory of change normalized in dominant engineering education frames techno-rational logic as the universalized logic of engineering, in turn affixing the scientific method as the methodology of engineering. Weak objectivity renders positionality virtually meaningless and masks the ways the supremacy of engineering technical solutions is laden with the logics of elimination, capital accumulation, and dispossession reconstituted in the academy as an arm of the settler state (Grande, 2018). All of these act in concert to reinforce the fatal couplings of power and difference represented by thin blue lines to make it so that dominant "engineering's socially constructed nature is massive and seemingly immutable, but in fact also affords us opportunity for change," (Pawley A. , 2019a, p. 451).

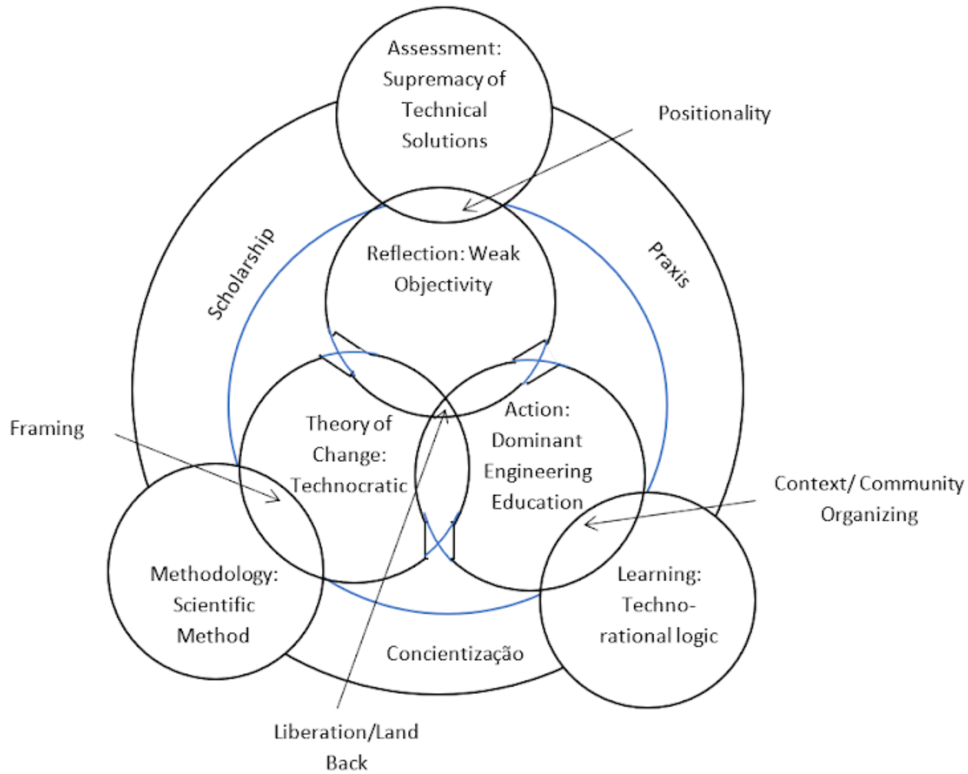


Figure 31: Applying the LEEM to dominant engineering, where thin blue lines remain largely intact and unbroken.

Moving toward beyond reform theories of change pushes for an understanding that dominant engineering itself is the builder of the tunnels/pipelines as infrastructures that ought to be abolished to (re)turn to a healthier, life-affirming ecosystem. Prof. Donna Riley, Prof. Amy Slaton, and I started wading through the “messy, collective process of learning/unlearning,” (Stein S. , 2019, p. 673) in a collaborative inquiry that we’ve so far written about in *A Third University is Possible? A Collaborative Inquiry within Engineering Education* (Valle, Riley, & Slaton, 2022). In it, we drew from *A Third University is Possible* to unpack relationships between dominant engineering and industrial complexes (la paperson, 2017).

6.4 Industrial Complexes

The term engineering derives from the word engineer, dating back to early modern references to builders of military engines, primarily mechanical contraptions used in war, leading to a need to distinguish civil engineering as a way for engineers to specialize in non-military project construction (Downey & Lucena, 2005). These origins resource colonial warfare, continuing through to modernity in the form of industrial complexes. Our use of the term, "industrial complexes" is in itself complex, a multi-scalar object of analysis broken up into statements, in much the way that Hill Collins and Bilge discuss complexity as a core theme of intersectionality (Hill Collins & Bilge, 2016). They unpack distinct but interrelated domains of power that industrial complexes cross: interpersonal, disciplinary, cultural, and structural. It is these domains of power that we leverage to deconstruct relationships structuring the assemblage of dominant engineering.

6.4.1 Dominant Engineering Builds and Maintains the Material Infrastructures of Industrial Complexes

Hill Collins and Bilge discuss how the structural domain of power refers to the ways intersecting power relations organize, shape, and structure institutions and organizations (Hill Collins & Bilge, 2016). These infrastructures uphold interconnected industrial complexes structured to maintain the systems outlined in Table 13. In Figure 32, we offer a rendition of an industrial complex, an assemblage designed to intertwine industry with social or political systems and institutions, as a concrete slab creating a separation between the various buildings built upon the slab and the land on which the slab sits. The buildings each represent their own industrial complex, sometimes analyzed individually (e.g. the academic-industrial complex) sometimes in relation to each other (e.g. military and prison industrial complex (The Red Nation, 2021)). The slab sits on stolen land, represented as gold both for the ways it is viewed as a natural resource to be extracted for profit and for the ecological damage the existence of the slab has caused. Dominant engineering is tasked with growing and maintaining the industrial complex, researching and training engineers on how to construct ever taller, more efficient buildings upon a foundation meticulously tested for cracks and reinforced for ‘optimum’ performance of the dispossession of life through its separation from land.

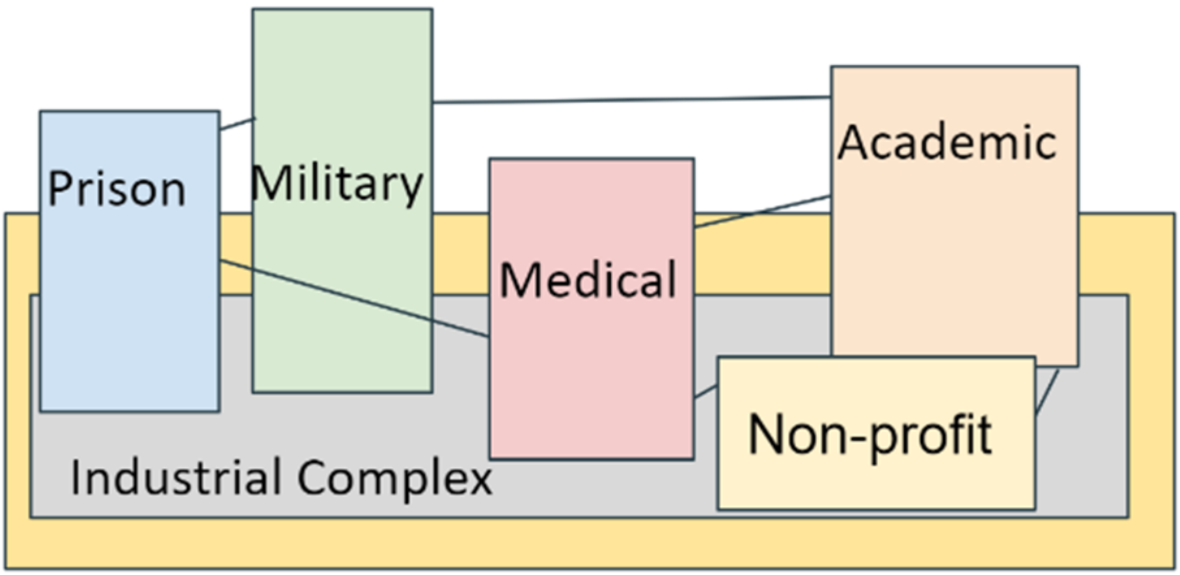


Figure 32: An industrial complex, home to interconnections amongst the prison, military, medical, academic, and non-profit industrial complexes represented as buildings, built on and in the industrial complex. The industrial complex lies atop stolen land.

6.4.2 Dominant Engineering has an Industrial Complex

Hill Collins and Bilge discuss how “when it comes to the organization of power, ideas matter in providing explanations for social inequality and fair play” (Hill Collins & Bilge, 2016, p. 10); that is, the ideas circulated and the means by which they are circulated shape the cultural domain of power. In taking up the formulations of “diversity, equity and inclusion” (or, DEI) since the early 2000s, engineering education and workforce planning in the U.S. have enacted a particular project of fairness. This is one in which innate endowments of talent and fortitude, as defined by existing economic systems (capitalism) and epistemic enterprises (universities and occupations), will rightly result in differing degrees of economic and personal security for individuals and in which, due to the supposedly replete cultural transformations of the previous decades, race, gender and other identifications cannot possibly be playing a role (Melamed, 2006). Meritocratic ideologies support industrial capitalism's long-standing stratified wage structures and vice versa. For example, the idea of engineering classrooms as inclusive, tolerant sites of learning fully shaped by DEI intentions makes complete sense of divergent educational opportunities across communities: not everyone can be an engineer, in every sense of those words. If we are unbiased, the absence of Black students from graduate programs in STEM, say, can only be explained by the intellectual and behavioral deficits of absent persons. That is, the "post-racial" U.S. need worry no more about anti-Black, misogynistic, anti-trans or other social-structural "flaws" and accepts that some persons will have greater wealth, more secure property rights, assured access to healthcare, greater environmental safety, and generally less difficult life circumstances than others; the achievement of well-being is contingent on one's ability.

With this foundation, resources for education, and DEI efforts to find the "missing millions" of BIPOC and women engineering personnel, proceed from extremely narrow and conciliatory presumptions (National Science Board, 2022). Across thousands of research projects, policy studies and program descriptions–funded by many millions in public and private research grants–we see no mention of white supremacism, anti-BIPOC and anti-gay violence, Black mass-incarceration or other documented conditions of the 2020s. These conditions are defined by the formal universe of DEI discourse and planning as unrelated to "under-representation." The fact that Black communities in the U.S. live in the afterlife of slavery

(Hartman, 2008), or that trans folks are murdered with regularity, are not ignored; rather these events are unthinkable in proximity to efficacious engineering.

DEI as a neoliberal catchall academic term functions with an aim of reconciliation, laden with moves to innocence obscuring notions of equity that act with an ethic of incommensurability. As Tuck and Yang discuss,

> …an ethic of incommensurability, which recognizes what is distinct, what is sovereign for project(s) of decolonization in relation to human and civil rights based social justice projects … guides moves that unsettle innocence, stands in contrast to aims of reconciliation, which motivate settler moves to innocence. Reconciliation is about rescuing settler normalcy, about rescuing a settler future. Reconciliation is concerned with questions of what will decolonization look like? What will happen after abolition? What will be the consequences of decolonization for the settler? Incommensurability acknowledges that these questions need not, and perhaps cannot, be answered in order for decolonization to exist as a framework." (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 29&35)

Ideas form the basis of discipline in the discipline of dominant engineering, the psychological complex engineering education instills in engineers through the disciplined manufacturing processes of professionalization directed to grow industry.

6.4.3 Dominant Engineering Professionalizes the Building and Maintaining of Industrial Complexes

Hill Collins and Bilge discuss how "in essence, power operates by disciplining people in ways that put people's lives on paths that make some options seem viable and others out of reach," (Hill Collins & Bilge, 2016, p. 9) where "different people find themselves encountering different treatment regarding which rules apply to them and how those rules will be implemented," (p. 9). Through the privileging of technical knowledge and expertise that the U.S. as a settler colonial nation state concentrates in dominant engineering, engineers are well resourced to research, design, test, and build material infrastructures upon stolen lands. Professionalization into the branching disciplines of dominant engineering has long required the disciplining of engineers to maintain the infrastructures of the industrial complex. As Harney and Moten discuss, "professionalization is not the opposite of negligence but its mode of politics in the United States," (Harney & Moten, 2013, p. 12) naming it "unwise to think of professionalization as a narrowing and better to think of it as a circling, an encircling of war wagons around the last camp of indigenous women and children" (p. 13). This negligence as a mode of politics is itself engineered, systematized into dominant engineering education through the rigor/us (Riley D. , 2017) manufacture of engineers to uphold colonial processes. Dominant engineering normalizes the industrial complex through the disciplining of professionalization. To refuse this normalization is to be made illegible in the professionalized practice dominant engineering.

6.4.4 The Infrastructures Maintaining and Maintained by Dominant Engineering are Upheld Through the Interpersonal Interactions that Shape the Education and Professionalization of Engineers

Hill Collins and Bilge describe how "power relations are about people's lives, how people relate to one another, and who is advantaged and disadvantaged in social interactions," (Hill Collins & Bilge, 2016, p. 7) where intersectionality can be leveraged as an analytical lens to highlight "the multiple nature of [how] individual identities … differentially position each individual," (p. 7). The interpersonal is often the level we experience the normalized harms of dominant engineering most intimately, where the disciplining of engineers, engineering educators, and engineering education researchers becomes visceral. Per la paperson, the level where "you are sensing how power 'in your face' is jointed to global latticeworks of power" (la paperson, 2017, p. 64).

The product of dominant engineering is industry itself, acting to construct, stabilize, and validate the material infrastructures of (prison, military, medical, academic, nonprofit, etc.) industrial complexes. The current and longstanding hegemonic condition is one where engineering is synonymous with industry, structurally maintained in such a way that engineers are professionalized through technical or techno-economic rationalizations that advance the colonial processes outlined in Table 13. As engineering educators and engineering education researchers, our entangled positions within the superstructure of this engineering-industrial complex in assemblage provides us the potentiality to study, teach, and otherwise build relationships that sever the fatal couplings of power and difference that constitute the social formations maintaining this hegemonic condition (Gilmore, 2002); (Hall, 1986). Positioning engineers as those who build and maintain industrial complexes is simultaneously "common sense," in that engineers build the infrastructures of modernity, and also potentially a break from precepts of dominant engineering when industrial complexes are understood as the socio-political constructs of death-making.

In her 2007 book *Golden Gulag*, Ruth Wilson Gilmore traces the political economy of prisons through California's history of welcoming and benefiting from the presence of defense contractors, laying the groundwork for the development of the state's prison system (Gilmore, 2007). Stringent sentencing guidelines introduced in the 1970s brought significant increases in incarceration rates and severe prison overcrowding. Political rhetoric emphasized traditional moralistic and punitive responses to societal transgressions and deemphasized rehabilitative approaches, and state officials responded by allocating funds, labor, and land toward expanding the capacity of the California prison system, despite economic recession, until it became the largest in the world. Racialized notions of criminality play out over this infrastructure.

The role of construction engineers in literally designing and building this infrastructure of white supremacy, and the role of industrial engineers in optimizing their efficient function, are briefly mentioned in Gilmore's analysis. She discusses a capital cost reduction study undertaken in 1996 by David Ashley and Melvin Ramey (Ashley & Ramey, 1996), both then civil engineering professors in the University of California system:

> "the central problem remained crime and its mitigation through imprisonment, and the solution turned on cost-effectiveness in the design-bid-build sequence for prison construction – rather than any reevaluation of, for example, the relation between crimes (old or new), education, and recidivism," (Gilmore, 2007, p. 118).

Gilmore goes on to say that,

> "the unspoken power of this study lies in the way the university presents itself, via its sober, analytical engineering faculty, as an eminently efficient institution," (Gilmore, 2007, p. 118).

So efficient, she notes, that the University abandoned affirmative action as "an inefficient (nonmarket) mode of resource allocation," (Gilmore, 2007, p. 118).

Gilmore notes in that passage the mis-framing of the problem, pointing us toward the abolitionist questions the engineers didn't ask. Can there be an engineering that asks abolitionist questions? That builds infrastructural support for social systems and life-affirming institutions that eliminate the need for incarceration? For those of us "in but not of" the academy, it is this break that we seek to expand through everyday actions that telescope into collective power. A shifting of the trajectory of engineering and engineering education toward the abolition of the fatal couplings of power and difference maintaining engineering in assemblage with the industrial complex. One of the many paths this abolitionist shifting of the trajectory of engineering and engineering education could take is through the consciousness raising and pedagogy of labor organizing, the central topic of chapter 7.

Chapter 7 Engineering Lab/or-Unions

This chapter considers the transformational potential of labor organizing within engineering, engineering education, and engineering education research through how it expended my consciousness around my labor as a materials scientist and engineer and labor organizer. It begins with an email exchange with my MSE department chair during the height of the 2020 GEO strike for a safe and just campus for all, moving through how I came to understand engineering through the lens of labor organizing, onto two EER studies conducted with Corey Bowen, Israa Ali, and Donna Riley on labor organizing as engineering education.

> I wanted to email you this week again asking you to issue a statement of support and non-retaliation for any participation in the GEO strike, as well as encouraging professors to cancel classes in solidarity with the strike. … I feel the recognition by [the dean of the school art and design] of the pedagogical imperative of supporting the strike is one which is particularly important. … I recognize that there is risk associated with publicly supporting a labor action, especially from an administrative position, and I also recognize that un-unionized Resident Advisors who are paid in food and housing are engaging in a strike with very few protections despite similar or arguably larger risks. I also recognize this is something that you feel our department has only loose associations with. There have been numerous pushes by students to engage more deeply in topics relating to the strike, but they have all been considered external to our engineering education and typically fall under the broad banner of DEI. I feel these are components of

the depoliticized and meritocratic ideologies present in engineering … which are manifesting themselves, and I encourage you to lean away from these.

I also understand that you and other faculty feel that you have not had a voice in crafting these demands or engaging in this struggle, and this is something that I can empathize with. I have repeatedly felt within this department, within this college, and within this university there have been decisions made where graduate students have not had a voice in, given consent to, or had an active role in decision making processes. … This is one of the major reasons why we have turned toward GEO, which as a union and entity has been committed to seeing us, affirming our experiences and existence, allowing us to engage in ways that meaningfully affirm our existence, our communities, and our struggles and engage in transformative actions to alter harmful conditions. I have never felt this through any official university channel in my time here. … We have repeatedly tried official channels the University has offered in order to meet our needs, and have continually time and time again have been told we have been heard but have not seen actions which reflect that. … I encourage you to push faculty to listen to us as students, as peers, and as people you are able to learn from, and then take action to affirm and support what we are actually saying and taking action for.

In solidarity,

Joey

Excerpts from email to department chair, Sept 14, 2020, 1:49pm

I recognize the efforts, professionalism and commitment of the faculty to support our education and research missions by taking on extra work at this difficult time to fill

> the gaps created by some graduate students on strike. … We urge all PhD students participating in strike to stand in solidarity with their advisors and develop a plan to balance fulfilling professional obligation with other activities.
>
> Excerpts from department chair email to department, Sept 14, 2020, 4:04pm

I remember our department chair in undergrad describing grad school in ways that sounded like a job right out of a labor horror story. He spoke of how grad school was awful, with grad student workers staying up all hours of the night running experiments in windowless rooms largely in isolation. He discussed experiencing failed experiment upon failed experiment, arbitrary deadlines, and years of stress unlike what we'd seen in undergrad. The sort of experience where you just get in, do your time, and go off to actually start living your life. A form of deprivation distanced from 'the real world,' a disembodiment dominant engineering demands (Riley D. , 2013). I remember in undergrad seeing cots set up in grad student offices so they could just crash after working in the lab, wake up, and keep working. To me it sounded like a hyper individualized experience that devalued life and was destined for mental health problems that I was not interested in playing into. But I had already accepted to come to UM so I resolved to not have that be my experience, remembering the years of seeing my dad work overtime to make it in this settler colony that sent him to an early grave.

Years later, it was those same sort of conditions that were parroted back to me by a professor describing how the LED was invented. That description came during a talk I gave in our department about activism and collective action, where he gave the same tired trope of a lone scientist tooling away for long hours in some company's research and development (R&D)

division to exemplify how progress is *actually* made. It's almost like the stories we tell in dominant engineering education valorize and normalize conditions of overwork.

Coming out of undergrad I felt those conditions of overwork deeply. I was already burnt out from doubling down on the coursework that was required to get a minor in mechanical engineering to better bridge my MSE degree and my work on EVT. The prospect of hopping from that into the sort of grad school narrative that was fed to me with just a summer break in between sounded massively unappealing. After requesting to defer for a year to recover, I was told if I did so I would need to reapply again next year and risk losing the RMF that ultimately became the funding I needed to shift my research trajectory. So I came in still excited to work on electrochemical energy storage systems, but also (naively) wanting to break from the labor conditions baked into narratives of overwork that grad school all but guaranteed. A large factor of why I chose UM for grad school was because I was looking for a place where grad students in the department seemed happy and like they actually knew each other instead of just acting like it for prospective students. What I did not realize at the time was that the impression I got during visit weekend was predicated on the folks here not having to face a number of the precarious conditions grad student workers faced at other universities I'd visited. It was nearly a year later when I signed up to be a GEO member that I learned this was because of the decades of organizing done by grad student workers through GEO.

At their core, unions are collectives of workers that come together to improve their living and working conditions, a form of collective care. Workers join in union as vehicles of social change to fight for dignity and respect amidst the multitude of inequities that structure our existence. I still remember when I first joined in union, becoming a part of GEO representing graduate student workers at UM. It was night time after another session of strategizing around how to push the city task force drafting recommended bylaws for a police oversight board toward a transformative vision for police oversight. After walking from downtown to a friend's car on central campus, a co-organizer and friend who was already in GEO asked me if I'd signed up to be a member. I'd come to know folks in GEO since they were part of the coalition working on the police oversight campaign that CAWS was a part of. In the backseat of the car I replied with a statement that has become familiar to me over the years as a GEO organizer, that 'I thought I was automatically a member of GEO' as a grad student. Quick to correct me, they let me know that was not the case although any graduate student at UM could join our union. They also brought up that I was a pretty rare case, an engineering student that showed up to organize, and once they got me signed up they invited me to a union meeting.

Soon after I signed up I was invited by members of our departmental grad student council (MSE GSC) to become one of our department's union stewards. Stewards take on the responsibility of organizing folks in a department to grow and maintain a healthy union culture, a feat that had proven rather difficult in engineering departments. As I discussed in chapter 6, graduate student research assistants (GSRAs) are not currently considered workers by the state although that is the main worker classification for engineering PhD student workers at UM. Although the state decided not to recognize us as workers, the indicents discussed in chapter 6 that eventually led to departmental DEI seminars were just one set of issues that show that lack of recognition didn't erase a need to improve our living and working conditions. So often, I'd see friends work over 40 hours a week in their research, veering toward 60 hours despite being paid for just 20 hours. To do otherwise was to risk making 'inadequate degree progress,' especially tenuous given the highly subjective nature of rigor and individualistic framing of the purpose of a degree. So often I would hear that folks *had* to be in the lab, because choosing to do otherwise would just harm themselves and/or piss off their professors. It positioned lab simultaneously as a (/the?) key site of Ph.D engineering education and Ph.D life, while relying on technical/social dualism to make lab seem separate from 'the real world' that included their labor union. One of the things that had been abundantly clear to me as I moved from engineering member to engineering steward to engineering steward organizer to union president is that dominant engineering education offered no education on labor unions or other forms of collective care, instead normalizing harmful labor practices and individualistic tendencies through depoliticization and meritocracy (Cech E. A., 2014). As Alice Pawley puts it,

> "We also teach students that their role in the economic production system will be as management, not labor, effectively hamstringing their education in collective organizing. As a result, because it probably will not cross most engineers' minds that organizing across employment levels, from line worker to management, to pressure company bosses to cut carbon emissions might actually work, they will not bother with it—a convenience to the corporate owners, for sure," (Pawley A. , 2019a, p. 449).

Yet it was exactly this sort of collective organizing over years that forced this multi-billion-dollar institution to divest from fossil fuels (Morris, 2021). The contributions I was able to make to that collective win felt so much more tangible and significant toward curbing climate change than the sum of my years of relatively isolated lab work. We organized climate strikes with high schoolers, undergrads, grad students, staff, professors, and other community members (Allbery, Harring, & Collins, 2019); (Murdock, 2019). We shamed the university president and board of regents at event after event, politicizing an endowment the tried so desperately to frame as impervious to sociopolitical considerations (Jesse, 2015); (Morris, 2021). We a blockaded regents meeting, with organizers connecting issues of fossil fuel divestment with structurally racist underfunding of Flint and Dearborn campuses and policing on Ann Arbor campus (Stein & Weinstein, 2019). I saw friends arrested and dragged through months of legal proceedings because University admin refused to drop trespass charges (Clark, 2019). All the while, the engineers I knew and had conversation after conversation with about the need to transition away from fossil fuels stayed in lab; the technocratic theory of change is a difficult one to undo.

I remember at a mandatory ethics training for the College of Engineering (CoE), the trainer centered a significant portion of it talking about the potential job action the lecturer's union (LEO) was considering because UM admin was unwilling to make enough movement in bargaining. I'd been attending LEO bargaining sessions for months, listening to stories of lecturers having multiple jobs and needing to go on food stamps to make ends meet, as well as the massive pay disparities between the flagship Ann Arbor campus and the Flint and Dearborn campuses. Rather than focusing on *why* the lecturers were considering taking collective action, we were instead forced to sit through a story about how during an internship the trainer had at an automotive company UAW members wouldn't let him use some tools, so since then he's had an unfavorable view of labor unions. That was used to frame a question about whether he should make his students suffer by joining the strike or not because some LSA folks wanted more money, and I was baffled. This is what passed for mandated ethics training in engineering? So amongst a room full of other engineering grad student workers I raised my hand to interject and talk about pay disparities between CoE and many other schools and colleges, the fact that this prestigious university paid lecturers poverty wages and this was their way of collectively fighting that precarity, and how his students could learn a lot from him participating instead of just sitting through more lectures. He gave some milquetoast response and quickly moved on. Years later, an engineering steward recalled being in that training to me and how that was one of many interactions that spurred them to step up and steward their department.

