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A Political Theory of Engineered Systems and A Study of Engineering and Justice Workshops

Dominic David Carrese
Dartmouth College, dominic.d.carrese.th@dartmouth.edu

A Political Theory of Engineered Systems and a Study of Engineering and Justice Workshops

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by Dominic Carrese

Thayer School of Engineering
Guarini School of Graduate and Advanced Studies
Dartmouth College
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Examining Committee:

Chair_______________________________
Elizabeth Murnane

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Klaus Keller

Member_______________________________
Russell Muirhead

Member _______________________________
Rafe Steinhauer

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F. Jon Kull, Ph.D.
Dean of the Guarini School of Graduate and Advanced Studies

Abstract

Since there are good reasons to think that some engineered systems are socially undesirable—for example, internal combustion engines that cause climate change, algorithms that are racist, and nuclear weapons that can destroy all life—there is a well-established literature that attempts to identify best practices for designing and regulating engineered systems in order to prevent harm and promote justice. Most of this literature, especially the design theory and engineering justice literature meant to help guide engineers, focuses on environmental, physical, social, and mental harms such as ecosystem and bodily poisoning, racial and gender discrimination, and urban alienation. However, the literature that focuses on how engineered systems can produce political harms—harms to how we shape the way we live in community together—is not well established. The first part of this thesis contributes to identifying how particular types of engineered systems can harm a democratic politics. Building on democratic theory, philosophy of collective harms, and design theory, it argues that engineered systems that extend in space and time beyond a certain threshold subvert the knowledge and empowerment necessary for a democratic politics. For example, the systems of global shipping and the internet that fundamentally shape our lives are so large that people cannot attain the knowledge necessary to regulate them well nor the empowerment necessary to shape them.

The second part of this thesis is an empirical study of a workshop designed to encourage engineering undergraduates to understand how engineered systems can subvert a democratic politics, with the ultimate goal of supporting students in incorporating that understanding into their work. 32 Dartmouth undergraduate engineering students participated in the study. Half were assigned to participate in a workshop group, half to a control group. The workshop group participants took a pretest; then participated in a 3-hour, semi-structured workshop with 4 participants per session (as well as a discussion leader and note-taker) over lunch or dinner; and then took a posttest. The control group participants took the same pre- and post- tests, but had no suggested activity in the intervening 3 hours. We find that the students who participated in workshops had a statistically significant test-score improvement as compared to the control group (Brunner-Munzel test, $p < .001$). Using thematic analysis methods, we show the data is consistent with the hypothesis that workshops produced a score improvement because of certain structure (small size, long duration, discussion-based, over homemade food) and content (theoretically rich, challenging). Thematic analysis also reveals workshop failures and areas for improvement (too much content for the duration, not well enough organized).

The thesis concludes with a discussion of limitations and suggestions for future theoretical, empirical, and pedagogical research.

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Chapter 1: Introduction

The foundational question of this thesis is: *How should we think politically about engineered systems?* Most of this Introduction therefore provides a defense of why that is an important question, for everyone, but with a particular emphasis on why it is an important question for 1) people who currently study and develop engineered systems and 2) people who currently study and develop political theory. That's because the former group has the most agency in forming and reforming engineered systems, while the latter group has the most agency in developing strong answers to this question.

In defending the need to think politically about engineered systems, I argue that existing theory and language is insufficient to understand and prevent harms caused by the category "engineered systems," and that we therefore need a political theory of engineered systems. I offer such a theory, putting forward a political definition of "engineered systems" that foregrounds their political and historical uniqueness—their potential to be big, fast, or long-enduring.

In support of this argument, I discuss recent calls from engineering educators to integrate an understanding of justice, and how engineered systems affect justice, into engineering education and practice. This work demonstrates the need for thinking politically about engineered systems, and provides essential building blocks to do so, but ultimately is unsatisfactory in providing a good way to think politically about engineered systems. I discuss how my theory builds on and provides a necessary complement to engineering justice literature.

I then use an analogy to a recently developed political theory of science to delimit and clarify the importance and scope of my theory. This analogy provides both a defense for thinking politically about engineered systems from a political theory perspective, as well as a preliminary way to think about what might be needed for a political theory of engineered systems.

The second main research question of this thesis is: *How might we help engineering students to think politically about engineered systems, and act accordingly?* This Introduction partly defends the importance of asking that question through my discussion of engineering justice educators. However, the main defense of that question comes in Chapter 3 where I review literature on teaching engineering ethics. That literature review introduces, supports, and clarifies the methods for a study of engineering and justice workshops that I conducted. A discussion of that study—its methods, results, and conclusions—forms the second half of the thesis.

The Shadowy Politics of Engineered Systems

Engineered systems—that is, systems that are big, fast, or long-enduring (what I call "bigfastforeverver" systems), or systems that use the mathematical methods and technics needed to build such systems—are political since they profoundly affect how we live in community together. In fact, much of the modern