GEO offered many opportunities for learning about collective organizing in ways that my engineering education otherwise refused to allow for and was frequently antagonistic towards. One of the many wonderful memories of this was when we packed the hallways of Wolverine Tower in solidarity with our Trans Health Caucus. The university had set up a transphobic healthcare plan that deemed certain medically necessary surgeries cosmetic, and the Trans Health Caucus had been organizing for years from the 2017 contract negotiations through to a series of special conferences won during that bargaining round (Weinstein, 2019). Yet UM admin had been missing the contractually stipulated meeting deadlines, so the TGNC folks on the caucus were calling for a show of support at the next meeting. As the group marched up to the floor of the meeting, folks working in the offices outside of the conference room were surprised to see the group of people in front of them and curious about what was going on. As people filled them in on UM admin's inactions, admin arrived for the meeting and pushed for everyone except a handful of GEO folks taking part in the special conference to go back downstairs. While the conference went on, we lined the hallways and waited. Some of us, realizing this hallways of folks sitting idle might be up for another act of solidarity, began distributing information on how to participate in a phone zap to support incarcerated folks. Phone zaps are actions that put pressure on specific people or institutions, in this case a prison and warden. The Incarcerated Workers Organizing Committee discusses why this action can be effective, since "flooding offices with phone calls effectively blocks a portion of their ability to operate plus it often punctuates its message by driving an office to pure bedlam. … This bit of operational crisis helps extract concessions or push back on repression that doesn't stand up well in the light of day," (Incarcerated Workers Organizing Committee, 2018). Solidarity gives rise to solidarity, and soon the hallways were full of folks participating in the phone zap.

That campaign headed by the GEO Trans Health Caucus eventually saw meaningful improvements to trans healthcare at UM during the 2020 bargaining cycle. Another campaign that carried over from the 2017 bargaining cycle was around expanding the number of DEI GSSA positions from the 6 won in 2017 for the entirety of the university. The GEO organizers from the 2017 contract campaign described the fight for these paid, unionized positions as a means to resource the uncompensated DEI labor of students. They describe how

> "students often find themselves doing DEI labor because it contributes to their survival, and because they (and their departments) know they are the best-equipped people to address ongoing climate concerns. As long as climate issues persist, students will be contributing to DEI labor out of necessity," (GEO DEI Campaign Committee, 2017).

Those DEI GSSA positions were won after a vast majority of union members authorized a walkout, pressuring admin to agree. The need for these positions has rung very true to my own experiences of doing and seeing many other minoritized friends at UM do uncompensated 'DEI' labor as a survival tactic. GEO members proposed expanding the number of these positions, including into the college of engineering, during the 2020 contract campaign. Admin rejected these proposals, saying that their initial agreement to the 6 positions in 2017 was a mistake. As stay at home orders from COVID-19 began, seeing them also reject proposals like those to curb the university's role in gentrification in the city and county with the phrase 'no one said you had to live in Ann Arbor' and reduce campus policing power furthered my understanding that despite being a third of the acronym DEI, equity is more of a tagline here than an ethic (McGee &

Bentley, The Equity Ethic: Black and Latinx College Students Reengineering Their STEM Careers toward Justice, 2017).

As an engineer seeing over the years how dominant engineering education is structured to benefit corporate interests through performances of professionalization that decouple harmful engineering lab conditions from labor unions as a means of undoing those conditions, EER seemed to offer infrastructural processes for intervention. One of the ways I'd thought of GEO is in relation to an engineering identity, since the job of graduate student worker is never the permanent labor position of any worker and gaining a strong education in labor organizing holds the potential to ripple into any further engineering jobs graduate student workers would go on to hold. This pedagogical element of unionism was a mentality I carried when in Fall 2020 our union went on strike over COVID and anti-policing protections in concert with the #ScholarStrike for racial justice (Butler & Gannon, 2020). Reflecting from the picket lines we captained on North Campus amidst groups of engineers, while getting responses from engineering professors to our strike like the one that kicked off this chapter, Corey and I both recognized one of the many rarities of this strike was that it was one in which engineers meaningfully participated; a counterstory of labor union participation amongst engineers. A counterstory is a technique of telling a story of those whose experiences are not often told and a tool for analyzing and challenging the story that is a natural part of dominant discourse (Solórzano & Delgado Bernal, 2001). After recouping from the strike being broken, we started an EER project looking into engineering labor union connections that have so far led to the papers *Liberatory Potential of Labor Organizing in Engineering Education* and *Experiences of Engineering Students Participating in an Abolitionist Labor Strike* (Valle, Bowen, & Riley, 2021)*;* (Valle, Ali, Bowen, & Riley, 2021).

7.1 Liberatory Potential of Labor Organizing in Engineering Education

7.1.1 Introduction and Background

Engineering is a field that both shapes and is itself shaped by oppression and inequitable power dynamics. Engineering education researchers have sought to study facets and intersections of racism, heteropatriarchy, capitalism, and militarism and colonization within engineering (McGee & Martin, 2011); (McGee & Bentley, 2017); (Holly Jr., 2020); (Stitt & Happel-Parkins, 2019); (Martin & Garza, Centering the Marginalized Student's Voice Through Autoethnography: Implications for Engineering Education Research, 2020); (Foor, Walden, & Trytten, 2007); (Pawley A. L., Learning from small numbers: Studying ruling relations that gender and race the structure of U.S. engineering education, 2019b); (Riley D. , 2008); (Cech & Waidzunas, 2011); (Riley, Pawley, Tucker, & al., 2009); (Blue, Levine, & Nieusma, 2013). In many ways, engineering education researchers have shown how these facets are fundamental to what is currently considered engineering epistemology. Owing to that history, peoples marginalized along many and varied axes of interlocking systems of oppression have continually faced discrimination within the field of engineering, a microcosm of their treatment within society more broadly ; (Stitt & Happel-Parkins, 2019); (Martin & Garza, Centering the Marginalized Student's Voice Through Autoethnography: Implications for Engineering Education Research, 2020); (Foor, Walden, & Trytten, 2007); (Riley D. , 2008); (Hill Collins P. , 2002).

Engineering education researchers have engaged with the means by which the many axes of oppression cause harm. Analogies such as leaky pipelines and pathways are used to describe the ways that minoritized engineers end up 'leaking' out of engineering, as the pathways to success are defined by and exist in overwhelming support of engineers with specific combinations of identities aligned with the hegemonic understanding of who an engineer is: a cis-gendered, heterosexual, middle-class, white male (Pawley A. L., Learning from small numbers: Studying ruling relations that gender and race the structure of U.S. engineering education, 2019b); (Lee W. , 2019). Discussions of why these phenomena persist in engineering have often been framed from a deficit perspective, which situates minoritized students as "deficient," perpetuating the idea that minoritized students possess motivational or cognitive deficits (Mejia, Revelo, Villanueva, & Mejia, 2018); (Mejia, Wilson-Lopez, Robledo, & Revelo, 2017). This can limit the perspectives from which engineering education research is engaged.

Engineering education researchers have also investigated means by which marginalized people navigate the culture of engineering. Foor et al. engaged with a narrative research methodology to tell a story about Inez, a first generation college attending, economically disadvantaged, multi-minoritized female undergraduate engineering student, forms of marginalization she faced in her engineering education, and sources of strength she drew from to persist (Foor, Walden, & Trytten, 2007). Martin and Garza used a power-sharing autoethnographic methodology to tell the story of the multitudinous factors in Chavonne Garza's life that shaped her journey to and within engineering (Martin & Garza, Centering the Marginalized Student's Voice Through Autoethnography: Implications for Engineering Education Research, 2020). This methodology illuminated ways that many institutions, including academia, were designed and continue to operate without her well-being in mind.

Researchers have investigated epistemological and ontological ways that marginalized peoples engage with STEM. Wilson-Lopez et al.'s investigation of funds of knowledge in Latinx adolescent approaches to engineering demonstrated ways that "participants' everyday skills and bodies of knowledge aligned with engineering practices" (Wilson-Lopez, Mejia, & Hasbun, 2016, p. 278). Verdín, Smith, and Lucena engaged the funds of knowledge framework to demonstrate ways that first-generation engineering college students' funds of knowledge related to their students' confidence in their engineering performance, classroom belonging, and in graduating with an engineering degree (Verdín, Smith, & Lucena, 2020). Samuelson & Litzler utilized the concept of community cultural wealth, based on the work of Tara J. Yosso, which uses an asset-based approach to understand minoritized student persistence by examining different types of capital developed by students in their families and communities (Samuelson & Litlzer, 2016); (Yosso, 2005). Martin and Newton combined the concepts of funds of knowledge and community cultural wealth to connect together multiple forms of capital and wealth present among recent underrepresented and/or socially marginalized engineering Bachelor's degree earners (Martin & Newton, 2016).

These forms of community cultural wealth have been leveraged by marginalized communities in ways that reconceptualize the forms and uses of engineered technologies. Rayvon Fouché defined the concept of Black Vernacular Technological Creativity, the process through which Black people's agency over the design, use, and overall engagement with technology is reclaimed (Fouché, 2006). Fouché outlined three ways in which Black Vernacular Technological creative acts can be seen: redeployment, reconception, and re-creation

> "Redeployment is the process by which the material and symbolic power of technology is re- interpreted but maintains its traditional use and physical form … Reconception is the active redefinition of a technology that transgresses that technology's designed function and dominant meaning … Re-creation is the redesign and production of a new material artifact after an existing form or function has been rejected," (Fouché, 2006, p. 642).

In a similar vein to Fouché's concept of Black Vernacular Technological Creativity is the concept of *rasquachismo* (Ybarra-Frausto, 1991); (Mejia & Pulido, 2018). According to Ybarra-Frausto,

> "To be *rasquache* is to posit a bawdy, spunky consciousness, to seek to subvert and turn ruling paradigms upside down. It is a witty, irreverent and impertinent posture that recodes and moves outside established boundaries…In an environment always on the edge of coming apart (the car, the job, the toilet), things are held together with spit, grit and *movidas*. *Movidas* are the coping strategies you use to gain time, to make options, to retain hope. *Rasquachismo* is a compendium of all the movidas employed in immediate, day-to-day living. Resilience at hand, *hacer rendir las cosas*," (Ybarra-Frausto, 1991, p. 191).

Rasquachimso has previously been applied within the engineering education research space by Mejia and Pulido, who utilized the concept to center everyday realities of Latinx youth that enable them to bring their embodied knowledge into an engineering context (Mejia & Pulido, 2018).

E.M. Garroutte coined the term Radical Indigenism based on radix, the Latin derivation of the word "radical," meaning "root" (Garroutte, 2003). Garroutte explains that "Radical Indigenism illuminates differences in assumptions about knowledge that are at the root of the dominant culture's misunderstanding and subordination of indigenous knowledge. It argues for the reassertion and rebuilding of traditional knowledge from its roots, its fundamental principles," transgressing academic boundaries, "when it requires that researchers also honor the methods and the goals of inquiry toward which indigenous philosophical assumptions direct us"

(Garroutte, 2003, p. 91). Julia Watson's concept of Lo-TEK [25] positions itself at the intersection of Radical Indigenism and design,

> "[Lo-TEK is] a movement that investigates lesser-known local technologies, traditional ecological knowledge (TEK), indigenous cultural practices, and mythologies passed down as songs or stories. In contrast to the homogeneity of the modern world, indigeneity is reframed as an evolutionary extension of life in symbiosis with nature," (Watson & Davis, 2019, p. 18)

Black Vernacular Technological Creativity, Rasquachismo, and Radical Indigenism engaged through concepts like Lo-TEK provide powerful examples of ways that Black, Latinx, and Indigenous scholars have developed asset-based theoretical frameworks that serve as counters to the continuation of the notion that, "in engineering, particularly, the material realities of students of color–which are perceived as non-sophisticated epistemologies–are replaced by dominant discourses," (Mejia & Pulido, 2018, p. 7). From this constellation of epistemologies and ontologies that have been decentered from traditional engineering scholarship, many new futures and modes of interaction can be created.

This paper seeks to build on previous critical and liberative work within engineering education by building a model connecting theories of change to practices, discussing the example of labor organizing as a vehicle for liberative changes within engineering. Engineering in the U.S. context relies on depoliticization and meritocracy as ideologies that underpin current engineering education and practice (Cech E. A., 2013), its positionality within broader systems of production, and its historically low presence of labor organizing (Meiksins & Smith, Why American engineers aren't unionized: A comparative perspective, 1993); (Meiksins & Smith, 1996). In addition, this study discusses ways that ideologies central to labor organizing sit in tension with existing hegemonic engineering ideologies, describes the ability of the principles of Bargaining for the Common Good to help engineers and their communities meet their needs, and clarifies that engineering does not inherently require technocratic solutions to communal problems and needs.

7.1.2 Positionality

[Corey & Joey] are both engineers, labor organizers with the American Federation of Teachers (AFT) local GEO-3550, and children of union members from working-class backgrounds. Both were participants in the 2020 GEO-3550 abolitionist strike for a safe and just campus for all (Stark, Ehrhardt, & Fleischmann, 2020). [Joey] was also taking graduate coursework in introducing the concepts of engineering education research during the writing of this paper, which provided a critical reflective space for learning and grappling with theoretical frameworks and their applications. We reached out to the [Donna] as a major scholar advancing social justice, including discussions of unions in engineering spaces, in engineering education research. [Donna] is from an upper-middle class background and has also witnessed firsthand the benefits of unions in the lives and livelihoods of family members. She is a member of the American Association of University Professors (AAUP), notwithstanding her middle-management position as a department head. She trained as an organizer with the Industrial Areas Foundation and has applied organizing techniques in pursuit of gender, LGBTQ+, economic, environmental, and racial justice over three decades of activism.

In writing this paper, we draw upon our own forms of community cultural wealth, particularly the familial capital stemming from experience with socioeconomic upward mobility as a result of the American labor movement, continuing with our own training and absorption into the professional class via our own and our familial engineering education. All three authors are marginalized engineers and draw on navigational and resistance capital that we have needed to engage with in order to traverse oppression within institutions of higher education. Importantly, we have also utilized our aspirational capital to conceptualize and envision what a more liberatory form of engineering could look like both broadly and within our own individual forms of engineering practice.

7.1.3 Background of (Engineering) Labor and Bargaining for the Common Good

Marx and Engels discussed the criticality of workers organizing during the industrial era in order to hold collective control over decision making pertaining to what the workers produce, how it is produced, and compensation of the fruits of the workers' labor (Marx & Engels, The Communist Manifesto, 1888). Marx's theoretical work and meticulous research into the industrial capitalist system was rooted in understandings of the dialectical way of thinking conceived of by Georg Wilhelm Friedrich Hegel, using a fundamental component of Hegel's dialectic, the inherent internal contradiction, to produce powerful critiques of the capitalist system (Marx, 1977 [1867]). In doing so, Marx laid much theoretical groundwork for industrial unionism in Western Society, with labor unions being the vehicle through which workers were able to advance their ability to control the nature and uses of their labor as well as gain increased access to the fruits of production (Boggs & Boggs, 2008 [1974]). Marx deeply understood the value of praxis, integrating theory and action toward the ultimate goal of social change (Marx, 1976 [1845]).

Engineering as a nascent field taking root in the industrial age and growing alongside industrialization saw many engineers engaging with questions of their positionality within society and questions of unionization (Noble, 1977). Throughout much of the industrial age continuing to modern day, engineers have sat with and worked through the internal contradiction of their position as both workers and managers, and thus with their sliding position between the working class and the managerial class (Nader, 1965). Shortly after World War I, there was an increasing class consciousness within the American Society of Mechanical Engineers which led Thorstein Veblen (Veblen, 1934), however erroneously, to posit in Engineers and the Price System that if there were to be a workers' revolution in industrial America, it would come via a "Soviet of Technicians." Layton unpacks Veblen's errors in reading the power, position, and organization of the engineering profession (Layton, 1962).

This internal contradiction has historically led to tensions within groups of engineers, with more managerial-minded engineers veering and lobbying for the growth of professional societies, which largely worked to exclude other technical workers as a means to protect the white-collar class position of engineers, and more worker-centered engineers opting for the formation and growth of engineering labor unions, which often included technical workers (Meiksins & Smith, 1996); (Meiksins & Smith, 1993). Notably the rise of industrial technologies, and with them the populations practicing engineers during the industrial age, facilitated the rise of corporate capitalism in 20th century America (Noble, 1977). Engineering saw a boom in unionization during the period of the 1930s-1960s, when roughly 10% of practicing American engineers were union members between 1946 and 1957 (Schuman, 1991). Some of these unions held progressive, anti-racist, anti-military stances, such as the Federation of Architects, Engineers, Chemists, and Technicians (FAECT), which served to weaken ideological, psychological, and organizational ties to management (Heifetz, 2000). FAECT members engaged in volunteer activism, questioned their engagement in the Manhattan Project and threatened to move their First National Convention venue after the Allerton Hotel, the convention venue, refused service to a Black member as the conference was proceeding. The threat of relocating the meeting if the Black member was not treated with respect led to the reversal of the hotel's decision (Heifetz, 2000); (Schuman, 1991).

Despite a sharp decrease in engineer unionization rates after WWII, a number of engineers still remain unionized and partake in highly visible labor actions. A strong example is the Boeing engineers strike in 2000, then hailed as the largest white-collar strike in history (Riley D. , Engineering and Social Justice, 2008). In addition to an active picket line, Boeing's 19,500 striking engineers and technologists were bolstered by solidarity actions from across American Federation of Labor and Congress of Industrial Organizations (AFL-CIO) unions, including railroad workers, UPS Teamsters, and Boeing machinists.

Recently, we have seen the creation of the Alphabet Workers Union as a means to organize engineers along with other workers at Alphabet and across its associated corporations, including Google (History of Alphabet Workers Union, n.d.). Their unionization push has gained traction not through traditional 'bread-and-butter' issues such as salaries and benefits, but instead through large and well documented problems with corporate culture regarding diversity, equity, and inclusion (DEI). This includes the firing of artificial intelligence researcher and ethicist Dr. Timnit Gebru, one of the few Black women within Google Research, which was connected to raising issues around racial and gender bias in products Google engineers are producing and posing questions about who their labor is actually benefiting (History of Alphabet Workers Union, n.d.); (Koul & Shaw, 2021).

This form of a DEI-centered unionization campaign, which is seeking to involve not only engineers but all workers at Alphabet and its subsidiaries, lends itself well to a form of labor organizing that Jane McAlevey calls whole worker organizing (McAlevey, 2018). Whole worker organizing has roots in the work of unions within the CIO during the 1930s, prior to its merger with the AFL in the 1950s. CIO organizers “understood that workers were embedded in an array of important workplace and non-workplace networks, all of which could be best accessed - and, for organizing on a mass scale, only accessed - by the workers themselves” (McAlevey, 2018, p. 33). The CIO-era methodology of whole worker organizing is “a bottom-up model in which workers have primary agency and are understood to be their own lever of liberation … [that can] win life-altering improvements,” and recognizes that workers “... are more structurally powerful when it comes to engaging their community in a fight” (McAlevey, 2018, pp. 28-29).

The Alphabet Workers Union, as well as many engineering unions, are structurally well positioned to engage in Bargaining for the Common Good contract campaigns. Owing to the forms of white-collar work many engineers engage in, the salaries and benefits packages engineers already receive are high compared to many other workers (National Association of Colleges and Employers, 2020). Given that salaries and benefits are the ‘bread-and-butter’ issues that unions have traditionally bargained most intensely over, engineering unions have the unique opportunity to focus their bargaining power toward making improvements within the broader communities impacted by their work. Bargaining for the Common Good is an offensive bargaining strategy which seeks to organize with community partners for contract demands which benefit and invest in the wider community as a whole, not just the bargaining unit of the union, expanding notions of the participants, processes, and purposes of bargaining (Bargaining for the Common Good Network, n.d.); (McCartin, Sneiderman, & BP-Weeks, 2020). Bargaining for the Common Good campaigns also center racial justice in their demands, addressing “the role that employers play in creating and exacerbating structural racism in our communities” (Bargaining for the Common Good Network, n.d.). By engaging the wider community, Bargaining for the Common Good allows for a strengthened connection between labor organizing, typically taking place primarily among members of a union's bargaining unit, and community organizing for improvements that seek to address root causes of injustice. Andre Gorz articulated the liberatory potential for a form of campaign like this in A Strategy for Labor, stating,

> to fight for alternative solutions and for structural reforms (that is to say, for intermediate objectives) is not to fight for improvements in the capitalist system; it is rather to break it up, to restrict it, to create counter-powers which, instead of creating a new equilibrium, undermine its very foundations (Gorz, 1964, p. 181).

Examples of recent Bargaining for the Common Good campaigns include the United Teachers Los Angeles (UTLA) contract campaign, which increased green spaces, put an end to "random searches" of students, provided assistance for immigrant families, and expanded access to nurses and counselors across the Los Angeles Unified School District (LAUSD) (Álvarez, 2019) and the Minneapolis based Service Employees International Union (SEIU) Local 26 janitors' strike for employer action to be taken to address climate change (Altamirano, Nammacher, & Dalal-Whelan, 2020). Likewise, worker organizing in engineering and engineering education workplaces can produce Bargaining for the Common Good campaigns and related improvements. Here, we outline an engineering and labor theory of change and create a liberatory engineering education model connecting it to methodologies, learning methods, and assessment methods that would support its implementation.

7.1.4 Theoretical Framework

In this paper, we have constructed a theoretical framework that seeks to blend concepts from within and outside of what has formally been used in engineering education. The goal was to construct a framework that offers a means to engage theories of change, which contain the critical component of power analysis, toward the development of an engineering education model for use in engineering education research and practice. Tuck and Yang have described a theory of change as “a belief or perspective about how a situation can be adjusted, corrected, or improved” (Tuck & Yang, 2014, p. 13), where “reflecting or imagining a theory of change is an ontological and epistemological activity, related to core questions of being and knowing” (Tuck & Yang, 2014, p. 126). Analyses of power are conducted using Hill Collins and Bilge’s intersectional analytical framework, which “identifies four distinctive yet interconnected domains of power: interpersonal, disciplinary, cultural, and structural” (Hill Collins & Bilge, 2016, p. 7). In this section, we introduce several existing theories that constitute our proposed theoretical framework.

Horton’s Popular Education and Freire’s Pedagogy of the Oppressed

Myles Horton, founder of the Highlander Research and Education Center, influenced by the Danish folk school movement and John Dewey’s (Dewey, 1916) idea that education should work to dismantle rather than perpetuate privilege, developed the Center’s core principle of popular education - that liberative education must be in solidarity with communities, recognizing people’s agency to learn, grow, and act on their own behalf (Horton, The Long Haul: An Autobiography, 1998). The Center has provided resources for education and participatory action research for the labor movement, the Civil Rights movement, the environmental justice movement, the LGBTQ movement, and numerous other social justice movements. During the Civil Rights struggle, Septima Clark developed citizenship schools at Highlander that provided literacy education and organizing skills to intervene in racist literacy laws propped up as barriers to voting rights throughout the South.

Paulo Freire similarly leveraged literacy as a tool for political enfranchisement and social justice in Brazil, and developed his critical pedagogy influenced by Fanon, Vygotsky, Gramsci, and others (Horton & Freire, 1990). Freire's critique of the "banking model" of education and focus on upending systems of power and privilege in schooling introduced learning as a practice of freedom that cultivates critical analysis and reflective action for change (Freire, 1970).

Mejia et al.'s critical consciousness approach

[described in chapter 3]

Hassan's learning-assessment interactions

[described in chapter 3]

Riley and Lambrinidou's Canons against Cannons

Riley and Lambrinidou explored the addition of six principles to the values and principles currently expressed in engineering ethics canon, namely the ethical principles:

- Engineers' primary goal is to help people in need and to address social problems
- Engineers challenge social injustice
- Engineers practice cultural and epistemic humility
- Engineers respect the dignity and worth of each person
- Engineers recognize the central importance of human relationships
- Engineers seek to live in peace with their individual selves, others, and the planet (Riley & Lambrinidou, Canons against Cannons? Social Justice and the Engineering Ethics Imaginary, 2015).

These ethical principles represent a revised framing of engineering purpose as a means to transform engineering practice.

la paperson's scyborg and assemblages

[also discussed in chapter 3,] la paperson introduced the concept of a scyborg as,

> "a queer turn of word that ... name[s] the structural agency of persons who have picked up colonial technologies and reassembled them to decolonizing purposes …The agency of the scyborg is precisely that it is a reorganizer of institutional machinery; it subverts machinery against the master code of its makers; it rewires machinery to its own intentions. ... It describes a technological condition of being embedded in an assemblage of machines," (la paperson, 2017, pp. xiv, 55, 62).

la paperson helps to contextualize the decolonizing purposes of scyborgs; "decolonization is, put bluntly, the repatriation of land, the regeneration of relations, and the forwarding of Indigenous and Black and queer futures - a process that requires countering what power seems to be up to," (la paperson, 2017, p. xv). la paperson also expands on the connections between universities and the concept of assemblages as collections of things or people:

> "(1) the university is an assemblage. It is a giant machine composed of myriad working parts, multiple systems. Each part can still be thought of as a discrete organism to be unplugged and replugged somewhere else. (2) The university is in assemblage. It is imbricated with other assemblages. … It is, like all assemblages, discrete from yet amalgamated with other assemblages in an endless matrix of couplings. (3) As assemblages, the priorities of "scale," as captured in the conventional hierarchical dichotomies of micro versus macro, historical versus ephemeral, data versus anecdote, echo into one another. So a small glimpse into a university classroom very quickly telescopes into scales of heterosexism, racial capitalism, and so on. The webs of pedagogical machinery are at once giant and intimate. It may feel like lying face down on

a monumental precipice, close enough to see the cracks in the stone as well as the chasm just centimeters away," (la paperson, 2017, pp. 62-63).

These concepts of scyborg and the university as/in assemblage provide space for engineers, particularly marginalized engineers, to recognize that the oppression we face is rooted in structures that exist across domains of power, or scales, and that these structures are reconfigurable within the spaces we occupy.

Godwin et al.'s critical engineering agency

This concept of a scyborg from la paperson, while relatable to the concepts of Black Vernacular Technological Creativity, Rasquachismo, and Radical Indigenism described previously, can also be tied to Godwin et al.'s concept of critical engineering agency (Godwin, Potvin, & Hazari, 2013). Critical engineering agency connects understandings of 1) engineering and engineering-related processes, 2) modes of inquiry commonly engaged with in engineering and related skills, 3) degrees of expertise related to engineering self-identification, 4) engineering as a foundational site for change. Critical engineering agency may influence professional identity development, how engineers envision the world and their position in it.

Lee et al.'s organizing framework for advancing understanding about supporting underrepresented students in engineering

The use of agency is also present within the organizing framework Lee et al. developed by interviewing student support practitioners across four universities (Lee, Lutz, & Nave, 2018). The purpose of the development of this framework was to advance the understanding of how to effectively support underrepresented students in engineering. This organizing framework encompassed four major themes: context, agency, process, and impact. Lee et al. divided agency into two categories: values, which are factors that motivate students, and choices, which are behavioral patterns exhibited by students. Lee et al.'s organizing framework provides a basis for understanding the university simultaneously as an assemblage and in assemblage through a lens of student support.

Mondisa and McComb's social community framework

The connection of student support to assemblages is also present within Mondisa and McComb's (Mondisa & McComb, Social Community: A Mechanism to Explain the Success of STEM Minority Mentoring Programs, 2015); (Mondisa & McComb, 2018) concept of a social community, developed in a context of STEM minority mentoring programs, which is "an environment where like-minded individuals engage in dynamic, multi-directional interactions that facilitate social support" (Mondisa & McComb, 2015, p. 152) and fosters the development of long-term participant outcomes. Mondisa and McComb also posited that the foundation of social community is social support, which they defined, citing Lakey and Cohen (Lakey & Cohen, 2000), as "the connectedness that participants feel to the community, including supportive actions and behaviors, the availability of actual support, global evaluations of quality and availability, and social roles and relationships" (Mondisa & McComb, 2018, p. 95). They also outlined outcomes for participants, which can stem from social support as resilience, engagement in communities of practice, and the building of social capital. This framework indicates that the intentional organizing of communities can be a support system for minoritized engineering students.

Coit's participationism and local action, not citizen participation

Katharine Coit investigated tactics used by the Community Action Program of the War on Poverty (Coit, 1978). In doing so, she recognized a difference between the type of citizen participation that the program sought via means that favored middle- and upper-strata groups and local action that seeks “to develop a class consciousness and critical analysis of capitalism …, to work out methods of self-management in associations or groups where leadership is shared rather than hierarchical and elitist …, and to develop a strategy that is truly conflictual …” (Coit, 1978, pp. 302-303). One of the mechanisms that she saw as highly prevalent in citizen participation groups was participationism, which is characterized by a lack of independence, a mobilization-based ideology, and a limited scope of action which prevents more than token power. She outlined ways in which citizen participation models imposed from above seek to control and co-opt movements. Coit outlined factors that are important to consider when engaging in local action and community organizing that are applicable to the forms of support offered to minoritized engineering students.

Yosso’s Community cultural wealth and Solórzano and Delgado Bernal’s transformational resistance

Yosso described community cultural wealth as “an array of knowledge, skills, abilities, and contacts possessed and utilized by Communities of Color to survive and resist macro and micro-forms of oppression” (Yosso, 2005, p. 77). Transformational resistance, put forth by Solórzano and Delgado Bernal, is a form of resistance capital within the community cultural wealth framework, which “refers to student behavior that illustrates both a critique of oppression and a desire for social justice” (Solórzano & Delgado Bernal, 2001, p. 319). Solórzano and Delgado Bernal used two events in Chicana/Chicano student history - the 1968 East Los Angeles school walkouts and the 1993 UCLA student strike for Chicana and Chicano studies - to develop the concept of transformational resistance. In doing so, they demonstrated how transformational resistance can exist in a mutually reinforcing relationship with local action, where the student behavior characterized as transformational resistance can generate local action, and how local action can build a student's transformational resistance.

Lindsay Pérez Huber built further upon this relationship between transformational resistance and local action by describing the impact of a student group for undocumented students on a group of low income, undocumented Chicana undergraduate students at a top tier university:

> "The DREAMS organization was critical in the women's ability to find their way within the university. However, this organization provided much more than navigational skills; it provided the opportunity to come together with a collective agency to resist oppressive conditions in and beyond the university for themselves, their communities, and future undocumented students. This organization was where the community cultural wealth of undocumented students converged to provide a set of navigational skills that could be utilized not only to get through the institution but to transform their current situations, exercising what Yosso (2005) describes as transformative resistant capital," (Huber, 2009, p. 720).

This asset-based framing utilized within community cultural wealth and the connection of transformative resistance through community organizing and local action represent connections that can be used to construct a model of education.

7.1.5 Liberatory Engineering Education Model

[discussed in chapter 3]

7.1.6 A Theory of Engineering and Labor

In her 2019 JEE guest editorial, “Asking questions, we walk,” Alice Pawley drew attention to the fact that our hegemonic understandings of engineering are socially constructed and constrained by a neoliberal mindset, binding engineers to techno-rational arguments (Pawley A. , 2019a). As an example, she discussed the culpability of engineering educators in worsening climate change by failing to “provide students with a moral language to think about engineers’ responsibility for climate change” (Pawley A. , 2019a, p. 449). Additionally, she explained that engineering educators

> “unwittingly indoctrinate students into neoliberalism as the only possible mode of economic development. Their job will be to work in an industrial machine; we do not articulate alternative modes of thought or help students develop cognitive lenses to conceive of a way of being outside this neoliberal worldview,” (Pawley A. , 2019a, p. 449).

Palwey discusses the learning method engineering educators employ as being one of indoctrination into neoliberalism, organizing students to learn to normalize working in “an industrial machine” (Pawley A. L., Learning from small numbers: Studying ruling relations that gender and race the structure of U.S. engineering education, 2019b, p. 449). Rooting in feminist standpoint epistemologies, Sandra Harding has discussed how the form of objectivity that dominates STEM fields works to uphold often unspoken social values, interests, and agendas that promote this form of indoctrination (Harding, 1992). Harding denotes this form of objectivity to be “weak objectivity,” in which “culture-wide assumptions that have not been criticized within the scientific research process are transported into the results of research” (Harding, 1992, p. 446). In doing so, Harding identified that the objects of scientific inquiry are socially constructed in ways that currently practiced methods of reflection through weak objectivity fail to account for.

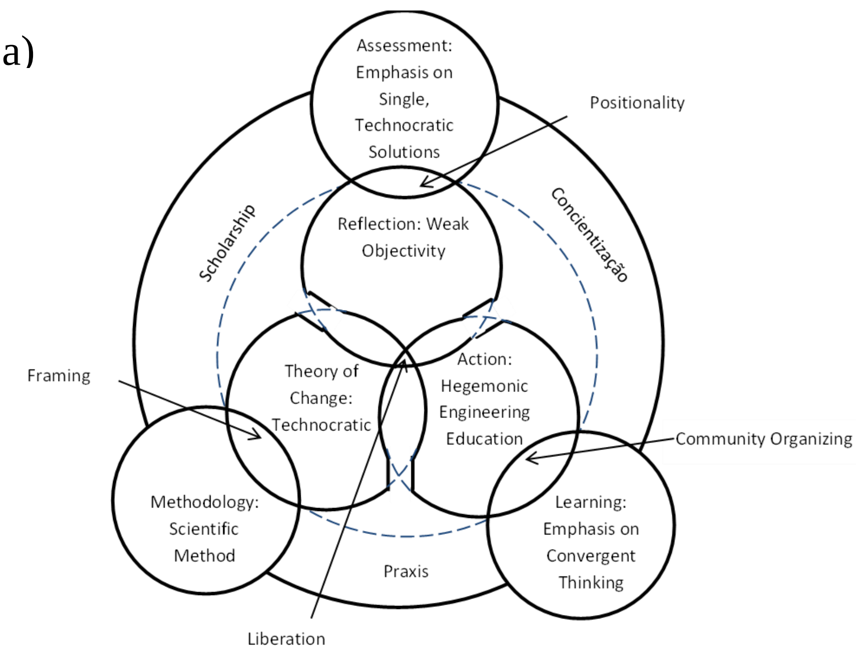
Intimately connected to this neoliberal pipelining of students to private industry and the use of weak objectivity as an assessment method are the skills that engineers are taught to believe are key to engineering practice and how those skills are taught. Daly et al. (Daly, Mosyjowski, & Seifert, 2014) utilized Treffinger et al.'s (Treffinger, Young, Shelby, & Shepardson, 2002) framework of cognitive operations underlying the creative process as a whole, which included divergent thinking, also referred to as generating ideas, and convergent thinking, also referred to as digging deeper into ideas. Daly et al.'s findings showed that even in exemplary engineering courses, convergent thinking was emphasized while divergent thinking skills were not very well represented, aligning with Pawley's (2019a) assertion that engineering educators do not help students to develop the type of divergent thinking that would position them outside of a neoliberal worldview. This in turn creates a feedback loop, as the neoliberal worldview produces a driving force for engineering education to focus students, with overwhelming emphasis, toward technocratic solutions bounded by possibilities within a market economy. In turn, that demand drives engineering educators to emphasize convergent thinking in the form of analytical skills bounded by set problems. This produces engineers who take on this neoliberal worldview bound by a technocratic theory of change, or what Pawley calls techno-rational arguments, as hegemonic engineering practice. The decentering of divergent thinking within engineering practice fundamentally bounds what theories of change engineers are capable of drawing inspiration from and engaging within their engineering education.

Figure 33a identifies connections between the components of the current bounded version of engineering education and practice when it is viewed through the liberatory engineering education model. These mutually reinforcing components generate significant constructed barriers to a liberatory engineering (education) practice, as indicated by the reduced size of gaps in the dotted thin blue lines. This represents a contradiction to be navigated through, where framing (methodology and theory of change), positionality (assessment and assessment method), and community organizing (learning and learning method) may provide pathways through scholarship, praxis, and/or concientização that allow for subversion of the constructed barriers that bound engineering education and practice.

The bounds current hegemonic engineering education practice place on theories of change that engineers may engage with, which are reinforced by the neoliberalism governing broader academic structures, have often required marginalized students to draw inspiration from their lived experiences outside of their engineering education, i.e. their funds of knowledge, cultural capital, and/or community cultural wealth, as strategies for survival (Wilson-Lopez, Mejia, & Hasbun, 2016); (Samuelson & Litlzer, 2016); (Martin & Newton, 2016). This use of these forms of wealth and capital as strategies of survival in the current form of engineering education and practice stands in contrast to forms of engineering practice guided by liberatory theories and frameworks, which provide more spaces for the community cultural wealth of marginalized people to be normalized as strategies to thrive, instead of solely to survive (hooks b. , 1994); (Love, 2019).

These groundings in community cultural wealth, particularly transformational resistance, allow engineers to engage their critical engineering agency as scyborgs and reconceptualize who an engineer is and what an engineer does. This results in the ability to align engineering work with the ethical principles advanced by Riley and Lambrinidou (2015), breaking engineering from the technocratic theory of change that binds it and the limitations on forms of ethics allowed to be considered within it. Through this reconceptualization, we can draw from our predecessors not only within what has traditionally been hegemonically advanced as engineering, but also those who are emblematic of what we seek engineering to shift toward and what it has looked like in the margins. Fouché discussed this in the way that Black Vernacular Technological Creativity has historically been utilized by African Americans, and the ways in which "in the technological realm, creativity by African Americans is regularly dismissed as cleverness, instead of being interpreted as smart, ingenious, or innovative" (Fouché, 2006, p. 647).

a)



b)

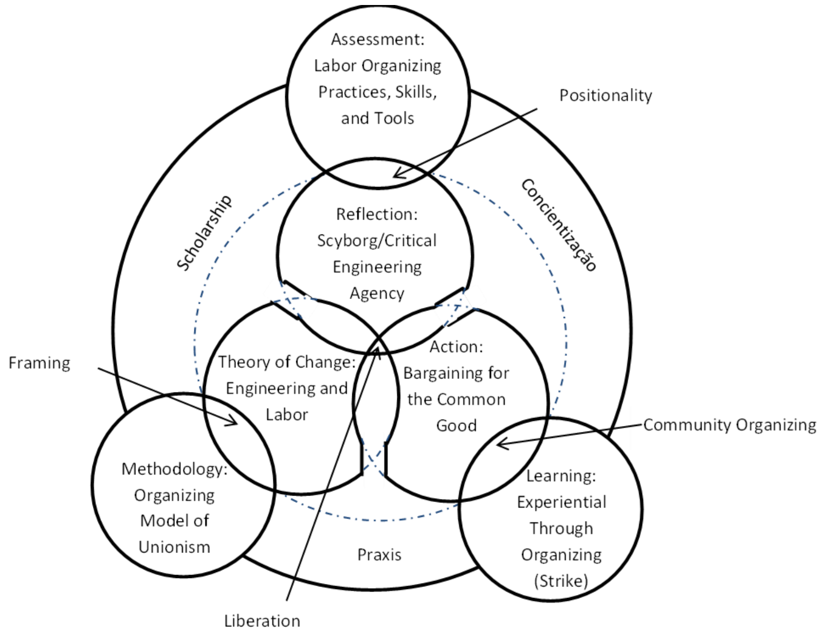


Figure 33: a): Mapping of technocratic theory of change and relevant components to our liberatory engineering education model. Note the increased size of the constructed barriers, [updated version in chapter 6] b) Mapping of engineering labor theory of change and relevant components to our liberatory engineering education model.

An engineering and labor theory of change can be understood through the framework of critical engineering agency. The technocratic, positivist framing of engineering can be used as a starting point for understanding 1) engineering and engineering-related processes, 2) modes of inquiry commonly engaged with in engineering and related skills, 3) degrees of expertise related to engineering self-identification as components of critical engineering agency (Godwin, Potvin, & Hazari, 2013). Framing the identity 'engineer' as fundamentally rooted in forms of labor allows for a change to incorporate labor concepts that can provide connection points for engineer(ing educator)s to tap into their scyborg agency, as the engineer(ing educator) is embedded within the assemblage of the university/worksite and engages with their engineering foundation to enact changes (la paperson, 2017). Leveraging an intersectional analytic framework labor organizing is capable of teaching, combined with the engagement of an engineering foundation allows engineers to reconfigure assemblages that allow the technocratic theory of change to maintain hegemonic control over engineering education and practice, thus shifting what engineering is considered to be toward directions more aligned with Riley and Lambrinidou's ethical principles (Riley & Lambrinidou, 2015). We use the liberatory engineering education model as a means to connect this theory of change to concepts that can function to make this theory of change actionable Figure 33b.

7.1.7 The engineer as community organizer (learning method and learning)

For our purposes, we draw on the life and work of Grace Lee Boggs to visibilize connections between engineering and community organizing that are intertwined with labor organizing. Grace Lee Boggs was a Chinese American philosopher and community organizer born to immigrant parents. She received a Ph.D. in philosophy from Bryn Mawr College in 1940, but was de-facto barred from further advancement in academia due to institutional racism (Boggs G. L., 2012). She is most well known for over six decades of labor, Black liberation, and community organizing work in Detroit during industrialization and particularly in the post-industrial decay brought on by factory automation. Much of the theoretical core of her work held its basis in the Hegelian dialectic, where she encouraged "two-sided transformation, both of ourselves and of our institutions" by working through the contradictions present within our current system and ways of being (Boggs G. L., 2012, p. 100).

One of these contradictions that Grace and her late husband Jimmy observed was the position unions were in during the 1970s, writing,

> "It is very difficult to accept, when so many struggles have gone into their organization, that unions today are the culmination of reformism, and that we have reached the point in history (in the United States) where the more you reform, the worse things get. It has never been so before. In the past, it was inconceivable that struggles for higher wages could act to destroy human rationality. Such struggles were progressive in the past in the

sense that the changes they engendered advanced everybody in society … we are talking about understanding, internalizing, recognizing that we are at the stage in the United States today where the changes which have been undertaken are not going to be, cannot be, undertaken by … people who are thinking about how to 'get ours.' They can only be undertaken by people who know what they want to change," (Boggs & Boggs, 2008 [1974], pp. 228-229).

This model of unionism, which focuses primarily on the expansion of wages and benefits for members of a union's bargaining unit, can be viewed in parallel with the political economic phenomenon of majorism, which maintains and reproduces preferential treatment of STEM fields within the academy and broader capitalist logics (Carrigan & Bardini, 2021). Carrigan and Bardini identify linkages between future salaries and class status as components impacting hierarchical rankings among engineering fields as well as across fields of study more broadly. Additionally, their identification of an expectation of students to be trained in skills deemed easily marketable over being educated to think critically and participate in civic society connects to the reproduction of the institutional power of dominant groups and acts as a barrier to potentially transformative social movements by shaping engineering education toward the production of "people who are thinking about how to 'get ours'" over "people who know what they want to change," (Boggs & Boggs, 2008 [1974], p. 229).

The drive for "people who know what they want to change" (Boggs & Boggs, 2008 [1974], p. 229) described can be connected to the form of community cultural wealth known as aspirational capital, defined by Yosso as,

"the ability to maintain hopes and dreams for the future, even in the face of real and perceived barriers. This resiliency is evidenced in those who allow themselves and their children to dream of possibilities beyond their present circumstances, often without the objective means to attain those goals," (Yosso, 2005, pp. 77-78).

When aspirational capital is combined with the transformational resistance discussed by Solórzano and Delgado Bernal (2001), engineers are capable of not only posing questions of who their labor is benefiting, but also of connecting with means to shift the benefits of their labor toward the broader community. Thus, allowing the learning method of a Bargaining for the Common Good campaign to be enacted. This process is demonstrated visually in Figure 33b. This is particularly salient for minoritized engineers, whose lived experience often allows them to accrue more of these forms of community cultural wealth.

Grace Lee Boggs' community organizing work also holds implications for learning methods leveraged in engineering education. Boggs posited that,

> "we need to create a much more intimate connection between intellectual development and practical activity, to root students and faculty in their communities and natural habitats, and to engage them in the kind of real problem solving in their localities that nurtures a love of place and provides practice in creating the sustainable economies, equality, and community that are the responsibilities of citizenship," (Boggs G. L., 2012, p. 157).

This aligns with the learning method of Bargaining for the Common Good, through which engineers are capable of leveraging and growing their social capital, a form of community cultural wealth, in their social networks through whole worker organizing. An example of a whole worker organizing network for an engineering graduate student is shown in Figure 34. Boggs' assertion that, "the important thing for us was to see the oppressed not mainly as victims or objects but as creative subjects" (Boggs G. L., 2012, p. 59) provides a means to link the community cultural wealth of engineers to the growth of practice with the form of divergent thinking discussed by Daly et al. (2014). From this, a social community can be nurtured and grown amongst students, faculty, and other community members, making space for engineers to practice divergent thinking by drawing on their community cultural wealth to solve local community problems. Engineering work centered in local problem solving and rooted in a social community becomes community organizing with the framing of engineering ethics and principles such as those advanced by Riley and Lambrinidou (2015).

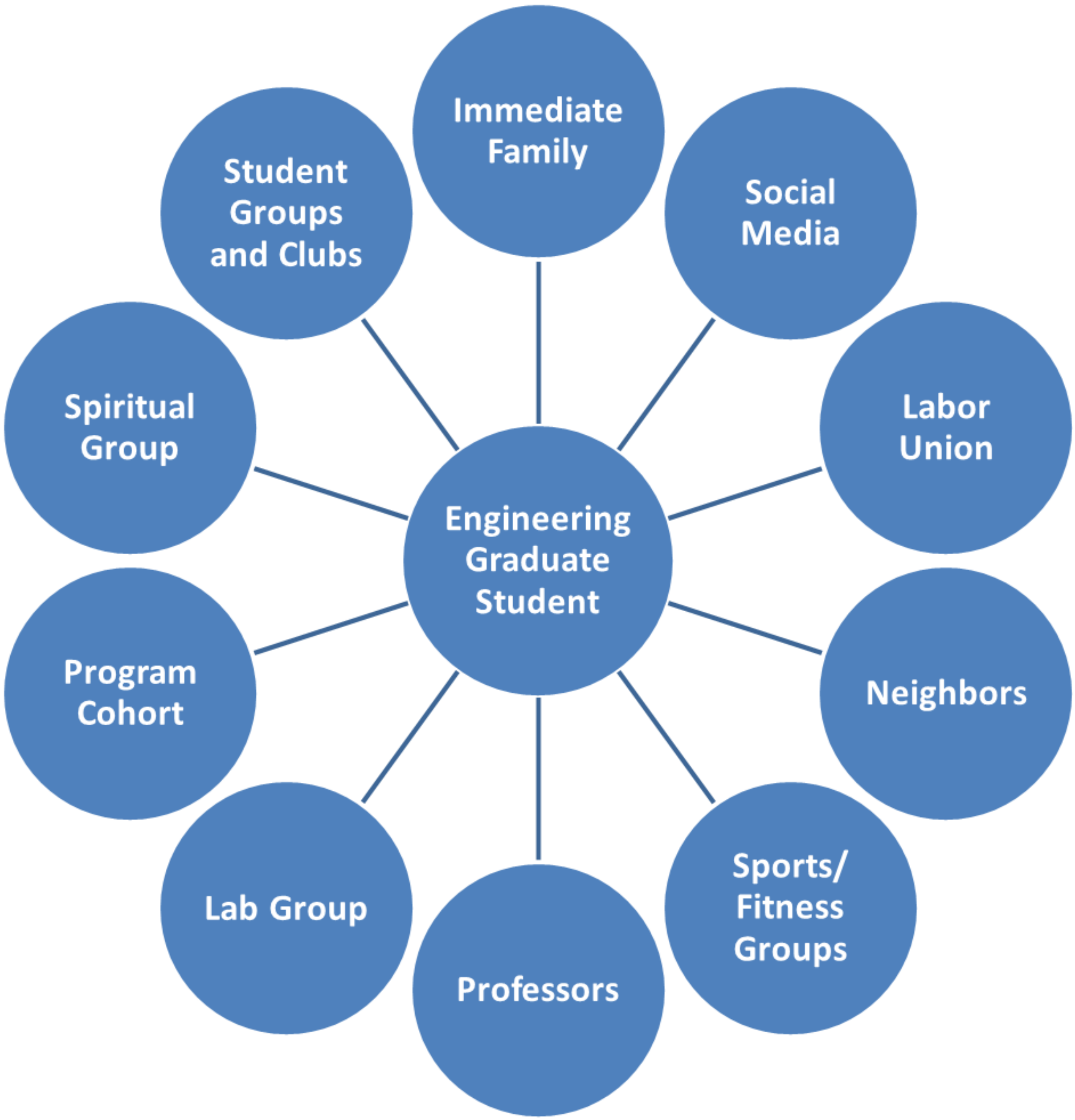


Figure 34: An example of a whole worker organizing network for an engineering graduate student, adapted from McAlevey's whole worker organizing network (McAlevey, 2018).

7.1.8 The strike as liberatory pedagogy (learning method)

Grace Lee Boggs' lifelong work to enact "two-sided transformation, both of ourselves and of our institutions" (Boggs G. L., 2012, p. 100) can be the type of critical engineering agency that we co-create with our students (Godwin, Potvin, & Hazari, 2013). However, a similar neoliberal framework to that which currently binds theories of change students are capable of engaging with in engineering education also operates more broadly within institutions of higher education. A case study of this can be seen in Matthew Johnson's book Undermining Racial Justice, in which he details the intentionality of administrators at the University of Michigan with which they upheld racial inequality in response to Black student activism,

> "First and foremost, administrators wanted to sustain the university's elite status and preserve a system that measured institutional quality by the "merit" and "qualifications" of its student body. … While preserving racial inequality didn't motivate policies at UM, campus officials usually knew that their inclusion policies would likely maintain racial disparities. If administrators were surprised about the outcomes, they were often surprised by the degree of those disparities, not by the mere existence of inequality. Consequently, racial disparities at UM can hardly be called unintended outcomes," (Johnson, 2020, pp. 2,4).

Drawing from Coit's framework of citizen participation and Johnson's example of the maintenance of racial inequality through the diffusion of student organizing power, neoliberal institutions employ comparable tactics to the ways in which citizen participation models imposed from above seek to control and co-opt movements (Coit, 1978); (Johnson, 2020). Coit detailed how citizen participation sought to impart middle class values to the poor, which shows parallels to how neoliberal run institutions seek to bound what forms of change are acceptable via feedback mechanisms and co-opting student movements. In doing so, University administrators consciously and unconsciously act to retain their ability to set boundary conditions on work and forms of protest, shifting the terrain for organizing students from a combination of divergent and convergent thinking to primarily convergent thinking by providing students with a bounded problem of assessing climate and recommending changes without the vested power to enact them. The normalization of this pattern within academia as a whole can be seen in how it propagates to engineering education through the ways in which engineers are professionalized, imbuing engineers with a theory of change in which, “we tell ourselves that through techno-rational arguments we can persuade people in power to make whatever limited changes are needed to excise discrimination and marginalization without touching the rest of the system” (Pawley A. , 2019a, p. 450). In this way, connections can be made between neoliberal University operations more broadly and the technocratic, positivist framework currently utilized within engineering, increasing the size of constructed barriers, as shown in Figure 33a. The technocratic theory of change, at best, shepherds engineers toward what Solórzano and Delgado Bernal described as conformist resistance, which:

> “refers to the oppositional behavior of students who are motivated by a need for social justice yet hold no critique of the systems of oppression. These students are motivated by a desire to struggle for social justice yet engage in activities and behavior within a more liberal tradition. They want life chances to get better for themselves and others but are likely to blame themselves, their families, or their culture for the negative personal and social conditions. They offer “Band-Aids" to take care of symptoms of the problem rather than deal with the structural causes of the problem. In other words, these students choose to strive toward social justice within the existing social systems and social conventions,” (Solórzano & Delgado Bernal, 2001, p. 318).

In doing so, the connections between engineering, engineering education, and transformative resistance are obscured, as well as the transformative change these connections are able to bring about if solutions are sought to address root causes of issues. This obscuring of reality that technocratic, positivist frameworks cause has created a pressing challenge for engineers and engineering educators.

Labor unions and organizing can provide members of engineering communities a means to alter university/worksite conditions. Historically, efforts have provided workers a means by which they have pushed for more democratic decision-making at their worksites, particularly around the products workers produce and how they are produced. The theories of change that become accessible through labor organizing can open up opportunities for engineers to engage in transformational resistance. Contract campaigns are opportunities for engineers to channel their aspirational capital through divergent thinking to craft demands that their union takes into bargaining. Divergent thinking is also utilized in the development of strategies and tactics employed in union organizing, including during contract campaigns.

One of the most powerful tactics that workers within a union can employ is the strike. Strikes have frequently been the tactic graduate student workers have needed to resort to in order to obtain union recognition and first contracts from universities (Harvard Graduate Students Union, 2019); (Graduate Employees' Organization, 2021); (Lee & Burton, 2019) *[This is the process graduate student workers at Indiana University have been forced to resort to by their University's administration, going on strike for four weeks in Spring 2022 with the expectation that their strike will continue in Fall 2022 unless significant movement is made on the part of the Board of Trustees. Union recognition is overwhelmingly supported by the faculty* (Indiana Graduate Workers Coalition, 2022)*]*. Owing to the inherently conflictual relationship between graduate workers and university employers during a strike, the action of striking can map to Coit's concept of local action that seeks to develop a class consciousness, to engage in methods of self-management, and to develop a truly conflictual strategy (Coit, 1978).

Through the action of a strike, space is created for students to engage in divergent thinking while utilizing their analytical skills to solve problems that have been determined by their community. Within engineering, this allows for the enactment of an engineering praxis toward liberation when viewed through the liberatory engineering education model, as shown in Figure 33b. Figure 33b demonstrates how the engineering and labor theory of change could be applied through an organizing model of unionism with a liberatory framing. This opens up potential for engineers to engage their critical engineering agency by reflecting on their positionality and what ways one can reassemble structures as a scyborg through the labor organizing practices, skills, and tools that are outlined in Table 15. Bargaining for the Common Good is leveraged as a form of action (learning method) in which learning is experiential and is achieved through community organizing, including in strikes. Strikes can thus be viewed as a form of liberatory pedagogy that make space for a type of social community in which engineering work centers in local problem solving, actively practices engineering ethics and principles such as those advanced by Riley and Lambrinidou (2015), and enacts changes through Bargaining for the Common Good campaigns. Leveraging this recognition of strikes as a form of liberatory pedagogy, we have concurrently sought to co-develop this theory and understand its implications through a qualitative study with graduate engineering student workers who participated in the 2020 GEO 3550 abolitionist labor strike (Valle, Ali, Bowen, & Riley, 2021).

7.1.9 Practices (learning methods and assessment methods)

Table 15: Practices, skills, and tools used in labor organizing, the organizing framework of social support outlined by Lee et al. (Lee, Lutz, & Nave, 2018), and the social community outcomes outlined by Mondisa and McComb (2015) as well as their connections to engineering education research methods and methodologies.

Practice/skill/tool	Description of practice/skill/tool	Connections to Lee et al.'s organizing	Connections to Engineering

		framework and Mondisa and McComb's social community outcomes	Education Research learning methods, assessment methods, and methodologies
1-on-1 organizing conversations	"The 1:1 meeting is a tool to establish, maintain, and grow relationships in organizing" (Sinnott & Gibbs, n.d., p. 16).	Agency (values), Agency (choices), Process (Institutional Experiences), Process (Affective Responses), Context (Student Attributes), Impact (Intentions) Communities of practice	Think-aloud/ verbal protocols, semi-structured interviews
Coaching	"... the goal of coaching is to help people find their own solutions to meet challenges, and the role of the coach is to ask questions to get people to uncover the	Process (Affective Responses), Process (Institutional Experiences), Context (Student Attributes), Agency (choices)	Think-aloud/ verbal protocols, semi-structured interviews

	answers in themselves" (Sinnott & Gibbs, n.d., p. 21).	Resiliency, communities of practice	
Storytelling and personal narrative work	"The discursive form through which we all translate our values into action is story. A story is crafted of just three elements: plot, character, and moral. The effect depends on the setting: who tells the story, who listens, where they are, why they are there, and when" (Ganz, 2008, p. 11).	Agency (values), Agency (choices), Context (Student Attributes) Social capital, resiliency, communities of practice	Narrative inquiry, autoethnography Focus
Group strategic goal setting	Collectively determine strategic goals that are measurable, focus resources, build capacity, use a point	Agency (choices), Impact (Intentions), Process (Institutional experiences) Communities of practice	Focus groups, collaborative inquiry, participatory action research

	of leverage, focus on a motivational issue, and can be replicated or emulated (Sinnott & Gibbs, n.d.).		
Power mapping	Helps to "identify important people or groups when strategizing, and when designing and implementing tactics" (Sinnott & Gibbs, n.d., p. 47).	Context (Organizational Characteristics), Context (Student Attributes), Process (Institutional Experiences), Process (Affective Responses), Impact (Intentions) Communities of practice	Focus groups, think-aloud/ verbal protocols, case study, narrative inquiry, participatory action research
Collective bargaining	"Collective bargaining is the process in which working people, through their unions, negotiate contracts	Context (Organizational Characteristics), Agency (Values), Process	Narrative inquiry, participatory action research

	with their employers to determine their terms of employment, including pay, benefits, hours, leave, job health and safety policies, ways to balance work and family, and more. Collective bargaining is a way to solve workplace problems" (AFL-CIO, 2021).	(Institutional Experiences) Process (Affective Responses), Impact (Intentions), Impact (Outcomes) Resiliency, Communities of Practice, Social Capital	

Table 15 outlines and describes practices, skills, and tools that are common within labor organizing that the authors have engaged with and used as a source of community cultural wealth to enhance our engineering education research and praxis. These practices, when utilized in the context of an engineering and labor theory of change, can be linked to learning methods, assessment methods, and methodologies that leverage various forms of community cultural wealth to build resistance capital as a form of scyborg agency. Table 15 shows how these practices can be used to build a social community as outlined by Mondisa and McComb (Mondisa & McComb, 2018) and utilize the organizing framework of social support outlined by Lee et al. (Lee, Lutz, & Nave, 2018) that can help engineering educators become transformational role models and mentors. Solórzano and Delgado Bernal (2001) provide a definition, citing Blackwell (1988) and Solórzano (1998), for transformational role models who could engage with the practices outlined in Table 15:

> "In the context of this study, transformational role models are visible members of one's own racial/ethnic and/or gender group who actively demonstrate a commitment to social justice, whereas transformational mentors use the aforementioned traits and their own experiences and expertise to help guide the development of others (Blackwell, 1988); (Solórzano D. , 1998). Thus, a mentor is involved in a more complex relationship than a role model in that [they are] someone who participates in one's socialization and development," (Solórzano D. , 1998, p. 322).

An example of a 1-on-1 organizing conversation and significant personal narrative work indicating how a strike can be a form of liberatory pedagogy is one between [Joey] and my technical research advisor during the GEO-3550 abolitionist strike. I had emailed my department chair explaining how the strike provided a means to affirm my existence, my validity within academic spaces of communities I am a part of, and struggles I have faced within the department and at the university in ways that official university channels have never provided [see email excerpts at the beginning of the chapter]. That email was forwarded to my research advisor, prompting a frank 1-on-1 conversation that included storytelling and personal narrative work. In it, I discussed the lack of acceptance and belonging that my department allows me to feel, ties these feelings have to systems of oppression whose manifestations within my engineering education experience were driving me toward self-defeating resistance and departure from engineering altogether, and how I was uninterested in becoming another decontextualized statistic of a multipli-marginalized engineering student departing from engineering and/or academia. The forms of community cultural wealth I was able to draw on prevented this departure and the personal narrative work contextualized my situation enough that my technical research advisor and I were able to come to a mutually-agreed-upon understanding that I would engage in more engineering education research that allowed me to interrogate some the very systems of oppression within engineering education that were driving me to nearly depart from engineering altogether. This was a 1-on-1 conversation, resulting from an abolitionist labor strike, that was critical to the creation of this conference paper. As hooks discusses, “I came to theory desperate, wanting to comprehend - to grasp what was happening around and within me,” (hooks b. , 1994, p. 59) and working with [Corey and Donna] on this paper helped me to engage in theory as a social practice. Collectively, the authors believe that further study into transformative, liberative engineering education is necessary for the principles outlined by Riley and Lambrinidou to be normalized as engineering practice (Riley & Lambrinidou, 2015), echoing calls from other engineering education scholars for engagement with methodologies that foster scyborg agency such as participatory action research, narrative inquiry, and autoethnography (Holly Jr., 2020); (Martin & Garza, 2020); (Slaton & Pawley, 2018).

7.1.10 Limitations (potential barriers)

There are multiple approaches that unions take for change-making, each with differing locations of where and with whom agency for change rests. McAlevey (2018) described three approaches to unionism: advocacy, mobilizing, and organizing. An advocacy model holds an elite theory of power, in which existing relations of power are not permanently altered and there is no focus on utilizing worker power. A mobilizing model also utilizes a primarily elite theory of power, relying on staff or activists, setting ambitious goals and declaring wins, even when they have weak or no enforcement provisions. The mobilizing model relies on grassroots activists, defined as those who are already committed, and does not seek to deeply expand their base. Our theory, however, is based on an organizing model, which seeks to "transform the power structure to favor constituents and diminish the power of their opposition. … [This model] prioritize[s] power analysis, involve[s] ordinary people in it, and decipher[s] the often hidden relationship between economic, social, and political power" (McAlevey, 2018, p. 11). An organizing model centers its power in workers' agency. Since advocacy and mobilizing models have been shown to center their power in locations other than the workers' agency, they are more reflective of the critique of unions that Grace and Jimmy Boggs offered and could limit the ability for engineers to engage their community cultural wealth to enact change through their union (Boggs & Boggs, 2008 [1974]).

Bargaining for the Common Good can become especially difficult for technical experts, such as engineers, if interactions with "the Public" are not transformative engagements. Lambrinidou discusses ways in which the interest of technical experts to "do good" can work to "diminish or exacerbate a community's social marginalization, validate or discount its agency and knowledge, and enhance or further undermine its access to and influence on expert research, resources, decisions, and solutions" (Lambrinidou, 2018, p. 9). Failing to recognize power dynamics that can arise between technical experts and non-experts serves only to continue to perpetuate harm and can visibilize contradictions between the intentionality to engage in Bargaining for the Common Good and the impact of the modes of engagement between engineers and the broader community. These contradictions can become especially salient when considering which populations are currently well represented within engineering and how that representation relates to community organizing.

Finally, engineers have continually grappled with the “boundary question” of whether to include technicians within their ranks. This is a manifestation of the contradiction within the professionalization of engineering as a field that has ties to both blue-collar and white-collar work. This contradiction, brought on by understandings of engineering professionalism, has historically served to build up a reliance on management-oriented engineers as leaders, causing a de-identification of engineering with blue-collar labor occupations that are more traditionally associated with labor organizing (Meiksins & Smith, 1996). The formation of the Alphabet Workers Union serves as an explicit example of how contemporary labor unions can address this; however, there is no guarantee that other engineering labor unions will engage with a diversity, equity, and inclusion-centered union organizing model capable of leveraging a Bargaining for the Common Good framework that the Alphabet Workers Union has positioned themselves to use (History of Alphabet Workers Union, n.d.). An example of union collective bargaining that did not utilize this framework was the Boeing strike of 2000, in which engineering workers engaged in the biggest white-collar strike in U.S. history to that point, but strike demands centered only on improvements to the wages and healthcare benefits of those in the bargaining unit (Riley D. , Engineering and Social Justice, 2008). This strike centered its power in workers’ agency, allowing engineers to engage in community organizing and constructing the opportunity for the strike to be liberatory pedagogy by growing solidarity and connections between the striking engineers and technologists and other workers and community members. However, the strike demands did not necessarily correspond to benefits to and investment in the wider community. An explicitly communicated approach utilizing a Bargaining for the Common Good framework would position unionized engineers to contribute to liberative organizing efforts, both inside and outside of academic spaces.

7.1.11 Conclusions

Engineering is currently a field shaped by systems of oppression that are antithetical to the lives and needs of people engineering technologies are intended to serve. Many other forms of engineering could exist that center localized community needs and break rank with the overreliance on technocratic theories of change. If we are to shift this conception of engineering, we need to engage with theories of change that consider current structures of power and move the field in liberative directions. However, we must also be mindful of the engineering field's interactions with and legacies of impact on broader communities.

In this paper, we have sought to outline one form that this process could take by creating a liberatory engineering education model as a container for conceptualizing how to make theories of change actionable. We created and applied a theory of change combining engineering and labor organizing as an example use of this model. Labor organizing can serve as a vehicle for power, allowing marginalized engineers to leverage their community cultural wealth not only toward surviving hegemonic engineering culture, but also toward coming into a scyborg agency that reshapes what engineering is and outlining potential ways that a transformed engineering praxis could look. We have identified Bargaining for the Common Good as a learning method that can enable engineers to leverage community cultural wealth in community organizing and described how strikes can be a form of liberatory pedagogy. We have also demonstrated a further need to explore the class dynamics of engineers and the dialectic relationship of class to engineering education and practice. We have deliberately chosen to couch this paper within the Equity, Culture, and Social Justice in Education Constituent Committee during its first year owing to its potential to critically engage with relationships underlying the ongoing bifurcation of wealth between poor and working class communities and the owning class further exacerbated by the COVID-19 pandemic as well as continual environmental devastation throughout the world. Additionally, the Black-led rebellions and uprisings for racial justice, multiple graduate student worker strikes across the U.S., and the fascist insurrection of the U.S. Capitol both have occurred since the committee's inception. With this in mind, we leave the reader with the following questions:

- As space is made for a more intersectionally representative engineering student body and workforce, how are we situating ourselves to provide students with the space to engage with the practices, skills, and tools needed to leverage their engineering education toward undoing structural harm instead of reinforcing it?
- What forms of pedagogy could be developed to engage engineers and engineering educators in transformative resistance, and how could they effectively be utilized toward liberation across multiple domains of power?
- What forms of daily praxis, scholarship, and concientização are we, can we, and/or do we need to be engaging with to become students' transformational role models and mentors?
- How can framings, positionalities, and community organizing be leveraged to visibilize frequently invisibilized components of the terrains of struggle in which engineering as a field and its practitioners engage?
- What theories of change can we engage that move beyond helping marginalized students to just survive their engineering education and instead make space for their relationship with engineering education to be a liberative one of healing and thriving?

7.2 Experiences of Engineering Students Participating in an Abolitionist Labor Strike

7.2.1 Introduction

This exploratory work-in-progress paper presents intermediate results from a qualitative research project unpacking aspects of the participation of engineering graduate students in an abolitionist labor strike. The goal of this research project is to understand what motivated engineering graduate students to participate in this strike, what their strike participation encompassed, and what broader relationships they see between their position as engineering students, union organizing, and engineering as a discipline.

Members of the Graduate Employees' Organization, American Federation of Teachers local 3550 (GEO) engaged in a strike from September 8th to September 16th, 2020, striking for a safe and just pandemic response at a large public university (Mirza & Andrew, 2020). Strike demands centered on safety and justice relating to both COVID-19 and policing. These demands centered common good elements around a universal right to work remotely during a pandemic, improvements to parent and caregiver accommodations, the waiving of fees levied on the international student community, extensions to degree timelines and funding in response to COVID-19, access to a disarmed and demilitarized workplace, the defunding of the campus police department by 50%, and breaking university ties with local police departments and Immigrations and Customs Enforcement (ICE) (Graduate Employees' Organization AFT Michigan 3550, 2020). The policing-related demands were rooted in an abolitionist strategy of non-reformist reforms (Stark, Ehrhardt, & Fleischmann, 2020); (Gorz, 1964). This concept of non-reformist reforms was articulated by Andre Gorz as a means by which Labor is able,

> "to fight for alternative solutions and for structural reforms (that is to say, for intermediate objectives) ... not ... improvements in the capitalist system; it is rather to break it up, to restrict it, to create counter-powers which, instead of creating a new equilibrium, undermine its very foundations," (Gorz, 1964, p. 181).

This strike took place during the COVID-19 pandemic and after the Black-led protest and rebellion wave in Summer 2020 brought on by police killings of Black people (Holly Jr., 2020). Engineering exists as a discipline that has been characterized as depoliticized and meritocratic, ideologies which run counter to those that typically undergird participation in labor unions and the undertaking of liberatory structural alterations (Cech E. A., 2013); (Meiksins & Smith, 1993); (Riley & Lambrinidou, 2015). Riley has discussed how prevailing forms of rigor in engineering, engineering education, and engineering education research reproduce inequality and function primarily to discipline, demarcate boundaries, and demonstrate white male heterosexual privilege, as well as the need to seek alternatives for evaluating knowledge (Riley D. , 2017). Slaton and Pawley further demonstrate ways that prevailing standards for engineering education research are assembled from politics that run counter to and stigmatize qualitative and small-n studies (Slaton & Pawley, 2018). Using analyses from intersectional, Queer, and Disabilities Studies theories, Slaton and Pawley assert that qualitative and small-n studies make space for epistemological shifts that position researchers to better confront structural inequities. Historically, participation of American engineers in labor unions has been low, reaching a high point of around 10% of American engineers during the 1940s-1950s (Meiksins & Smith, 1996). Labor strikes that have included significant engineering participation have been a rare occurrence, with one of the most notable being the Boeing strike of 2000 (Riley D. , 2008). Thus, the 2020 GEO strike provides a significant opportunity to deepen understandings of connections that exist between engineering and organized labor. This paper seeks to identify relationships between engineering and labor from the vantage point of graduate student engineers who participated in an abolitionist labor strike by considering the following question: *how do* *engineering strike participants position the role of union organizing and mobilization within their view of engineering?*

7.2.2 Theoretical Framework

[Described in 7.1.1]

7.2.3 Positionality

The first and third authors, Valle and Bowen, are labor organizers with the American Federation of Teachers (AFT) local GEO-3550, marginalized engineers, graduate student workers, children of union members, and participants within this study. As engineering graduate students whose primary fields of study are not engineering education, this work represents a departure from the technical scholarship of our fields. As early career scholars, we recognize forms of political risk inherent to incorporating labor into the scholarly field of engineering education. Pawley, Cech, Riley, and Farrell have discussed their experiences of targeted harassment resulting from visibilizing facets of engineering education that counter hegemonic understandings of STEM education in response to their scholarship (Pawley, Cech, Riley, & Farrell, 2019). Owing to this state of academia and the field of engineering education, we sought to heed the advice Liboiron (2016) gave for interventionist research in science and technology studies and establish intentional networks of care and solidarity prior to engaging in this research. Due to the relative newness of our engineering education program, the availability of the researchers at our own institution, and the inherently conflictual nature of this scholarship with the institution we are situated in, we sought external collaborations for this work that could simultaneously assist in scholarly research and in building networks of solidarity and care.

We reached out to the fourth author, Riley, as she is a major figure advancing social justice and one of the few professors discussing unions in the engineering education research space. She works at a different institution and is thus removed from any involvement in the strike and free from any judgment that might follow from such involvement. Her institution does not presently have a union, so her collaboration here does not threaten current political conditions on her campus. She is a tenured professor, and thus is afforded the privileges of academic freedom and job security, among others, enabling her to provide strategic guidance in navigating this kind of work in academic engineering settings. At the same time, she serves as a department head, which entails some political precarity, even as it carries certain power and visibility. While acutely aware that this collaboration may represent some kind of transgression of expectations related to her role (to not question or challenge institutional systems of power), she frankly sees her role quite differently.

Many of the participants in this study are friends and colleagues of the first and third authors, further emphasizing a need to distance ourselves from the data collection process and strive to preserve the authenticity of their voices. After establishing a collaboration with the fourth author and thinking through potential ramifications for this work, we reached out to the second author, Ali, who is an undergraduate student in the engineering college. She is not in the union nor taught a course at the university. These factors allowed her to reduce biasing within the data collection process. This author was present on campus as the pandemic and policing crisis unfolded and therefore experienced the events mentioned in this paper firsthand. Additionally, this project was unique to typical aerospace engineering work but she chose to get involved because of its impact.

7.2.4 Methodology

Our study is utilizing a narrative analysis methodology based on the work of Pawley and Phillips (2014). As outlined by Pawley and Phillips, Mauthner and Doucet (1998) proposed a voice-centered approach of conducting four specific readings of each transcript:

- Reading 1: The researcher reads the data for the overall plot and story with attention paid to respondent's identification of critical developments, important characters, and side stories. (Mauthner & Doucet, 1998, p. 126)
- Reading 2: The researcher focuses their attention on the way the speaker feels and speaks about herself. The researcher studies how and when the speaker used the active voice, in what situations, with whom, and furthermore, when the active voice shifted to a passive one. The goal is to see "how she speaks of herself before we speak of her." (p. 128)
- Reading 3: The investigator studies the "interpersonal relationships" in the speaker's life by identifying how the respondent spoke about the relationships within their homes and workplaces to both people and institutions. (p. 131)
- Reading 4: The researcher codes for the macro-structures in the life of the respondent, i.e. the disembodied social, political, and cultural forces that reify themselves in the life of the speaker through the critical developments and nature of relationships in the speaker's story.

  When all the readings are taken together, Mauthner & Doucet's voice-centered approach allows for sociological analysis without neglecting either the co-construction of the interview made through the prompts of the interview questions, or the voice of the respondent" (Pawley & Phillips, 2014, p. 7).

Clair et al. also outlined the concept of The Collective Story, which allows for the telling of a story of a "social category rather than … a particular individual's story" (Clair, Chapman, &

Kunkel, 1996, p. 250), while providing anonymity at the expense of authenticity in connecting the researchers, who serve as storytellers, with the participants. The individual participants are decentered as the main constructors of the narrative that is told. The Collective Story was chosen as our approach as a structural means to reduce potential forms of retaliation participants could experience in their career trajectories.

Methods

Recruitment

This study focused on graduate engineering students who participated in the 2020 GEO strike. Our study was approved by the Institutional Review Board at the University of Michigan (IRB). Participants were recruited using a sampling method that was informed by author involvement and purposeful in order to get a range of perspectives from varying levels of involvement in the strike and in the union. 15 participants were interviewed as a part of this study. Participants were asked to fill out a demographics form to provide self-described information about their Ph.D. program, race and ethnicity, gender, sexual orientation, and estimated family income prior to enrollment in an undergraduate program. They were also asked to provide a pseudonym for use in the study.

Interviews

Semi-structured interviews were conducted over the virtual meeting platform Zoom. Interviews were conducted by the second author, an undergraduate student, so as to reduce the impact of pre-existing relationships among participants and researchers within the interview setting. Audio and video were recorded during each interview, along with live auto-transcriptions using a feature in Zoom. Interview times ranged from 16 to 50 minutes in length. Interview questions revolved around:

- motivation for participation in the strike,
- descriptions of what participant involvement in the strike looked like,
- what they and their engineering peers thought about the abolitionist policing demands,
- any connections they understood to exist between engineering and labor, and
- whether and why they believed their peers also understood the connections they understood to exist between engineering and labor.

Data Cleaning and De-Identification Process

A data cleaning method similar to that outlined by Pawley (2019b) was used. Transcripts generated using Zoom live auto-transcriptions were reviewed along with audio recordings to check for accuracy of the transcript. We then created a pseudonymized transcript, which included generalized demographics information of the participant and suggested alterations to anonymize information we believed to be identifiable. Member-checking was employed; copies of the audio recording and the original transcript along with an editable version of the pseudonymized transcript were sent to the participants. Participants were then asked to review their pseudonymized transcript for inaccuracies, anything they regretted saying, or information they believed to be identifying. Suggested edits by the researchers were also member-checked by the participants. Any changes suggested by the participants were accepted by the researchers. The research team then made a copy of the member-checked pseudonymized transcript to erase edit history on the document and deleted archived email correspondence with participants, records of audio recordings, video recordings, demographics form responses, and prior versions of the transcript, leaving the research team with only the de-identified, member-checked version of the transcript.

Analysis

The research team used Mauthner and Doucet's "voice-centered" approach (1998) to analyze the de-identified transcripts. Performing the four specific readings allowed for identification of major themes as macro-structures through the fourth reading, including those aligned with the engineering and labor theory of change for each interview (Valle, Bowen, & Riley, 2021). Clair et al.'s Collective Story method (Clair, Chapman, & Kunkel, 1996) was then used to combine themes that emerged across different interviews. Analysis was performed on the de-identified transcripts generated from interviews with 7 of the participants for this work-in-progress paper.

7.2.5 Results to Date

Our summary of results identified 4 major themes, each with several sub-themes. The four major themes that emerged across multiple interviews in the analysis process were *perceptions of depoliticization, meritocracy, and majorism, labor as a vehicle for change, engineers being community organizers, and strikes as opportunities for liberatory pedagogy within engineering*.

Perceptions of depoliticization, meritocracy, and majorism were believed to reduce strike participation from engineers (theme 1)

Cech (2013)described ways in which prominent ideologies within engineering culture negatively impact the ability of engineers to think about social injustices. These ideologies include depoliticization, the belief that social and political issues are tangential to engineering labor, and meritocracy, the belief that the social system functions properly and rewards the talented and hard-working. Additionally, Carrigan and Bardini discussed majorism,

> "an emic term undergraduates used [in the authors' study] to describe a value system that maintains and reproduces preferential treatment of science and technological fields and their practitioners. Majorism is a cultural outcome of the neoliberal system that prioritizes economic output broadly within society and, in particular, in higher education. This political economic phenomenon grafts onto other forms of discrimination—homophobia, racism, sexism—aiming to quash potentially transformative social movements and reproduce the institutional power of dominant groups, especially those aligned with globalization and corporate activism (Duggan, 2003)," (Carrigan & Bardini, 2021, p. 3).

Participants noted disconnections between engineers and labor education (subtheme 1a). They discussed that labor education was not a part of their engineering education, making it difficult for themselves and their peers to make contact with the union, understand the strike and labor organizing more broadly, and process their positionality in relation to the strike. Some participants mentioned how their engineering departments operated as if a strike was not even occurring.

Engineering as a professional sector in the U.S. has historically had comparatively low rates of unionization (Meiksins & Smith, 1996). Aster described prevalent engineering culture as exhibiting a dichotomous, depoliticized understanding of engineering work and life:

> "… we're … kind of drilled into us that like, just culturally engineers kind of keep their heads down and so it's easier just to like, 'okay, I'm going to do my work. And then I'm going to go home and have my weekend.' So I think that it's also, like the softer sciences

> are, are often looked down upon, it's like, 'Oh, you're a liberal arts major. Like what are you going to do with that.'"

Aster also describes a key component of majorism, the stereotyping liberal arts degrees as inferior (Carrigan & Bardini, 2021).

Maria described frustration with her wealthier peers' detachment from issues the union was striking over:

> "… I'm sorry but like engineering students are benefiting [from the union] … if we didn't get [the union-won benefits], … (sigh) It's frustrating. Like, I remember talking to one person and he's like, 'I don't see why we need an emergency check, it would just sit in my bank account' and like you are so fucking detached from the reality of most students that I just can't speak to you right now. Like you're just so detached."

The individualistic understanding exhibited by Maria's peer, who questioned why graduate students might need emergency funding during a global pandemic, is indicative of a form of depoliticization around class. This form of depoliticization can indicate an uncritical reflection of positionality in relation to the class status of other graduate students.

Mobilizing strategies were not particularly effective (subtheme 1b). Participants described the general ineffectiveness of strategies geared toward turnout and mobilization instead of political education and relationship development. McAlevey discussed the mobilizing model of unionism as a form of pragmatic, business unionism in which the purpose of the union is solely to improve material conditions (McAlevey, 2018). This model seeks to bring high numbers of people to the fight, often without their communities along with them, in a way that does not center power in worker agency.

For example, Jon David discussed structural barriers that functioned to obscure connections between the realities of engineering graduate students and the strike demands:

> "… engineering grad students … are really very isolated from the rest of campus. Um, and especially a lot of that has to do with the physical separation, but a lot of that also has to do with like … these GSI [graduate student instructor] demands don't necessarily apply that often. So we all have GSRAs [graduate student research assistant positions], and some of the demands … I don't think they got why they were being advocated for."

In doing so, he identified a need for a greater connection between engineering graduate students and the social justice demands being advanced by the union to counter the depoliticization that can cause this disconnection. This connecting work is made difficult by the use of mobilizing strategies, which do not always center political education.

Maria likewise expressed that, without relationship building over time, the amount of political education required to overcome depoliticization in the engineering context can be overwhelming. She described the need to have conversations to develop understanding, but also the difficulty of doing so when someone's first interaction with the union is during a strike:

> "… I think one of the hardest things about the strike is the information and setting it up, of the context and there's just so much to unload at first that it's just … It's just too intimidating. It's too much up front. It just, it comes off as like the university's an asshole and we have to like be justice and like … That tone in any conversation when you're just initially talking with people, it's just, it doesn't go well."

The lack of diversity in engineering impacts how issues are understood and addressed (subtheme 1c). Participants discussed the disproportionately low representation of marginalized students within the engineering college as a reason why many engineers could not contextualize the conditions and motivations behind the strike through their own lived experiences or the experiences of engineers with whom they were in contact (Carrigan & Bardini, 2021); (Foor, Walden, & Trytten, 2007). Aster, for example, described impacts of the predominance of whiteness in the engineering college on students' ability to understand the strike demands:

> "I think … the engineering [college] is, probably whiter than some of the other [college]s on campus. … I think we have an abysmal amount of Black students in the engineering [college] … Just because the students aren't there to serve either as examples of people who are experiencing these prejudiced environments or being able to see people actively being prejudiced against these students because they just aren't in the [college]. … The entire absence of [the Black] community [in the engineering college] makes it hard to see the necessity of such like, the things we were fighting for this strike."

[*At this point, it's helpful for me to reflect that this quote contributes to the anti-Blackness in EER as its construction erases the Black community in the engineering college* (Holly Jr., 2020). *Aster is white as are 3 authors on this paper. This should either have been more deeply contextualized in the areas of the engineering college Aster is referring to as opposed to a generalization of the college as a whole or just not published at all. E.g. The entire absence of [meaningful relationships with the Black] community [from the experiences of the people in the engineering college I was trying to organize] makes it hard [for them] to see the necessity of such like, the things we were fighting for this strike. I apologize for its publication and take accountability for doing so* (Mingus, 2019)] Aster thus recognized engineering to be a prejudiced environment. Her connection of identity and the under-representation of Black communities in the engineering college to the lack of ability to understand the necessity of the strike demands indicates that a lack of representation can drive depoliticization. Richard echoed this connection by describing how a lack of lived experience with police violence can limit support for racial justice to conceptual support rather than material:

> "… I feel like there's a lot just around, um, disconnects between people's lived experiences that haven't necessarily had to coincide with police violence and tactics to support people whose experiences have … had to coincide with police violence. … So like I think … there's like the abstract support of like racial justice and stuff like that. But then in terms of like actually turning that into concrete steps, um, I think that's where a lot of, I want to say, especially engineers um, can get tripped up."

Participants also recognized the impacts of power dynamics between students and professors, the latter of whom are frequently more conservative (subtheme 1d). Participants discussed difficulties they and their peers faced in navigating their relationships with faculty members, who have more institutional power than the graduate student participants. Aster, for example, discussed power dynamics at play in engineering Ph.D. advising relationships:

> "… in an engineering Ph.D., we are very closely tied to our one mentor and they have a lot of power over us. They completely determine, um, like what we work on, how much work we do, and they are the kind of key to us getting paid. Like our, our pay is routed through the work that we directly do on the grants that they, um, win. … And so we are very dependent on having this relationship with our PI. … I think that being so tied to someone who you would be withholding your work [from] and be very directly like potentially alienating through the process of striking, can have a lot higher consequences just by the nature of our kind of contract with the school and how our education is arranged."

The power dynamics Aster describes can serve as a depoliticizing barrier by leaving students hesitant or unwilling to challenge the power their advisors have over them. A number of participants discussed this as a way to contextualize low strike participation from international engineering students. In turn, this form of entrenched power can be tied to a lack of support for minoritized students in the college as described by AK:

> "... [this university] is not doing a good job supporting underrepresented students in general, that may just be the [engineering college], again I can't speak to [other colleges] and how that works. How, I mean there's like the certain, the certain entrenched power structures and like the tenure system, how you have a bunch of old white professors that … [are] causing major issues."

They also discussed how conservatism among the engineering professors detracted from the power of the strike. This is not unexpected, because engineering has been shown to have one of the highest percentages of conservatives among all academic disciplines (Riley D. , 2008). Matilda described faculty conservatism in a refusal to acknowledge the political nature of their work:

> "I think that department leadership and many engineers think that they can somehow avoid making it political. That it's not political until they make it political and that's where I think they're wrong. It's already political whether or not they want to accept and address the fact that it's political, but they think that it's somehow won't be political if they don't talk about it or participate in it. Like that somehow their acknowledgement of it being political is what makes it political, which is not true. Yeah. So from the perspective of like department leadership, um, they clearly see graduate students making it political, even though it was already political - they see it as the graduates made it

political and that - that's a problem because education isn't supposed to be political by the popular rhetoric."

Participants also lamented that their formal engineering education was frequently shaped by corporate or industry influence (subtheme 1e). Carrigan and Bardini described how, "corporations and university agendas align as funding is largely concentrated within STEM, profit-making fields as a way to generate greater output and larger future profit for both parties" (Carrigan & Bardini, 2021, p. 13). Multiple participants discussed facets of this influence. Richard described how corporations shape engineering education to fit their needs, including at the expense of engineers applying their labor toward community benefit:

> "… who has been crafting the narrative of what engineering is? At least for a while, largely it has been … massive corporations. Right? And there's been a lot of reasons why it is that they would want to kind of tailor the way that engineers think or are educated in order to make us more productive workers for them in whatever type of labor that they would like us to do, … really kind of instead of what type of labor we want to do, (chuckles) um, or what type of labor would actually be helpful to our community."

Similarly, Matilda described the role of the military industrial complex in engineer depoliticization, including the individualistic framing that allows for others to profit off of engineering labor:

> "I think it is in the interest of people who get wealthy from the military industrial complex to make sure that engineers don't question their role in that system and think about their work as being apolitical. … it's easy [for] us [as engineers] to say, 'oh, well, I make more money than other workers around me as an engineer and I should be grateful of that, and I'm advancing the fields of science and technology, and maybe I'm even

protecting myself and my family, and my country, maybe, maybe I buy that rhetoric.' But it's easier to just think that it's apolitical, it's way easier to not even have to think about the bigger picture. But when you do that - when you, when you don't think about the bigger picture and you just start applying that labor, what happens? You get a paycheck and your paycheck might be a little bit better than other workers so you feel pretty good about yourself, but somebody else at the top just got super rich off of your labor. And when you do that labor again tomorrow, they get even richer and even richer. So it's in their interest to make sure you think your work is de-political."

Maria similarly described a separation of engineers from the moral and ethical consequences of their work and how that separation benefits corporate interests:

"… [to] face [engineers] with the thought that, you know, what they're doing actually has consequences when you consider them, they're gonna say 'that's not my job. I'm just the engineer, that's management, that's business, that's something else.' Because really, they're there to do this very specific thing. And the fact is, um, if you were to try to get them involved in all these other things, it's going to take away time from the main reason they're there. Which can harm their compensation, that can harm their involvement, it can harm their hiring later on. And so I really don't think that engineers are going to want to do something that isn't in their job description. And that benefits the company."

Thus, the participants were able to pinpoint ways that corporate interests maintained perceptions of depoliticization, meritocracy, and majorism that they identified in the engineering education environment.

Labor as a vehicle for change in engineering (theme 2)

Participants in the strike explicitly communicated organized Labor to be a mechanism through which changes in the field of engineering could occur. Valle, Bowen, and Riley (Valle, Bowen, & Riley, 2021) articulated an engineering and labor theory of change in which labor can be a vehicle for liberatory change in engineering and engineering education, particularly when labor unions engage a diversity, equity, and inclusion-centered organizing model.

Participants described the union as an entity they could use as an outlet for their politics and as a means to politicize their engineering education (subtheme 2a). The prevalence of the ideology of depoliticization in engineering serves to promote the notion that social and political concerns lie outside of the realm of engineering. Jon David described joining the union as a site for political work, describing himself as having a "strange perspective" for being an engineer seeking to engage in political work:

> "I think I have a little bit of a strange perspective because I came into [this university] immediately wanting to do like political work and I joined the union pretty quickly. Um, basically, as soon as I realized that you didn't have to be a GSI [graduate student instructor] to [join]."

Importantly, the strike participants saw the union as a means to make improvements to their material conditions (subtheme 2b). They described the union as an institution that has improved working and material conditions for graduate student workers, particularly relating to wages, healthcare benefits, and anti-discrimination policies. Matilda, for example, described the value of the union to working class students: "Without the union, the thing that makes working class students like me even able to pursue graduate studies … would be gone."

Richard described the impacts the union has on students' standard of living and an example of a union campaign for improved transgender health care led by transgender members:

> "… your standard of living has kind of been set by how much it is that the union has been able to push the university … One of the big wins that has … come out of the past three years has been … our trans healthcare coverage ... back in like 2017 … the university, pretty much said like 'go away, like this isn't something that should be in the contract,' … Now like I think our university has one of the best like trans health coverage plans in the nation (chuckles) … and that effort was led by trans folks. Right? So it was like people who are seeing this very like real, intimate problem that personally relates to them … are given a vehicle by which they can help solve that problem, not only for themselves, but also for other like other generations that are coming behind them."

In doing so, Richard frames improvements to material conditions as a result of power struggles between the union and the university, depicting the union as a means to engage in problem solving.

Participants discussed how the union was an institution capable of altering organizational conditions at the university and also how the union itself was a site for organizational characteristics to be altered (subtheme 2c). The organizing framework for advancing understanding about supporting underrepresented students in engineering developed by Lee et al. (Lee, Lutz, & Nave, 2018) demonstrated organizational characteristics as one of the key components of the context of students and their institutions. They described how organizational characteristics presented challenges for marginalized students and ways that organizational characteristics influenced how student support practitioners and the students they support operate within the institution.

Fundamentally, Aster described a form of power the union allows graduate student workers to access in relationship to university administrators: “I think that having the union is really powerful in that university setting because it forces [university administrators] to listen to us when not having that access would make it really easy for them to ignore us.”

Additionally, Jon David described how the strike was representative of the union itself shifting toward being more political in its orientation toward social justice:

> “Yeah, I'm, um at least doing this sort of thing [in striking] is it's more of… it’s more GEO is moving more towards what I sort of expected and hoped it would be when I, when I initially joined. Which is a broad organization that for sort of social justice, as well as bargaining for people that is like sort of used as a political instrument, um, more than just like very strictly a Labor Organization.”

In light of Lee et al.’s framework, the strike’s enactment of methods for instituting organizational change is a concrete example of the type of action that holds potential for greater underrepresented and marginalized student support within academia (Lee, Lutz, & Nave, 2018).

Engineers can be community organizers (theme 3)

Valle, Bowen, and Riley (2021) discussed the potential for engineers to be community organizers, leveraging concepts from whole worker organizing as a way to nurture a social community. Mondisa and McComb defined a social community as “an environment where like-minded individuals engage in dynamic, multi-directional interactions that facilitate social support” (Mondisa & McComb, 2015, p. 152).

The concept of whole worker organizing was repeatedly alluded to by participants (subtheme 3a). McAlevey discussed whole worker organizing as a recognition and leveraging of embedded social relationships that a person has in their workplace and community toward transformational change (McAlevey, 2018). Billie described how his involvement in the union began through his relationship with Richard, his friend, the sense of community he feels with other graduate workers through the union, and how striking provided a means to counter injustices:

> "It started primarily with my involvement through my [friend, Richard]. So he was the one that first initially got me involved, but what motivates me to continue [in GEO] is, um, I guess my sense of community with my fellow graduate students … graduate workers. I think it's important that, you know, we're here at the [this university] and we identify ourselves as individuals who are, um, workers and, um, [pertaining] to working here in this environment, we have a responsibility to speak out, um, and at least, you know, let ourselves be heard when it comes to injustices, where there … where there is a discrepancy with how things should be done from our perspective. And so **the strike was a, I guess, a structural tool** to navigate that and to voice our opinion."

Similarly, Maria described the personal interactions that drove engineers to strike and continue to stay involved:

> "So, like, if anyone in engineering was a part of the strike, I feel like it's because of the people they interacted with, that kept them there. Um not to say that people weren't generally interested on their own, but I think it would have been harder for them to give that much more time or energy or effort if there wasn't someone who they could believe in to stay and back them up."

These relationships between engineers at the human level thus constitute a vital component of the organizing process that impacts their ability to enact change.

Leveraging agency of la paperson's scyborg (la paperson, 2017), participants discussed actions that they engaged in and key conversations they had with others that resulted in increased participation in the strike (subtheme 3b). Billie described how communication with his research group and with other engineers developed solidarity that increased strike participation: "members of [my] research group and I all collectively decided to withhold our labor." He explained that they collectively discussed the issue and then brought it to their advisor, who was supportive. They felt a need to communicate with their advisor privately, directly, and honestly to maintain a positive future working relationship. Billie went on to explain:

> "I think the graduate students that I know who participated, it came from a sense of community. So if they saw their fellow peers, engineering peers, going on strike and going out there and voicing their opinion, they are more likely to join in. So, the sense of, you know, everyone's all in it together, solidarity, concepts like that, it's been one motivating factor."

Billie leveraged the institutional machinery of his research group, subverting its intended use to instead create a way to collectively withhold labor, acting in solidarity as a means to motivate others.

Participants discussed ways in which unions could be a means to fight for benefit to the wider community as a whole, instead of just the bargaining unit of the union, through the framework of Bargaining for the Common Good (BCG) (subtheme 3c). Bargaining for the Common Good seeks to organize with community partners to achieve this, particularly by centering racial justice in union demands, seeking to address root causes of injustice, and combatting "the role that employers play in creating and exacerbating structural racism in our communities" (Bargaining for the Common Good Network, n.d.). Bargaining for the Common

Good is a framework of union bargaining that centers race in analysis and strategy while expanding traditional notions of participants, processes, and purposes of bargaining (McCartin, Sneiderman, & BP-Weeks, 2020). In an attempt to embrace of this framework, Matilda described how her participation in protests against police brutality drove her to propose including the policing-related demands on the strike platform:

> "I was very upset that, at the … general membership meeting, that the discussion over why we were going on strike was all COVID concerns when I had been marching with people in Ann Arbor and Ypsilanti … [who were] planning demonstrations against police violence … I had traveled to Detroit to participate in the … Detroit Will Breathe demonstrations. Those were extremely moving experiences for me and given - given the fact that national discourse was so centered, at the time of George Floyd's murder, around policing and discrimination-related state institutions, it seemed like an absolute waste of an enormous opportunity to improve conditions for the most marginalized people that we are now seeing were even worse than we thought they were. … So I called in that general membership meeting for the addition of policing-related demands in support of people of color at the university to be added … to the strike platform. That got enormous support immediately from the general in the rank and file membership, even while [some members] continue[d] to hedge. It - when, uh, the vote ended up taking place, it overwhelmingly passed. Because there was [so much] support for policing demands from the people of our union."

Matilda indicated that the strike presented an opportunity to leverage the power of the union towards racial justice as a communal benefit. Also looking at the strike through a lens of power, Richard discussed power dynamics at play between the union and the university while also framing the importance of the demands for the benefit of the entire community:

> "… I think the driving factor for me [to participate in the strike was] … trying to have the university … administrators in particular, cede some of their power. But yeah, I think like the actual common good elements of the demands were particularly important, especially for like … with the policing, like, certainly, but I guess also like in the way that the COVID demands were articulated around like … this is really kind of for the safety of the entire community."

Building a sense of community, helping engineers move into shared struggle, and engaging in work for community benefit are all components of community organizing participants exhibited.

Strikes as opportunities for liberatory pedagogy (theme 4)

Valle, Bowen, and Riley (2021) argued that strikes can be understood as opportunities for liberatory pedagogy in engineering education. Strikes can provide an opportunity for students to engage in transformational resistance, which Solórzano and Delgado Bernal describe as "student behavior that illustrates both a critique of oppression and a desire for social justice" (Solórzano & Delgado Bernal, 2001, p. 319). In doing so, strikes also allow engineers to engage in divergent thinking, also called idea generation (Daly, Mosyjowski, & Seifert, 2014). Divergent thinking has been shown to not be well represented in engineering education, where convergent thinking, or digging deeper into ideas, is generally more heavily emphasized.

Participants discussed the strike as an outlet for political action (subtheme 4a). They indicated a broadly felt anger around inadequacies in the university's COVID re-opening plan and a need for local action in the wake of Black-led uprisings and rebellions for racial justice following a series of killings of Black people by police. Jon David described these political motivations for engineers to participate in the strike: "… lots of engineers … have grievances with their departments, … have issues with how the school's [operating], and as well as just have political commitments that they were um, sort of interested in seeing with[in] … the strike."

Like Jon David, Billie described the strike as a politicizing action, framing it as a moral responsibility around recognizing that what the university administrators were doing was wrong and choosing to act against it:

> "I think [a motivating factor for engineers to participate in the strike] is kind of like a sense of moral responsibility, so I felt like a lot of folks knew that this was the right thing … to do. Like they knew that the university is wrong, and they knew that they weren't doing enough, and it was their responsibility to speak up about it. And that to be silent was … to be silent was to be, like doing the wrong thing."

Finally, participants reflected on forms of learning that they experienced by participating in the strike (subtheme 4b), highlighting forms of pedagogy, education, and experiences that were not otherwise prevalent in their engineering education.

Billie described how his participation helped him recognize systems that reinforce hegemonic power structures:

> "I think that this is my first time in part of an organized action against the university and I think I recognize just how much power the university does have, um, over its employees and no matter what [the university may] say to the press or, you know, [through] emails to folks … Their actions really speak louder than their words and it really does show that … if you do have the power to enforce like or just activate legal measures it … like really puts a, like **handcuffs the folks who are trying to, um, speak out**. So there are, I do

think it's … the laws really do make it difficult for people in general to, um, let themselves be heard in an organized fashion, I'd say."

In countering these existing structures of power, Matilda discussed the sense of fulfillment another engineer expressed regarding their strike participation, contrasted with the lack of fulfillment from their technical engineering work:

> "We can actually change the world. And people talked about that in … these conversations that we had …'I've been a graduate student for five years and this is the first time I've ever felt like I've actually done something fulfilling with my time,' people would make comments like that. And those comments are both inspiring and also a little bit sad, that like the de-politicization of engineers is making them feel like that … they're making them feel like that or making them do work that isn't fulfilling."

Participants showed that the action of striking helped them to align with their morals, better understand power structures, and gain a sense of fulfilment.

7.2.6 Discussion and Future Directions

Emergent themes from this narrative analysis tentatively support components of the engineering and labor theory of change, including that engineers can use their positionality for community organizing and improvements to the common good and that strikes can be a form of liberatory pedagogy in engineering spaces. These data support the existing understanding of the effectiveness of community organizing (Freire, 1970); (Horton, 1998); (Ganz, 2008). This work also makes a contribution to the literature on depoliticization, meritocracy, and majorism, illustrating how these phenomena impact efforts to equitably change the material conditions in and around the neoliberal universities.

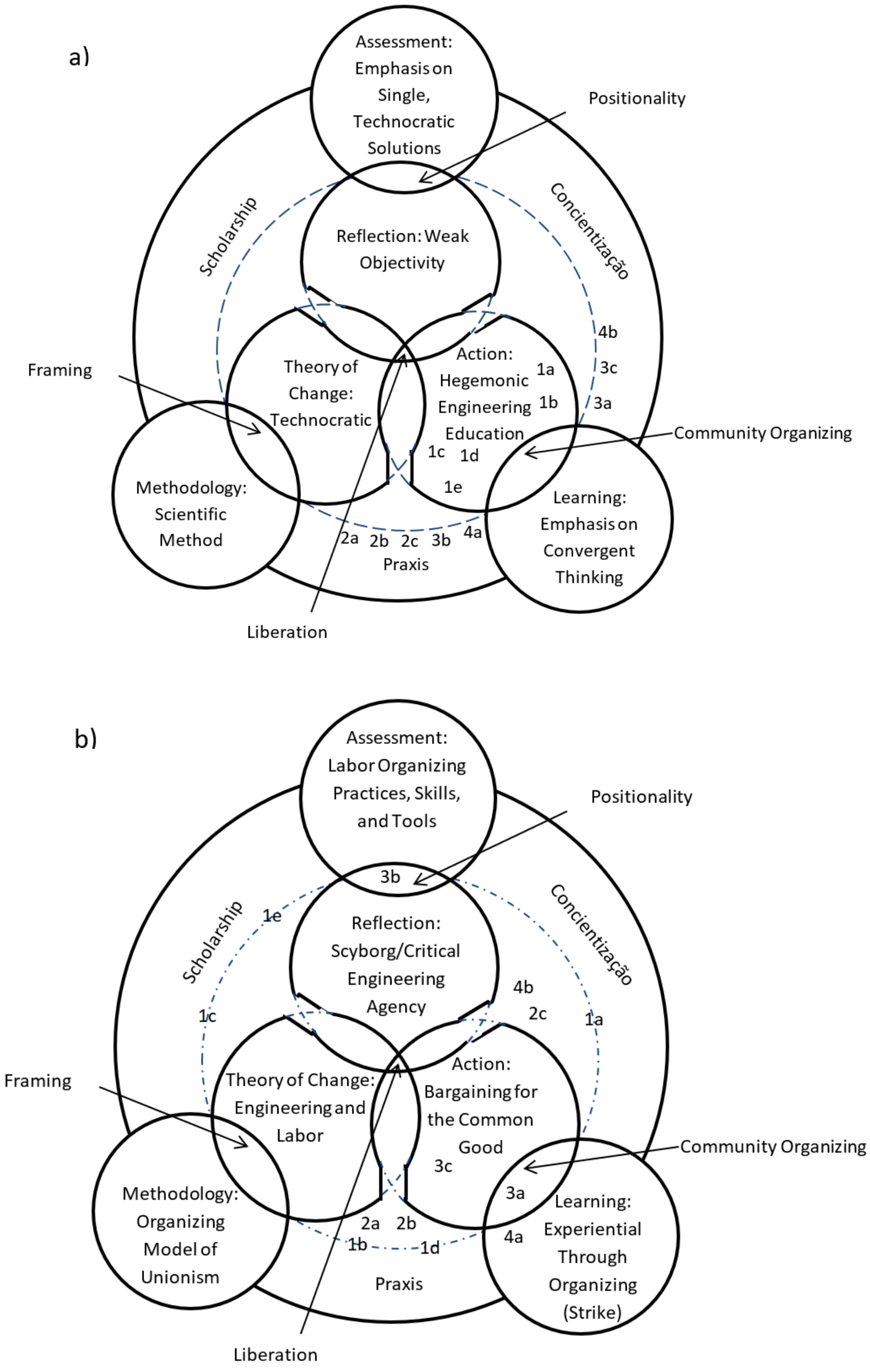


Figure 35: Mapping of subthemes onto the liberatory engineering education model proposed in (Valle, Bowen, & Riley, 2021) using a) the technocratic theory of change, where themes sitting outside of the dotted thin blue line are blocked by constructed barriers, and b) the engineering and labor theory of change, where themes sitting along the dotted thin blue line constitute constructed barriers.

In Figure 35, we map the emergent subthemes onto versions of the liberatory engineering education model using the current, technocratic theory of change (Figure 2a), and [an] engineering and labor theory of change (Figure 2b), both of which are discussed in greater depth in (Valle, Bowen, & Riley, 2021). In doing so, we can see that the subthemes relating to theme 1 around dominant ideologies operating within engineering education fit within the action (learning method) of the current, hegemonic form of engineering education, while they serve as a barrier to engaging in scholarship, praxis, and/or concientização toward liberation in an engineering and labor theory of change. The nature of themes 2-4 pushing up against the constructed barriers in the version of engineering education utilizing a technocratic theory of change is indicative of risk in participating in the strike. Alternatively, a version of engineering education utilizing an engineering and labor theory of change allows for some reduction of the constructed barrier size and salience, reconfiguring engineering education to allow subthemes from themes 2-4 to become more normalized within engineering.

Future directions for this work include:

- Further analysis of the remainder of the 15 interviews to construct a collective story, building on the themes emerging from this work-in-progress paper.
- Meet with participants to discuss the themes that emerged from analysis, gather their input on the theming, development of a collective story, and conclusions, and address how their role in this study can be more fully recognized and credited.
- Increasing understanding of how Labor can be a means of intervening in the ideologies of depoliticization, meritocracy, and majorism on the neoliberal STEM campus. How can the lenses of Labor and theories of change allow for exploration of the interrelations of these three ideologies?

A focus on engineering labor through the lens of abolitionist labor organizing and labor unions can help engineering educators and engineering education researchers rupture notions of professionalism within dominant engineering, alleviating some of the difficulties engineering labor organizers face in organizing engineers due to dominant ideological constructions in engineering, and expanding the horizons of hope through different theories of change. The work of bringing that about is deeply relational and life affirming, yet requires engineers, engineering educators, and engineering education researchers to overcome the political distance placed between engineering and labor. Pragmatically, the neoliberal catchall of DEI has offered some cover for this over the years, however more explicitly resourcing labor and community organizing and training is a means for this work to grow. It is with this in mind that I came to work on the Undergraduate Engineering Collaborative Growth Series (UECGS) discussed in chapter 8.

Chapter 8 UECGS and Life Affirming Technologies

8.1 The Undergraduate Engineering Collaborative Growth Series (UECGS)

Over the years Corey and I had worked together as a couple of GEO's lead organizers in engineering and had become good friends. I had seen her transition into EER after difficult experiences in her own department, doing so about a year before I did. She would tell me about how different the classes were compared to the sort of technical engineering classes we'd been used to and started sending some EER readings over to me. Erin Cech's DEI seminar gave me a starting point for reading EER papers that critiqued dominant engineering culture, and the papers and books Corey would send me started giving me even more of a sense of how EER allowed for making the problems I and many of my friends had been facing in engineering studyable. One of the ways I had been navigating those problems as part of SFTP, GEO, and the Society of Hispanic Professional Engineers (SHPE) was working with folks in those groups in collaboration with others to coordinate and co-facilitate workshops centered around building collective power amongst engineers. The meeting with departmental administration described in chapter 6 pushed me to get involved in SHPE to strengthen my connections with other Latinx engineers. It has been difficult for our department to recruit Latinx graduate students and faculty to begin with, compounded by a departmental structure that was not designed to meet our needs and refused to do so when asked. So I resolved to teach ways for us to build the infrastructures necessary to meet our needs.

As I transitioned into EER with Prof. Sakamoto's support and RMF funding, an opportunity to apply for a DEI faculty grant presented itself as Corey was putting together a qualitative study on barriers faced by multipli-marginalized undergraduate engineering students as a follow up to a quantitative study she'd led alongside Dr. (now Prof.) Aaron Johnson and Prof. Ken Powell (Bowen, Johnson, & Powell, 2020). All of the workshops I and others had been putting on had been unpaid labor, so when Corey asked me to help turn the qualitative study into a workshop series that could actually see folks paid for their DEI labor I jumped at the opportunity. It also made me recognize the labor I was doing was DEI GSSA labor, which made it particularly upsetting that the University admin had refused to increase the number of DEI GSSAs. I had brought them up at a CoE DEI event when an administrator from another college was brought in to discuss DEI efforts there. When their presentation was over, I asked whether they had ever considered compensating students (admin had the state characterizes us as students, not student workers, so that our union would not be legally recognized). They responded that they had not thought of compensating students for their DEI labor before. That interaction became a motivating factor for us seeking college funding to begin doing so.

Corey's existing relationships in EER helped her reach out to Prof. Joi-Lynn Mondisa, who agreed to be a consultant for the workshop series. We describe the format of the series, including where we used Ganz's storytelling method (described in chapter 4) as well as some of the practices we learned as labor organizers (described in chapter 7), in *"The Undergraduate Engineering Collaborative Growth Series": a Diversity, Equity, and Inclusion Program Supporting the Empowerment of Marginalized Students* (Bowen, et al., 2021).

8.1.1 Introduction

This workshop series for marginalized engineering students took place within the engineering college at a large, prestigious research university in the Midwestern United States. In a prior quantitative study, some of the academic circumstances that hinder working class students and students of color at this engineering college were identified, including underrepresentation, lower likelihood of graduation, increased time to graduation, and lower grade point average (Bowen, Johnson, & Powell, 2020). One purpose of this series was to better understand factors that influence these circumstances from the perspective of marginalized students. It is necessary to identify these factors in order to address the sources of the problems at their roots, rather than enacting reactionary initiatives that label marginalized students themselves as the source of problems (Love, 2019). Additionally, the authors sought to design a program for marginalized under- graduate engineering students to support their ability to build agency toward the enactment of constructive changes to the educational system. To address these dual purposes, a team of graduate student and faculty researchers designed a series of events framed around the Theory of Liberation, titled the "Undergraduate Engineering Collaborative Growth Series" (UECGS), which took place in four installments over the course of the 2020- 2021 academic year. UECGS was funded by an internal faculty grant from the engineering college focused on efforts to expand diversity, equity, and inclusion (DEI). This paper will focus primarily on the methods used to design and implement UECGS, a practical framework which the authors believe is transferable to a wide variety of institutional settings. We will highlight the intentional use of critical and liberative perspectives in the development of the research methods.

8.1.2 Theoretical Frameworks

Paulo Freire is considered to be one of the founders of our modern understanding of critical theory (Kincheloe, 2004). His "Pedagogy of the Oppressed" (Freire, 1970), originally published in 1968, is a manifesto of educational empowerment to resist capitalistic and colonial oppression. In this work, Freire outlines the concept of conscientizac¸ ˜ao, or critical consciousness, the learned ability of individuals to recognize systemic oppression as it exists within society, and the vital role of education in fostering and developing it (Freire, 1970). Over time, scholar-activists have built on the principles of Freirean critical theory and applied them with a focus on other bases of oppression; critical race theory (Delgado & Stefancic, 2017), (Ladson-Billings & Tate, 2016), radical feminism (hooks b. , 2000), (Arvin, Tuck, & Morrill, 2013), and queer theory (Kumashiro, 2003) focus on experiences of oppression on the primary bases of race, gender, and attractivity, respectively. Using the framework outlined by Bowen et al. (Bowen & Johnson, 2020), the Theory of Liberation is an umbrella theory encompassing all critical theories regardless of foci. As Robin D. G. Kelley wrote,

> "You've got to be able to cross those lines of race, gender, sexual identity, sexual orientation - not to erase those lines or pretend they don't exist but, on the contrary, make them hyper-visible. Radical empathy means working across identity lines by making them hyper-visible in order to recognize specific struggles that people on different sides of those lines experience. This recognition is fundamental for any change" (Tuck & Yang, 2014, p. 94).

Donna Riley (2003) has previously discussed the application of liberative theories in an engineering pedagogical context as a means of helping students identify existing oppressive structures. Agency, however, is a necessary precursor in order to enact change. Allison Godwin defined critical engineering agency as "a student's perception of their ability to change their world through everyday actions as well as [their] broader goals in life" (Godwin, Potvin, & Hazari, 2013, p. 3). UECGS seeks to support students' collective development of critical engineering agency toward change as well as to introduce students to the concept of change theory. Tuck and Yang have defined theories of change as "belief[s] or perspective[s] about how a situation can be adjusted, corrected, or improved" (Tuck & Yang, 2014, p. 13). As an educational program, UECGS applies liberative pedagogy (Riley D. M., 2003) as the theory of change for disrupting oppressive structures within engineering academia.

8.1.3 Positionality

The first two authors [Corey & Joey], as multipli-marginalized engineers themselves, developed UECGS by leveraging lessons from the labor and community organizing experiences they have had during their graduate education. Bowen is a cisgender, heterosexual white woman from a working class background, and Valle, who is queer, is mixed Latinx/white and also from a working class background. They note that UECGS is an attempt to construct a form of engineering education that would have felt more life-affirming than their own experiences in undergraduate and graduate engineering studies. Faculty collaborators, Mondisa, Johnson, Sakamoto, and Powell, provided support in shaping the series and obtaining funding.

8.1.4 Methodology

In the implementation of UECGS, we attempt to engage in a praxis of liberative pedagogy by making space for participants to raise their critical consciousness. We thus apply the Liberatory Engineering Education Model (Valle, Bowen, & Riley, 2021) as the methodology for the creation of UECGS. This model combines Mejia et al.'s Freirian critical consciousness model (Mejia, Revelo, Villanueva, & Mejia, 2018) and Hassan's learning-assessment interactions model (Hassan, 2011) to visualize pathways through which liberative efforts can be realized despite barriers imposed across domains of power. Using this model, we can construct pedagogical components that combine to reduce the salience of these barriers. The application of the Liberatory Engineering Education Model to this project is shown in Figure 36. As shown in Figure 36, we employ participatory action research as the methodology of UECGS itself. As described by Israel et al., participatory action research has five key components: “It is participatory ... It is a cooperative and co- learning process ... It is a reflective process ... It is an empowering process ... It achieves a balance between research and action goals and objectives” ((Israel, Checkoway, Schulz, & Zimmerman, 1994, p. 163). In accordance with this methodology, the research intends to co-create knowledge between both the researchers and the participants and invoke cooperative, constructive action that builds toward change. UECGS was formatted as four two-hour workshops with optional feedback and coaching sessions between the work-shops. Engineering graduate students were recruited to serve as facilitators and note takers in focus groups at each of the workshops. All programming was held virtually due to the COVID-19 pandemic. The following subsections describe each component of the series. Table 16 outlines the components of UECGS and maps their connections to the Liberatory Engineering Education Model.

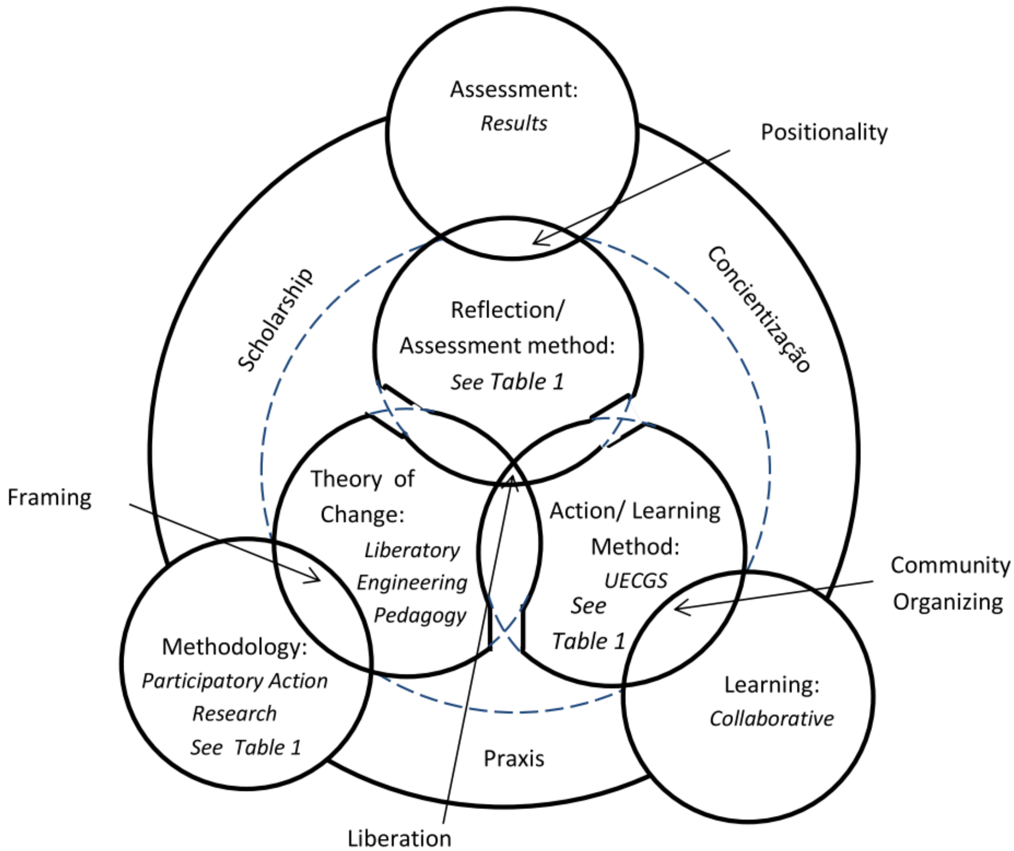


Figure 36: Mapping of UECGS within the Liberatory Engineering Education Model (Valle, Bowen, & Riley, 2021).

Table 16: Methodological Approaches Utilized in Each Component of UECGS and Connections to the Liberatory Engineering Education Model (Valle, Bowen, & Riley, 2021).

Event	Methodological Component	Learning Method	Assessment Method
Workshop 1	Focus Groups Collective visioning exercise	Naming and hearing lived barriers Naming and reading collective visions	Notes and reflections Collectively-written document
Workshop 2	Individual worksheets Focus groups Concept mapping post-workshop	Naming connections between existing theories and personal goals Discussion of connections made Aligning workshop content with participant needs	Worksheet data Notes and reflections Jamboard
Workshop 3	Individual worksheets Focus groups	Developing personal and public narratives Sharing and feedback on personal and public narratives	Worksheet data Notes and reflections
Workshop 4	Individual worksheets Focus groups	Developing pod and power maps Sharing and feedback on power maps	Worksheet data Notes and reflections
1-on-1s	Critical conversations	Sharing, active listening, and reflection	Recordings and reflections

Workshop 1: Student Experiences and Collective Visioning

The first event of the UECGS took place in October 2020. The central activity was focus groups with collaborative, facilitated conversations on the following topics: belonging, recruitment and outreach, institutional DEI efforts, the classroom environment, mentoring, and conflict resolution. The participants had previously been asked to rank the six focus group topics in their order of preference. Students were put into these focus groups via Zoom breakout rooms with the goal of naming barriers they perceive and experience as well as harms they have experienced resulting from those barriers. The facilitators provided framing questions as needed to keep the flow of ideas coming and encouraged participants to build on each others' statements. They also encouraged participants to utilize online collaborative Google Jamboards, in which students could write notes, draw or paste pictures, or share anything else they wanted to. After two thirty-minute rounds of focus groups, the students came back into the main Zoom room and engaged in a collective visioning activity. Working from a Google Doc, the students wrote statements that they believed were false but wished would become true about the reality of society within engineering. These statements built up rapidly into a bulleted list. The students were also invited to add in sub-bullets below each statement with questions that would need to be addressed and/or directions that we would need to move in as an engineering community in order to bring the vision into reality. This exercise served as a means to envision, prefigure, and theorize an experience that was better fit to engage the students' whole selves into the field of engineering (hooks b. , 1994).

Workshop 2: Theories of Change

The second workshop introduced participants to several theories of change. For each theory, an example was provided of how student movements at the students' university had previously utilized that theory and what tangible changes resulted from that movement. Participants then began formulating methods of applying these theories of change to their current educational environments. They moved into focus groups to connect a particular vision or goal, which they could select from the visioning results in the first event or construct themselves, to the theories of change presented. Participants were also asked to brainstorm skills or tools they would like about to learn about in order to feel more prepared to enact theories of change. Workshops 2 through 4 also incorporated mood analysis. In each workshop, participants were asked to describe their mood using Brackett's Mood Meter as they entered the workshop and as they were left (Brackett, 2020). This provided a way to gauge empowerment by comparing the feelings participants were bringing with them into the space to those they left with. Documented mood shifts could be used as a tool to provide rapid feedback to facilitators and organizers planning future events.

Workshops 3 and 4: Tools for Change

The participant responses about necessary skills and tools from the second workshop directly informed the content of workshops 3 and 4. Bowen and Valle performed thematic analysis on member-checked notes from the second workshop, then performed a mapping exercise to connect interrelated themes in order to determine the content of workshops 3 and 4. Thus, workshops 3 and 4 were used to provide students with an introduction to, examples of, and practice with skills and tools that aligned with their stated needs.

1-on-1 Feedback and Coaching Sessions

1-on-1 feedback and coaching sessions took place between the workshops. These sessions were recorded with both video and audio, so it was stressed to participants that it was optional to participate. Participants chose to meet with either Bowen or Valle, and conversations were unstructured, revolving around participants' personal experiences and organizing goals. These sessions were scheduled at one hour in length, but in practice lasted between 30 minutes and 3 hours. The sessions served to provide additional support to students as desired by further situating UECGS within their experiences in the engineering college.

8.1.5 Methods

In accordance with the application of critical and liberative frameworks, it was imperative that the event allow the student participants the opportunity to build power collectively, rather than maximize the power and control of the researcher. For this reason, the faculty members on the research team did not attend the events, the events were hosted using a Zoom for Healthcare platform, which does not record video or audio, and the identities of participants are not known to the faculty members on the research team. These methods were employed in order to reduce structural barriers that could prevent participants from feeling comfortable sharing their experiences. Because the event was not recorded, note-takers were employed to document the conversations within the focus groups, which serve as a major component of the qualitative data. The events were facilitated by Bowen and Valle, and focus group facilitators and note-takers, henceforth referred to as the facilitation team, were graduate students from the engineering college.

The facilitation team and participants were financially compensated for their labors on this project, in recognition that student DEI work is labor which is frequently rendered invisible (Mercer-Mapstone, Islam, & Reid, 2021). Sharing experiences about harm, be it systematic, institutional, interpersonal, or internal, is an ask for emotional labor, so students must be compensated for that labor with liberative frameworks in mind. Participants in UECGS were compensated $15 per hour for the duration of the events in the series (including any 1-on-1 sessions they attended), and the facilitation team members were paid $20 per hour for their time at the events, for their individual preparation, and for approximately two hours of professional training before the start of UECGS. A professional facilitator was hired to provide the training.

Participant Selection

Institutional Review Board approval for the embedded studies was obtained from the institution at which the research was conducted. UECGS was advertised via email through the researchers' existing channels within the university, which included participants in a liberative event organized by a team of graduate student volunteers including Bowen and Valle, identity-based engineering student groups on campus, and a daily newsletter sent out to the student body from the engineering college's student affairs office. Advertisements included a link to an electronic intake form. To communicate the researchers' desire to recruit marginalized students, the form stated, "we are looking for participants with at minimum one of the following identities: women or non-binary, people of color, family background less than approx. $100,000 per year, LGBTQ+, or other marginalized identity." The intake form contained the following items:

- Name and email address
- Engineering department and year within program
- Gender, ethnicity, race, and sexual orientation (short- answer text response)
- Annual family income (multiple choice options: less than $50,000, $50,000-$100,000, $100,000-$150,000, or above $150,000)
- "Do you have any needs of the space such that you can feel safe engaging with this material? (This can include needs regarding other people's attendance impacting your safety. If such a need arises, we will figure out how to best meet your needs on a case by case basis.)"

- “Some of this material may evoke strong emotions for participants. If an exercise becomes difficult for you to handle, what are your needs from facilitators?”
- “Do you have any accessibility needs you would like us to know about?”
- “Is there anything else you would like the graduate student researchers to know?”

The self-reported identities of the applicants are shown in the left-side pie graphs in Figure 37. In this data, we have grouped the short-answer responses of students’ race/ethnicity into the categories shown, and we followed up with the students individually in cases in which we were unsure.

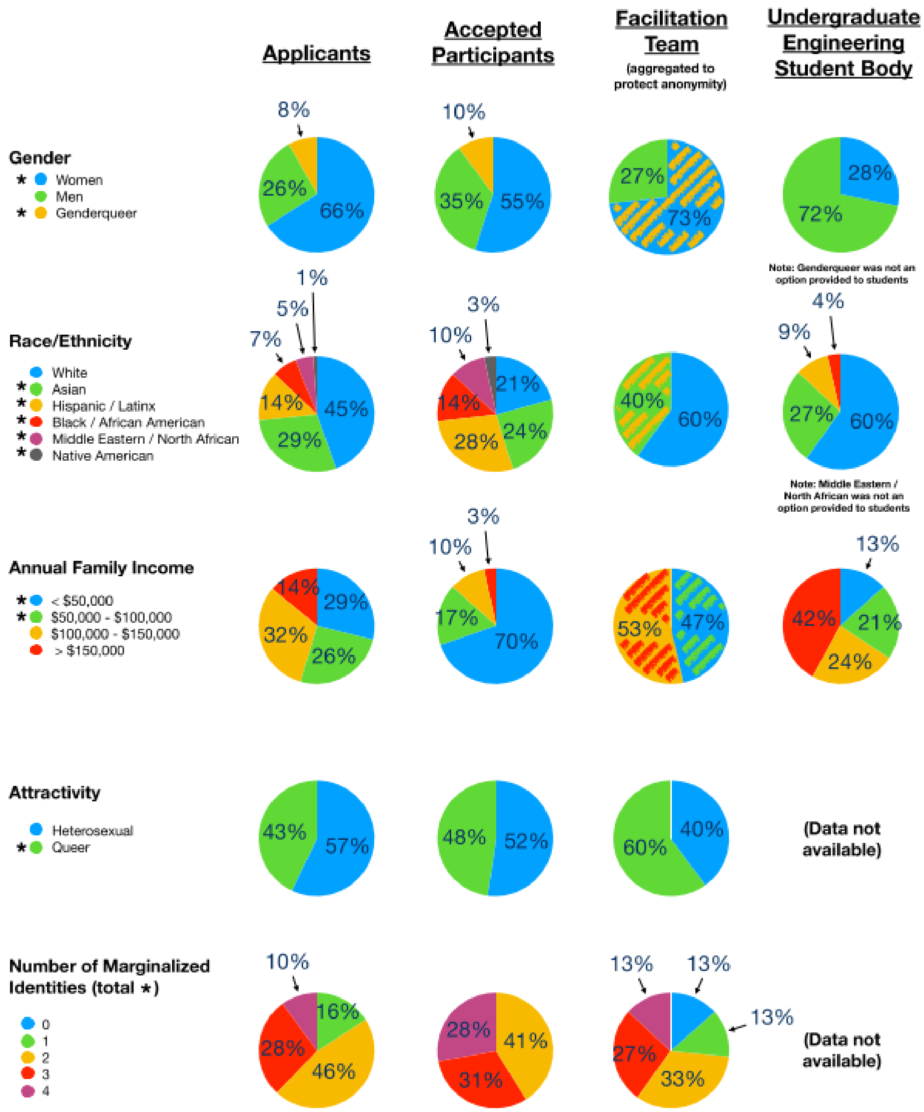


Figure 37: Demographic composition of UECGS applicants, accepted participants, graduate student team, and undergraduate student body within the engineering college (Bowen, Johnson, & Powell, 2020).

Table 17: Framework for a quantitative engineering student marginalization index (empty boxes had no points awarded).

Identity Aspect	1 Point	1.5 Points	2 Points	3 Points
Gender	Woman		Genderqueer	
Race/Ethnicity	Other non-white		Hispanic/Latinx	Black / AA or Native American
Annual Family Income		\$50,000 - \$100,000		Less than \$50,000
Attractivity	Queer			
Year	5th year +			
Ability	Disability			

It was decided by the research team and graduate student facilitation team that there should be approximately six participants in each of the six concurrent focus groups. We worried that larger focus groups might negatively impact student comfort and collaboration. In case more students applied than our team could accommodate, we developed a framework to quantify marginalization to prioritize multipli-marginalized student participation. The framework is detailed in Table 17. Each applicant is assigned a total marginalization index by summing the point contributions from each aspect of their identity shown in the table. The numerical values attributed to each identity are determined based on the quantitative results in (Bowen, Johnson, & Powell, 2020). For example, the results indicate that Black/African American students and students from families making less than $50,000 a year are especially hindered in academic outcomes at this engineering college, so these two groups are assigned the maximum of three points in the marginalization index. In the case of students whose answers were linked to multiple racial/ethnic categories, the one that is rated the highest number of points in the marginalization index is assigned.

As shown in Table 17, one point was awarded to applicants who identified as having a disability, either physical or mental, although this was not explicitly asked in the intake form. The researchers added one point to an individual's marginalization index if they self-identified as having a disability in their answers to the long-answer text questions in the intake form.
It is fully recognized by the researchers that a quantitative analysis of marginalization is inherently extremely problematic, as students' experiences with oppression cannot and should not be reduced to a single numerical value. However, this task is undertaken in order to prioritize the participation of students who are multipli-marginalized. We also note that a similar

marginalization index was utilized by Settles et al. in (Settles, et al., 2019). The authors do not intend to use this marginalization index in any analyses of data collected at UECGS events.

Facilitation and Note-Taking

The facilitation team was recruited from current graduate students in the engineering college known to Bowen and Valle. A diverse group of students with a variety of experiences in education research and/or advocacy work were asked to support the research in paid roles. 13 graduate students agreed to participate. Of the group of 15 graduate students, including Bowen and Valle, 11 identified as women or non-binary, 6 were non-white, 9 were queer, and 7 grew up in households with annual incomes of less than $100,000 per year. Pie charts showing the demographic distribution of the graduate student team in comparison with those of the study participants and engineering college undergraduate student body are shown in Figure 37. Note that some facilitator demographic information has been aggregated in order to protect anonymity, and annual family income of the facilitation team is self-reported income level when first applied for undergraduate study. Participants are students who attended at least one of the four workshops. From Figure 37, it can be concluded that the facilitation team, while very diverse compared to the overall undergraduate student body, was not as diverse as the selected undergraduate participants.

The graduate student facilitation team first completed the required Human Subjects Research Protections course through the university's Office of Research Ethics and Compliance. They were then professionally trained during a ninety-minute session led by Vidhya Aravind, the Learning Director of We the People - Michigan, whom Bowen and Valle employed due to her extensive experience both conducting and teaching effective facilitation. The training covered topics such as grounding, vulnerability, agency, honesty, multipartiality, and active listening.

Also within the training, the graduate students worked collaboratively preparing potential facilitation questions for each of the six focus groups in the first workshop. The formalized facilitation training was imperative to ensuring the creation of inclusive, equitable, and constructive spaces within focus groups.

Member-Checking

Member-checking with the participants was employed at various stages in the research, including live-checking during note-taking and approximately a week of open review of the notes after the event. This member-checking process was meant to ensure that participants' identifying information had been adequately anonymized and that the data collected was reflective of what the participants intended it to represent (Creswell & Miller, 2000). Students did choose to participate in the member-checking process, clarifying their statements and deleting details that had the potential to identify them. Follow-up emails were sent to individual participants referring to questionable sections and statements within the notes in order to ensure adequate anonymity as determined by the participants.

Once Bowen, Valle, and all the participants were satisfied with the anonymization, participants' names were switched to pseudonyms they had selected and all the data was copied and pasted into a new document with no file history. Only then were the faculty researchers allowed access to the data. Through this open and transparent process, the researchers are confident that the notes are accurate portrayals of participants' statements during the event and that risk to the individual participants is minimized.

8.1.6 Results and Discussion

Participant Selection

The research team's goal was to secure about 30 participants in UECGS, but 90 students filled out and submitted the intake form within only a few days of advertising. We feel that this is an important research result in and of itself. Given the goals of UECGS as articulated to students via the intake form ("the researchers are seeking to better identify the barriers faced by marginalized undergraduate engineering students and provide trainings to equip students to work collaboratively towards change"), we conclude that there is immense desire within the student body for greater agency in enacting student-driven structural change within the engineering community.

Of the students who submitted the UECGS intake form, the average marginalization index was computed to be 3.43 with a standard deviation of 1.65. Based on programmatic capacity, we had to limit the number of participants admitted into the program. Therefore, we chose to admit students who had an index score greater than or equal to 4.00, which resulted in 38 admitted students. Of these students, 31 completed the consent and preparation process and participated in at least one workshop. The demographics of the admitted students who participated in at least one workshop are shown in the pie charts in Figure 37. The last row of pie charts shows how many marginalized aspects of identity are attributed to a student, which are labelled with an asterisk in the figure. For example, a Black, working class, LGBTQ+ woman is defined to have four marginalized identities as shown in this pie chart. From these results, we conclude that our marginalization index was effective at prioritizing the participation of multipli-marginalized students.

Data

In this section, we provide examples of some of the data produced in UECGS. The complete dataset will be analyzed in future research. The visioning exercise at the end of the first workshop established a collective ideal of participants' desired world. While the students only had approximately five minutes to ideate, ideate, they filled over three pages with thoughts on their collective vision. Examples of statements generated include:

- No one associates my feelings to any extremes because of my race
- No one assumes I got into a competitive college because of my minority status
- End of cisnormativity
- We have emotionally intelligent students and professors who do not shame or judge people
- Mental health is a real thing with real consequences
- I don't feel like I'm not doing enough if I'm not extremely stressed out all the time
- I feel validated and proud of my academic accomplishments, and prepared for my future after graduation, without comparing myself or competing against other students
- Money shouldn't impact education
- I feel as though my voice and ideas are worth being heard
- People no longer search for a sense of purpose - they naturally know it

During the second workshop, after connecting components from their collective vision to theories of change, participants identified skills and tools they would need in order to feel more confident working toward the enactment of their vision. The research team then mapped these skills and tools, which are represented by the yellow bubbles in Figure 38. They noticed that these items mapped broadly into three categories, storytelling, power-mapping, and first-step organizing, and that the use of the first two of these categories (green bubbles) would help effectively accomplish the third (blue bubble). Thus, the third and fourth workshops were designed to build participants' comfort and skill with the organizing tools of storytelling and power-mapping, respectively.

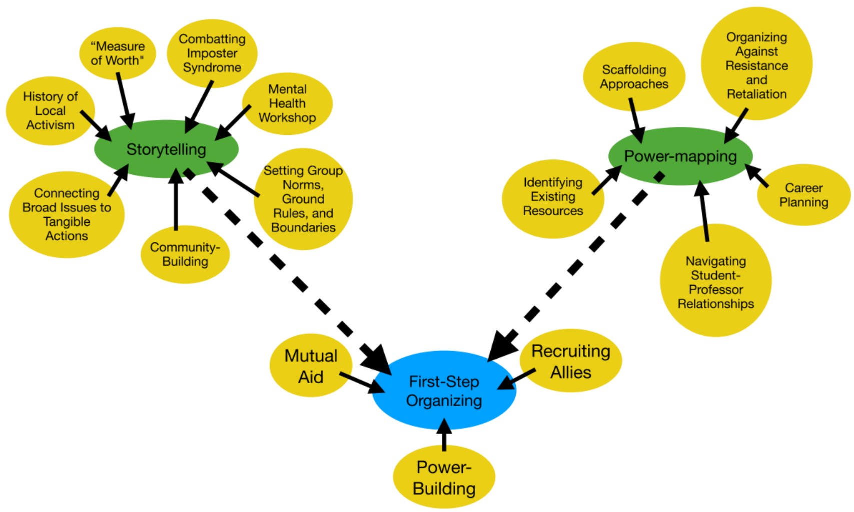


Figure 38: Graphical depiction of analysis of workshop 2 results.

In the final workshops, participants were first introduced to the concepts of storytelling, "the art of translating values into action through stories" (We The People Michigan, 2018, p. 29), and power-mapping, the placement of various actors based on their likely stances pertaining to the organizing goal. Valle shared examples applying these techniques to his own personal experiences and organizing goals. Participants were then provided time to work individually on worksheets that, along with the notes taken by the facilitation team, constitute the data collected for the research from these two workshops. Developed from the work of Ganz, the worksheets provided scaffolding through which the participants developed their own personal narratives (also called stories of self), public narratives (also called stories of self, us, and now), and power maps (We The People Michigan, 2018). Then, the participants shared their stories, organizing goals, and power maps within their focus groups and provided constructive feedback to one another. This gave them practical, tangible opportunities to build confidence around their abilities to organize for change within the engineering community. As an example of an individual's work within the final two workshops, we introduce Stephen, a trans woman of color from a low-income background. In her story of self, Stephen shared that she was raised by strong feminists but had grown up with a male point of view. She saw the action of coming out as trans as intimately connected to her personal value system. Upon developing her public narrative, she articulated the point that male engineers, who currently dominate and control engineering spaces, needed to stand up for gender equality within the field, thus referring to the agency of these already powerful actors. However, upon developing an organizing goal later in the workshop, she wrote the following scaffolded responses (her words italicized):

> We are organizing (who/your constituency): *Women and allies in STEM*
>
> To Achieve (what strategic goal): *Gender equality in STEM*
>
> By (how/your theory of change): *Having the older generation establish an equality-based culture that then the younger generations will absorb and develop. Concrete examples: equality seminars required for [graduate student instructors], media portrayals of smart, powerful women in stem, more female professors*

As shown by her organizing goal, Stephen's focus had transitioned. She began the workshop thinking to ask those with social power to behave differently, but she ended it with a goal of empowering those who, like her, were directly affected in negative ways by the current reality to directly change that reality. While building solidarity-focused relationships with other multipli-marginalized students, she had successfully begun to formulate methods for action. Stephen's results are similar to those of other participants, who each had unique perspectives on their organizing goals. However, the participants expressed interest in supporting one another's goals with collective action as they worked toward building a better future for themselves and their peers.

8.2 Coming Out (A Nucleation Site)

In the first UECGS event, TGNC participants brought up the (mis)use of pronouns in engineering classroom environments and ways that contributed to (a lack of) belonging. Dax, a queer, white, non-binary participant, explained how:

> "[At the] start of the class[, professors would say]: ladies and gentlemen or his or her. [During class, the] professor will start with his, and correct to say his or her instead of they. [To shift this behavior, a] need [exists for] a non-negligible amount of students who are non-binary [and other people] who notice it- They can put pronouns in zoom and still [be] called the wrong pronoun. [This] happens with professors too. [I had] never been asked in an engineering class (prior to Covid) about pronouns, or stating pronouns [in class] when introducing themselves. It's still not normalized at all."

Dax described what Z Nicolazzo, a transgender higher education reseacher, identified as gender binary discourse (Nicolazzo, Just go in looking good: The resilience, resistance, and kinship-building of trans* college students, 2016); (Nicolazzo, 2017); (Haverkamp, Bothwell, Montfort, & Driskill, 2021). Z Nicolazzo described gender binary discourse as one of the three primary forms of everyday obstacles for TGNC students along with sex segregation and gender bashing. Z Nicolazzo discusses gender binary discourse as "a constellation of words, phrases, actions, rules (written and unwritten), and social realities that regulate 'appropriate' gender identities, expressions, and embodiments on campus" (Nicolazzo, 2017, p. 167) cited in (Haverkamp, Bothwell, Montfort, & Driskill, 2021, p. 57). This is also reflected in how Moss, a queer, Middle Eastern/North African (MENA), non-binary participant discussed difficulties that coming out in their department brought:

> In my personal experience, when I came out as non-binary … the sheer number of people who didn't know what that was [made me feel] put on the spot and [that I] felt like I became this spokesperson for all gender non-conforming people. [Those experiences] made me really uncomfortable and that shouldn't happen for a school as big as Michigan with other non-binary or trans people. I can agree with GSIs being more understanding [than undergrads], but even so as someone who doesn't fall into the male-female gender identities I personally really really do not like when they ask us to go around and share our pronouns. [I am] not always comfortable coming out in every classroom, every time I introduce myself with they/them pronouns, someone comes to me after and says something stupid. I think there's a better way for professors to do this other than putting students on the spot. … It's an internal struggle every time I go to a new engineering class about whether I'll reveal my pronouns or my name, since it's different from the name I use on canvas. … Mostly [my] peers, not faculty, [were] refusing to use my pronouns. [That] added to other stressors. [I] became the target for questions about non-cis orientations after I came out. I don't want this to be the experience of other NB individuals.

The comments from Dax and Moss hit home and pushed me to reflect on my own experiences in engineering. I thought about how I was not out in any engineering spaces because I was already dealing with a number of other stressors from existing in dominant engineering and had not wanted to open myself up to face the issues they were facing as well (Haverkamp, et al., 2019); (Cech & Waidzunas, 2011). The vast majority of TGNC folks I knew were outside of engineering in the various organizing spaces I was in, keeping a separability between engineering and being out that I had just grown to normalized. I also thought about the way we had framed UECGS as aimed toward reducing barriers to expressing our whole selves in engineering education spaces and the horizons of possibilities from the participants collective vision. It had me recognize that the barriers to coming out in engineering seemed a lot lower for me now that my departmental interactions were fewer and mainly via Zoom due to COVID-19. I was near the tail end of grad school and the skills, tools, and practices I learned through community and labor organizing had helped me navigate many distressing situations. Moving away from dominant engineering toward EER functioned as a critical consciousness raising process in which I embraced a new *conocimiento* around the politics of coming out in engineering. As Stephen described, coming out became intimately connected to my value system. The opportunity to sit and process the experiences of Dax and Moss shifted my understanding of engineering as a terrain of struggle, its structures, and the scyborg agency I had to maneuver on and reshape those structures. Rather than mainly an invitation for harassment or the sort of tokenization that has seemed so commonplace in dominant engineering, coming out now seemed like a move toward "a social capacity for human freedom based on a cultural-economic infrastructure that supports the transformation of oppressive relations that are the legacy of genocidal conquest, settler colonialism, racial slavery/capitalism, compulsory hetero-patriarchies, and global white supremacy," (Rodríguez, 2010, p. 15). So I did, revising my stakes in the knowledge produced and eventually seeing coming out shape my use of queer theory in this thesis.

8.2.1 Teaching Theories of Change with Traditional MSE Concepts

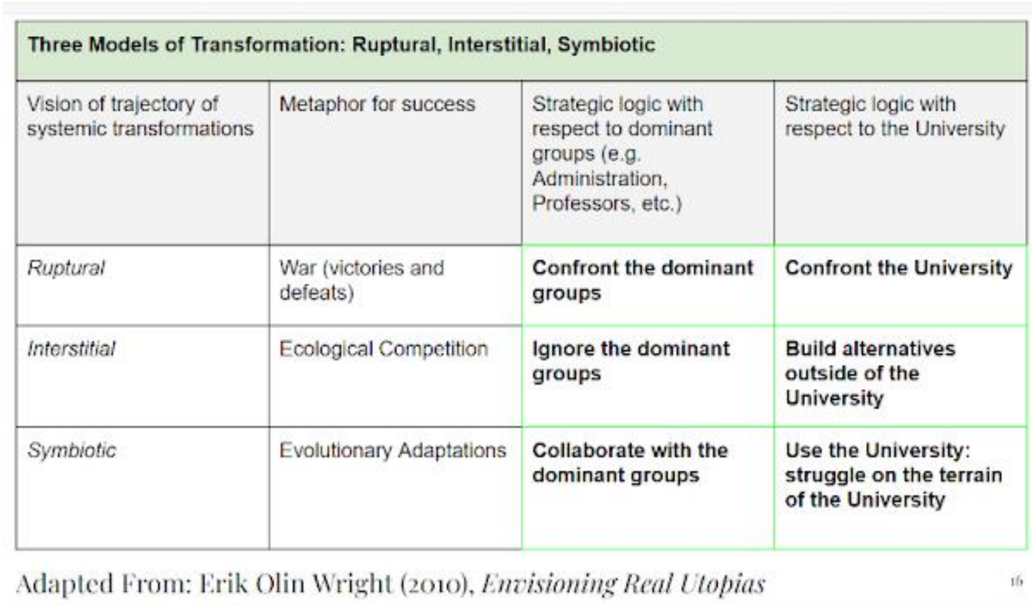
In the second event we started talking about theories of change and it gave me space to consider them in relation to materials science and engineering concepts. In particular, a friend had shared a slideshow with me including three theories of change discussed by Prof. Eric Olin Wright in *Envisioning Real Utopias* (Wright, 2010). The slideshow contained information on three models of transformation outlined as theories of change, see Table 18. Given the format of the theories of change workshop, I did not feel capable of giving a primer on the distinctions between the political traditions associated with the various transformations, a rundown on orientations toward the state, nor logics relating to the capitalist class with any of the nuance I feel those distinctions deserve. To compensate, Table 18 was altered to depict logics with respect to dominant groups and the University, see Figure 39. Political tendencies and pivotal collective actors were not highlighted in the table, but were discussed through examples. The capitalist class was instead altered to dominant groups, with administration and professors as example positions within the university that participants had raised in the first workshop. The logic with respect to the state was replaced with logic with respect to the University, a reflection of Grande's theorization of the university as an arm of the settler state (Grande, 2018).

Table 18: Three Models of Transformation: Rupture, Interstitial, Symbiotic (Wright, 2010).

Vision of Trajectory of Systemic Transformations Beyond Capitalism	Political Tradition Most Closely Associated with Logic of Transformation	Pivotal Collective Actors for Transformation	Strategic Logic with Respect to the State	Strategic Logic with Respect to the Capitalist Class	Metaphors of Success
Ruptural	Revolutionary socialist/ communist	Classes organized in political parties	Attack the state	Confront the bourgeoisie	War (victories and defeats)

Interstitial Metamorphosis	Anarchist	Social movements	Build alternatives outside of the state	Ignore the bourgeoisie	Ecological competition
Symbiotic Metamorphosis	Social democratic	Coalitions of social forces and labor	Use the state: struggle on the terrain of the state	Collaborate with the bourgeoisie	Evolutionary adaptations

I sought to explain these three strategies through MSE concepts, see Figure 40. A ruptural strategy was represented by mode 1 fracture, when a crack/break opens up as a result of two opposite forces creating tension stronger than the bonds holding the material together. An interstitial strategy was represented by a carbon interstitial atom in a lattice of iron atoms in a form of steel. A symbiotic strategy was represented by a larger (green) alloying element and a smaller (red) alloying element in the lattice of iron atoms. I highlighted how these strategies were not mutually exclusive by pointing to how there were also interstitials in the type of steel used to show the symbiotic strategy. I also highlighted the distortions to the bond lengths in the lattice of iron atoms brought on locally by the interstitial and symbiotic strategies.



Three Models of Transformation: Ruptural, Interstitial, Symbiotic			
Vision of trajectory of systemic transformations	Metaphor for success	Strategic logic with respect to dominant groups (e.g. Administration, Professors, etc.)	Strategic logic with respect to the University
Ruptural	War (victories and defeats)	**Confront the dominant groups**	**Confront the University**
Interstitial	Ecological Competition	**Ignore the dominant groups**	**Build alternatives outside of the University**
Symbiotic	Evolutionary Adaptations	**Collaborate with the dominant groups**	**Use the University: struggle on the terrain of the University**

Adapted From: Erik Olin Wright (2010), *Envisioning Real Utopias*

Figure 39: Three Models of Transformation slide used during UECGS theories of change workshop (Wright, 2010).

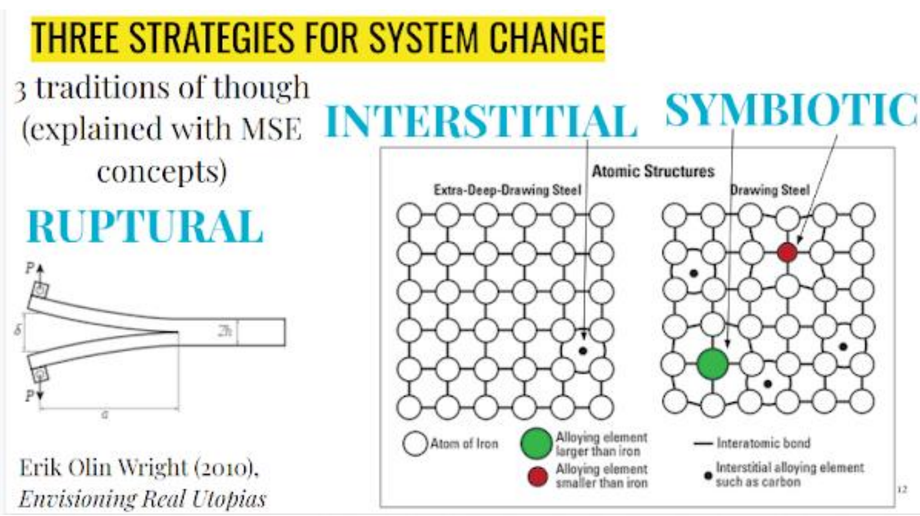


Figure 40: Three Strategies for System Change slide used during UECGS theories of change workshop.

8.2.2 Queering 'defects' and Nucleation and Growth as a Theory of Change

One of the things that displaying interstitial and symbiotic theories of change as lattice interstitials and substitutions had me thinking about is the way that 'defects' are discussed in materials science and engineering. Being a GSI in MSE 220: Introduction to Materials and

Manufacturing during the semester before my thesis defense gave me a stark reminder. 'Defects' in the structures of materials have direct connections to material properties via resistance (e.g. stiffness as resistance to mechanical deformation) within dominant materials science and engineering education. Within a positivist paradigm, there is an emphasis on the control and manipulation of 'defects' to achieve certain performance metrics (e.g. electrical conductivity, hardness, research productivity, grant acquisitions, civility). When the 'defects' act to improve desired performance, they often become welcomed mainstays in the structure (e.g. carbon in an iron lattice to form steel, n and p type dopants in semiconductors, a 'comfortable' amount of diversity in a department). Often 'defects' do not act as intended, for example causing phase changes that decrease performance.

I've learned about 'defects' as departures from some idealized "perfect" crystal structure, 'imperfections' where descriptors such as "foreign" atoms, and "junk" that "infiltrates" a crystal structure are not uncommon. The ways I was taught about and expected to teach about 'defects' started to have unsettling connections to xenophobia, white supremacy culture (Okun, 2021) and narratives about a need for more diverse teams in engineering *because* they improve economic performance. Lines started blurring between the ways 'defects' in crystals were discussed and how the lead instructor of the course would frame students who were failing as lazy, unwilling to attend class, and incompetent, dragging down the average score of the class; 'defects' decreasing performance as measured. 'Defects' that were repeatedly told by the lead instructor to drop out. All the while these sorts of students that I had in discussion section consistently attended, participated, and demonstrated an understanding of the material. The course was just not structured to recognize their knowledge. Pushing back against the deficit perspective framing these students as deficient earned me the label of 'insubordinate,' a military term for those defiant of authority; a ‘defect’ (Mejia, Revelo, Villanueva, & Mejia, 2018). ‘Defects’ are thermodynamically favorable, yet they are often targets for elimination (e.g. glassy secondary phase and ZrO2 from NASICON, students failing in a structure not built for them, engineers who aren’t interested in continuing the “empire-self-making project of the United States," (la paperson, 2017, p. 28) en route to more favored (economic) performances in dominant engineering.

Part of being in *Nepantla* within dominant MSE left me feeling like I was at an interstitial site. In dominant MSE, I exist in but not of the idealized structure, not occupying the position expected of me; akin to what is now called a ‘Frenkel defect,’ see Figure 41. ‘Frenkel defects’ are when an ion is expected to occupy a lattice site, but instead occupies an interstitial site and leaves a vacancy. The interstitial ion experiences greater strain from a change in local bonding while other ions move into some of the space made by the vacancy. This is a way I can connect existing in *Nepantla* to dominant MSE concepts. Framed as ‘defect,’ I was pushed to believe the extra tensions I was experiencing compared to those who occupied the idealized structure were my own fault and expected to hop back into the idealized structure (e.g. the narrative I was fed that the way I could uplift the Latinx community was to stop raising concerns about discrimination, keep my head down, go back to lab work, and get out of here with a degree discussed in chapter 6). This perspective made the idealized structure seem immutable, a tunnel to just move through rather than try to break down. Yet I am not deficient, and this structure is neither ideal nor immutable. Rather than ‘defect,’ I am a transformation to this structure that opens up space for other non-dominant ways of knowing and being, a defector. Not the expected performance, but one that refuses to continue going on with business as usual in a structure already identified as harmful.

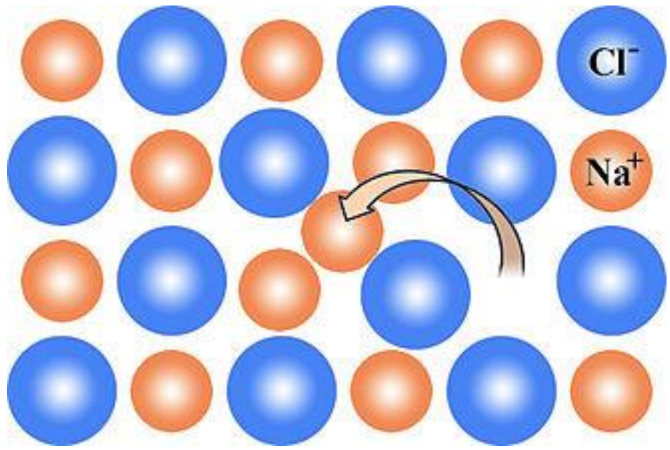


Figure 41: A transformation in a NaCl crystal structure commonly called a 'Frenkel defect' (Wikipedia, 2022).

That is where EER offers an opportunity for reframing the structure. In EER 602, we learned about situated learning. Coined by Lave and Wenger, situated learning posits that learning is inherently a social and communal activity done in communities of practice (Lave & Wenger, 1991). In situated learning, there is an 'authentic learning environment' where a "newcomer" (or beginner/novice) begins at the periphery of a community. Through collaboration, interactions, and engaging, including with "oldtimers," (or expert/master) the newcomer comes to be enculturated in the beliefs, behavior, and culture of the community of practice, see Figure 42. This offers both a means to understand cultural replication and cultural change, as newcomers become oldtimes they replicate components of the dominant culture in the community of practice while also altering other components of the dominant culture based on their experiences. As someone who has been enculturated into materials science and engineering through undergrad and grad school, I am in the community of practice. Part of why I choose to remain here is because I can bring in components from other communities of practice I am in and help this community of practice take responsibility for the violence it is predicated upon and the harm it continues to enact. It also allows me to refuse harmful components of dominant MSE culture, instead drawing from the other communities of practice I am in to nucleate and grow abolitionist practices here. This shifts askable questions from “what do we have now, and how can we make it better?” to instead ask “what can we imagine for ourselves and the world?” (Kaba, 2021, p. 3).

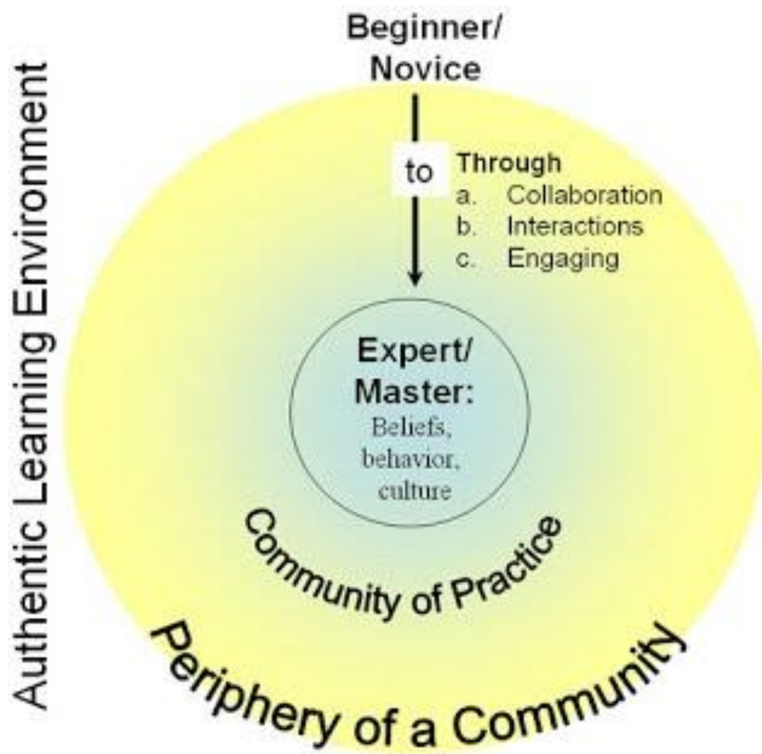


Figure 42: Model of Situated Learning (Learning Theories - Situated Learning, n.d.).

What happens if we see ourselves as atoms in a lattice? Each of us is agentic and existing in relations. What would it mean for us to narrowly focus on controlling each other, manufacturing consent to enable violence? Would we stop what we are doing? Would it transform how we theorize change? Would we imagine something better for ourselves and the world? Instead of a ‘defect’ in dominant MSE culture, I’m part of an unexpected heterogeneous nucleation site of sorts, a scyborg in assemblage (la paperson, 2017). I offer an opportunity to transform the microstructure that is the ecosystem of this community of practice, seeking to change relationships and undo harmful conditions. I think of this as a nucleation and growth theory of change, an emergent strategy refusing the authority of dominant MSE as given. In *Emergent Strategy: Shaping Change, Changing Worlds*, adrienne maree brown discusses emergent strategy as

> "strategy for building complex patterns and systems of change through relatively small interactions … Emergent strategy is how we intentionally change in ways that grow our capacity to embody the just and liberated worlds we long for," (brown, 2017, pp. 2, 24).

She describes fractals as one of the elements of emergent strategy,

> "a never-ending pattern. Fractals are infinitely complex patterns that are self-similar across different scales. They are created by repeating a simple process over and over in an ongoing feedback loop," (brown, 2017, p. 51).

Within dominant MSE, fractals can be seen in crystallographic structures. As can nucleation sites. They are already studyable concepts within MSE, but they are currently engaged with through a positivist paradigm ensuring relationships of domination, control, and separability. In EER, Amy Slaton and Alice Pawley talk about the power and politics of qualitative, 'small-n' studies toward unsettling essentialisms and privileges (Slaton & Pawley, 2018). They discuss a stigma in EER against qualitative, 'small-n' studies, in favor of generalizable, 'large-n' studies; a reflection of the relationships of dominant engineering to positivist paradigms. Each 'small-n' could act as a nucleation site in dominant MSE, growing an abolitionist focus on relationships and how we address harm across scales (Kaba, 2021).

In this non-dominant, abolitionist form of MSE, relationships are no longer predicated on controlling and generalizing to maintain industrial complexes. The thin blue lines upholding separability (e.g. technical/social, land/life, subject/object) begin becoming undone. Each student moving from the periphery of this community of practice toward its center shapes change. We hold the potential to nucleate and grow life-affirming community infrastructures in place of what exists currently, especially if we *embrace the abolition of the settler colony as an engineering project*. This community of practice *could* assemble students into scyborgs, each undoing fatal couplings of power and difference holding this current, dominant form of MSE together by pulling scrap from the thin blue lines in MSE to change the ecosystem as they grow. That might offer a way to re-center the trajectory of MSE toward liberation/land back. Attempting to do so is an obvious transgression, refusing to take the authority of the dominant culture as given (Simpson A. , 2016). In our own fumbling attempts down that path, Donna, Amy, and I have gathered some life-affirming technologies being used by folks already doing that type of work in *A Third University is Possible? A Collaborative Inquiry within Engineering Education* (Valle, Riley, & Slaton, 2022).

8.3 Life-Affirming Technologies

> If the academy is concerned about not only protecting and maintaining Indigenous intelligence but also revitalizing it on Indigenous terms as a form of restitution for its historic and contemporary role as a colonizing force (of which I see no evidence), then the academy must make a conscious decision to become a decolonizing force in the intellectual lives of Indigenous peoples by joining us in dismantling settler colonialism and actively protecting the source of our knowledge: Indigenous land.

- Leanne Betasamosake Simpson, (As We Have Always Done: Indigenous Freedom Through Radical Resistance, p. 172)

As the academy is the primary nucleation site for the education and professionalization of engineers and for the growth and reproduction of dominant engineering, engineering education and the research thereof can function not only as superstructural vectors for the interruption of dominant engineering and the engineering-industrial complex it sustains and is sustained by, but its abolition. Building on Gilmore's multiscalar object of analysis that holds a goal of figuring out "what [and who] makes oppressive and liberatory structures work, and what [and who] makes them fall apart," (Gilmore, 2002, p. 17), la paperson seeks a multiscalar subject of power in their use of scyborg, elaborating:

> "I am using subject here to include a person (the scyborg) who is interpellated in lattices of power (the scyborg is at once subjugated by power, produced as a subject by power, and a subjective participant in power) but also the wills, forces, and desires that surround and exceed a person (the scyborg in assemblage). The scyborg is a who/what that powers multiscalar dynamics in lattices of power," (la paperson, 2017, p. 64).

It is this agentic, multiscalar subject of power, the scyborg, that we can embody to act across scales of engineering, engineering education, and engineering education research. Toward this end, we can leverage the set of axioms which la paperson offers as propositions upon which the structure of a third university can be built:

- It already exists. It is assembling. It assembles within the first and second universities.
- Its mission is decolonization.
- It is strategic. Its possibilities are made in the first world university.
- It is timely, and yet its usefulness constantly expires.
- It is vocational, in the way of the first world university.
- It is unromantic. And it is not worthy of your romance.
- It is problematic. In all likelihood, it charges fees and grants degrees.
- It is not the fourth world.

- It is anti-utopian. Its pedagogical practices may be disciplining and disciplinary. A third world university is less interested in decolonizing the university and more in operating as a decolonizing university.
- It is a machine that produces machines. It assembles students into scyborgs. It assembles decolonizing machines out of scrap parts from colonial technology. It makes itself out of assemblages of the first and second world universities. To the degree that it accomplishes these assemblages, it is effective (la paperson, 2017, pp. 52-53).

It is here that Grande's suggestion of "a parallel politics of dialectical co-resistance" (Grande, 2018, p. 60) between "abolitionist and decolonial theorizations of the academy as articulated through Black radicalism and critical Indigenous studies, respectively," (p. 47) through "a corpus of shared ethics and analytics: anti-capitalist, feminist, anti-colonial," (p. 61) can be particularly salient for the interlinked fields of engineering, engineering education, and engineering education research. As Tuck and Yang discuss, "enslavement is a twofold procedure: removal from land and the creation of property (land and bodies). Thus, abolition is likewise twofold, requiring the repatriation of land and the abolition of property (land and bodies)," (Tuck & Yang, Decolonization is not a metaphor, 2012, p. 30). Decolonization, as a double movement of anticolonialism and rematriation (la paperson, 2017) does not have a synonym and is not a metaphor (Tuck & Yang, Decolonization is not a metaphor, 2012), although its movements can find resonance with abolitionist movements, particularly as Grande describes, through refusal.

Tuck and Yang discuss refusal in the context of research, naming ways they have embedded refusal "throughout the[ir] research process, at all stages of inquiry," (Tuck & Yang, 2014b, p. 815), saying:

> "Refusal makes space for recognition, and for reciprocity. Refusal turns the gaze back upon power, specifically the colonial modalities of knowing persons as bodies to be differentially counted, violated, saved, and put to work. It makes transparent the metanarrative of knowledge production—its spectatorship for pain and its preoccupation for documenting and ruling over racial difference. Refusal generates, expands, champions representational territories that colonial knowledge endeavors to settle, enclose, domesticate. We again insist that refusal is not just a no, but is a generative, analytic practice," (Tuck & Yang, 2014b, p. 817)

Refusal as a generative, analytical practice can take the form of caretaking. In The Red Deal, The Red Nation describes how "caretaking is often unrecognized work that is heavily gendered, severely criminalized, and never fairly compensated," (The Red Nation, 2021, p. 23) delineating that "a green economy should be born from, and center the labor and needs of, caretakers," (p. 23) described as "educators, healthcare workers, counsels, water protectors, and land defenders" (p. 23). Caretaking within the academic-industrial complex can be an abolitionist, anticolonial strategy of presencing and "standing with." As Kim TallBear describes, "a researcher who is willing to learn how to "stand with" a community of subjects is willing to be altered, to revise her stakes in the knowledge to be produced" (TallBear, 2014, p. 2).

One example that glimpses decolonizing care-laden strategies is the Pre-Engineering Education Collaboratory (PEEC) project at Oglala-Lakota College (LeGarry, 2016). At Oglala-Lakota College (OLC), pre-engineering education shifted its center to support tribal sovereignty, developing local expertise and addressing community priorities on the Pine Ridge Reservation. This meant becoming place-based, preserving and incorporating Indigenous knowledge and perspectives, and honoring the tribe's non-extraction commitments. In student-centered and experiential learning, students improved the quality of life of tribal members while also earning credentials in, for example, aspects of green construction. Such an approach disrupts managerial tendencies in engineering, values rather than stigmatizes practical knowledge or trades certifications, and neutralizes the epistemic violence of engineering education by recognizing, honoring, and incorporating these elements holistically. Finally, the deep care embedded in OLC's value of non-abandonment could not form a starker contrast to dominant engineering education's weed-out culture. Students attend OLC as long as it takes, and in one of the highest poverty zip codes, the community comes together to find the resources for students to continue to completion. With the implementation of these approaches using constructivist pedagogies, retention rose from 20 to 60 percent, the number of graduates doubled, and they enjoy a 96 percent placement rate of students into jobs on the reservation (i.e. staying in the community to further the nation's goals), or into graduate school. Such an approach further disrupts mainstream diversity discourse around talent shortages. The value of technoscientific mastery is not contribution to industry's bottom line, high salaries, or capitalism writ large - it is the furtherance of the Lakota nation (and is aligned with its non-extraction commitments).

While the PEEC collaborations in South Dakota and three other states live within existing power dynamics between predominantly white universities and tribal colleges, and likely reproduce some of those dynamics, at the same time one can glimpse the possibilities of la paperson's third university. Care work as an affirmation of life is already embedded in pieces of the first and second universities, work that can take anticolonial shifts through what could be understood as abolitionist strategies. The folks at Rustbelt Abolition Radio discuss three distinct yet interrelated flavors of abolition that each engage with forms of refusal:

1. Autonomist Abolition entails a strategy of fugitivity or constant refusal of the instruments of capture and their “catch all solutions” while, at the same time, building hyperlocal (though dispersed in undetectable networks) infrastructures for sustaining bodies (people, collectives, swarms) in resistance.
2. Insurrectionary Abolition entails a direct confrontation and antagonizing of the “big P” Police and its constant attempts to maintain order, while simultaneously attempting to liberate occupied territories.
3. Procedural Abolition entails winning and defending non-reformist reforms enshrined in policies that diminish the reach of the carceral state while simultaneously redirecting collective capacities towards social infrastructures that do not reinstate carceral instruments of capture and control (Rustbelt Abolition Radio, 2020).

Autonomist Abolition can be understood through the framing and methodology of mutual aid, which Dean Spade discusses as “collective coordination to meet each other’s needs, usually from an awareness that the systems we have in place are not going to meet them,” (Spade, 2020, p. 7). Spade outlines three key elements of mutual aid as:

1. “Mutual aid projects work to meet survival needs and build shared understanding about why people do not have what they need,” (Spade, 2020, p. 9)
2. “Mutual aid projects mobilize people, expand solidarity, and build movements,” (p. 12)
3. “Mutual aid projects are participatory, solving problems through collective action rather than waiting for saviors,” (p. 16)

Mutual aid structures often function at the size of research labs (Barnard Center for Research on Women, 2022). Abolitionist educator Mariame Kaba offers a lens into how these sort of community-based safety projects are already operating through “1 Million Experiments,” emphasizing that the aim is not to present alternatives to police and prison but rather the building of different structures grounded in transformation instead of punishment (One Million Experiments, 2021). Lab structures in engineering could be realigned toward mutual aid projects, refusing dominant engineering and acting simultaneously as spaces of engineering, engineering education, and engineering education research. As many organizers are naming, we need mass movements of millions of people to refuse the death-making of this industrial complex structure, for which dominant engineering acts as a keystone (The Red Nation, 2021); (Spade, 2020); (One Million Experiments, 2021). We as engineers, engineering educators, and engineering education researchers cannot continue to rely on a relational system that separates us from these mass movements.

Insurrectionary abolition is outside of the scope of this paper, a refusal on our end that we hope leaves space for your own radically imaginative practice as to how it may connect to dominant engineering, engineering education, and engineering education research. Procedural abolition within the academy can be framed through a lens of transformative justice. Drawing from movements within university contexts and the staircase of accountability for individuals in the Creative Interventions toolkit (Creative Interventions, 2020), Stas Schmiedt and Lea Roth from Spring Up discuss stages of accountability and taking responsibility at organizations or institutions where there is normalized harm, see Table 19 (Barnard Center for Research on Women, 2019). They particularly highlight how activists and organizers are catalysts that drive continual community pressure for the organization or institution to further its efforts to take accountability or responsibility when the institution has deemed it has done enough.

Table 19: Stages of accountability and taking responsibility for normalized harm in organizations or institutions. Drawn from Stas Schmiedt and Lea Roth's discussion with Mariame Kaba (Barnard Center for Research on Women, 2019).

Stage	Description and Institutional Response
Whistleblower	An individual or group of people come forward naming normalized harm. This can often be connected to specific, egregious incidents. Response is typically denial and gaslighting.
Performative Apology	Escalation from community members demanding the institution addresses the harm. Response is a performative apology without shifts in behavior.
Committee is formed	Continued pressure leads to the formation of an institutionally committee comprised of activists and institutional actors with little institutional power. The committee investigates the harm and generates a list of recommendations or suggestions. Response is an acknowledgement of recommendations, but often no meaningful engagement.
Assessing the problem	Some form of audit, survey, working group, and/or hiring of external consultants. Results may or may not be publicly released. Responses often neglect to mention specific ways the assessment will be acted on (if at all).
Create a support role	Hiring of a representative of the community into a tokenizing, support role. This is often one of the suggestions from the problem assessment and is a first tangible action taken by the institution.
Shifting in community norms	Implementation of new curriculum, new onboarding practices, new reporting mechanisms. Stage where you start seeing institutional or cultural change as consistent and ongoing shifts as a result of the problem assessment. Stops being performative and begins to function as a new transformation.
Institutionalization of changes	High level administrators, trustees, and/or board members going through a new training or review process.

Systemic leadership change	Systemic leadership change to reflect the community, apology for complicity in ongoing normalized harm, reparations. Complete reconfiguration of the structure of the institution, who has power within it, and resourcing the apology.

Another glimpse of life-affirming technologies related to the third university can be found in Aotearoa/New Zealand. As part of reparations settlements related to the 1840 Treaty of Waitangi, school lands were transferred from the Crown to various Maori tribes (Iwi), with the government subsequently paying rent to the tribes for continued university operation (Deed of Settlement, 1995). This shift in monetary and real estate assets accompanied and facilitated further shifts in cultural assets. Bilingual and bicultural education has been part of public education there for decades, and Maori knowledge and Maori traditions have a more central place in universities in Aotearoa/NZ than in other settler nations such as the United States. In this context, Maori scholars Angus and Sonja McFarlane have advanced the Braided River approach (He Awa Whiria) (Macfarlane & Macfarlane, 2019) to marry Indigenous and western knowledges across many disciplines including engineering (Hughes, Prpic, Goldfinch, & Kennedy, 2018).

It is important to not misunderstand this example. Reparations have not been a perfect solution for past injustice, and tribal compensation has been riddled with inequities that continue to be expanded, corrected, and revised (Ryan, 2013). It does provide to us in North America a glimpse of the possibilities of shifting power and resources. (It also suggests the essential importance of shifting material and cultural assets, not just epistemics.) What if the considerable resources identified within U.S. land grant universities (Lee, et al., n.d.) were returned to tribes? What could be different if those universities rented from the indigenous caretakers of our land? What cultural practices, epistemics, and ontologies would come to the fore? Ojibwe author

David Treuer (2019), in telling the history of Native America since Wounded Knee, describes elements of what we might imagine could transpire in third universities. What sort of structures might you/we build to turn this from theory to praxis?

Chapter 9 (In)conclusions: Preguntando Caminando

> "We should accept that sometimes the anticolonial move is to stop. To not do the research if you don't have permission from Indigenous people and governing bodies. To not propose research with Indigenous groups or on Indigenous land unless you've been explicitly invited by those groups. To not use the sample extraction method that creates toxic chemicals that require land to absorb. To stop carbon-intensive research that directly impacts Arctic and other Indigenous peoples. All forms of ceasing or mitigating the entitlement to Indigenous life and land are anticolonial science, and can be practiced by anyone," (Liboiron, 2021b, p. 876).

Something that I've found more and more troubled as I have been writing this thesis is the assumed boundary between dominant engineering, engineering education, and engineering education research. Each operates in different ways at different scales, offering different askable questions. They all exist in the same ecosystem regardless of whether you choose to acknowledge all of the scales they operate at and assemblages they exist in maintaining those operations. The critical consciousness raising process this autoethnographic methodology has allowed me to cultivate has given me a new *conocimiento* about living in the U.S. settler colony on Anishnaabeg lands and fatal couplings of power and difference structuring dominant engineering to maintain the settler colony. It's given me space to understand my graduate school experiences in relation to settler colonialism and start acting in ways that reflect that understanding. This doesn't signal an arrival at any particular point, more a recognition of a path as a process and relationships shaping that path, see Figure 43. It's given me an understanding that “hope is a discipline,” and an assemblage of that discipline I can recognize and be present in is abolitionist engineering.

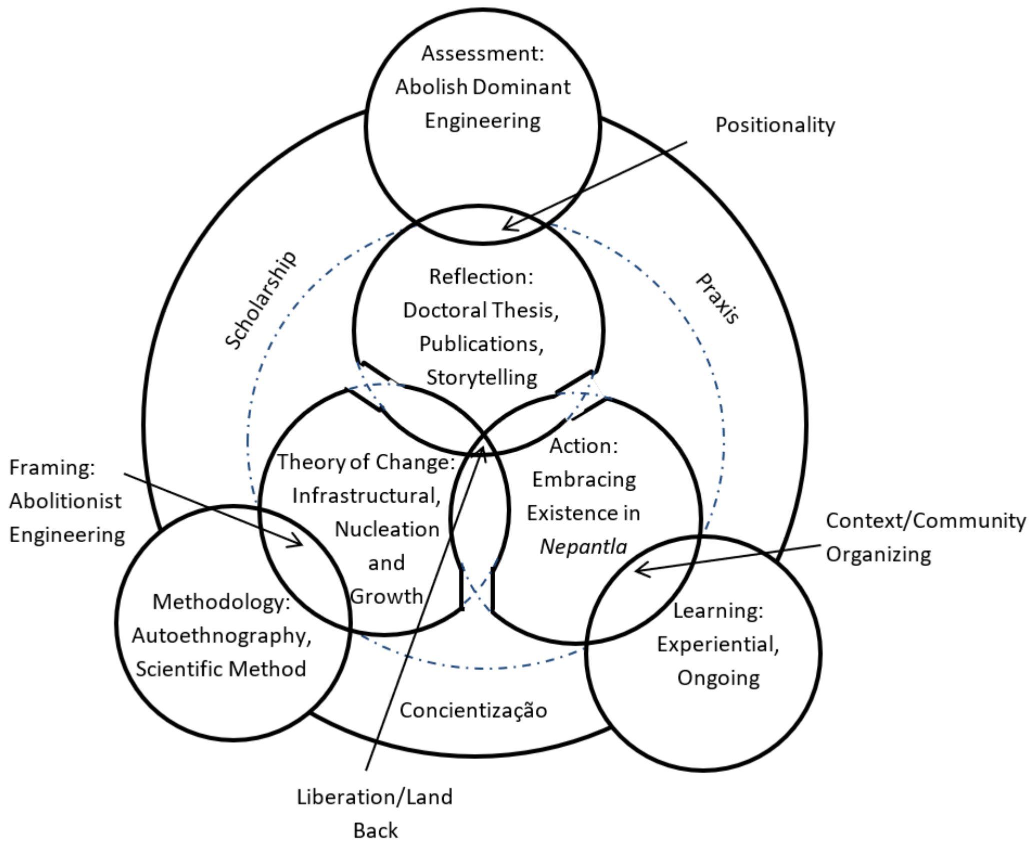


Figure 43: LEEM applied to this doctoral thesis.

My assessment is that transforming the current, dominant structure of the discipline of MSE to take on an abolitionist performance can hold liberation/land back as a horizon of hope. One of the requirements in this transformation is a recharacterization of its structure, infrastructures, and superstructures. Framing abolitionist engineering as this recharacterization through a theoretical framework of queer theory and abolition, I attempted(/am attempting) to engage an infrastructural theory of change beyond reform of dominant engineering by being differently in dominant MSE. I call(ed) that infrastructural theory of change a nucleation and growth theory of change to make a connection point to concepts in dominant MSE as well as offer connection points to life-affirming technologies that might make that theory of change actionable. I consider this nucleation and growth theory of change a hypothesis in conversation with the hypothesis and relaxed use of the scientific method in the One Million Experiments project, which explores snapshots of community-based safety projects; “1ME expands our ideas about what keeps us safe, and celebrates the work already happening to build solutions that are grounded in transformation instead of punishment,” (One Million Experiments, 2021). I(‘m doing/) did this through a methodology connecting autoethnography and the scientific method. Embracing existence in *Nepantla* as part of that emphasis on being differently helped me gain a new *conocimiento*. This thesis was(/is) an opportunity (for me and hopefully you as well) to queerly reflect on how my(/your) positionality is shaped by settler colonialism. Settler colonialism and the systems upholding it have me very far from a (sustained) performance of liberation/land back, but I recognize it as an aim. Liberation/land back is a decolonial desire that an anticolonial step to stop my participation in dominant MSE prompted. I(/we) as (a) settler(s) have many more anticolonial steps to take to materialize that decolonial desire and close epistemology-ontology divides driving an exclusionary relationship with nature and colonization of Indigenous cosmologies (Watts, 2013). One of the quotes this brings me back to is “Aura Bogado (2017) encourages White folks to think about the Zapatista saying “preguntando caminamos,” which she translates as “asking questions, we walk,”” (Pawley A. , 2019a, p. 447). As I have walked this path of my years in grad school, I have asked many questions and gotten some answers giving me a sense of where to walk toward and more questions to ask. I’ve grown pods of folks to help me navigate times where violence, harm, or abuse happen to me, where I go to for support in taking accountability for violence, harm, or abuse I’ve done, and/or when I witness violence as part of the networks of solidarity and care needed for interventionist research

(Mingus, 2016); (Liboiron, 2016). These have led me to questions like: what does a materials science and engineering that engages mutual aid to improve material conditions in people's lives look like rather than ignoring these conditions as irrelevant, externalized subjectivities? One that shapes "a cultural-economic infrastructure that supports the transformation of oppressive relations that are the legacy of genocidal conquest, settler colonialism, racial slavery/capitalism, compulsory hetero-patriarchies, and global white supremacy," (Rodríguez, 2010, p. 15) through solidarity instead of charity and the maintenance of industrial complexes. What technologies in the assemblage of dominant engineering might be repurposed toward those sorts of abolitionist materials science and engineering projects? The lab? The class? The research paper? The grant? The tenure structure? The dominant forms of MSE drives unsustainable growth and over-consumption subsidized and maintained by violence, while non-dominant forms struggle to nucleate and grow toward the affirmation of life and undoing of fatal couplings of power and difference. None of what I've described in this thesis has felt like the active decolonization that the land acknowledgement kicking it off encourages, yet the moves from lithium solid state battery research to sodium solid state battery research toward researching how engineers could be educated differently were intended to reduce the harm of earning a PhD in this field, offer a non-dominant trajectory in MSE, and have helped me maintain hope amongst a multitude of overlapping crises unfolding during my time as a graduate student. It is my hope that you find the path described in these pages illuminating, sparking questions and acts that move toward liberation/land back.

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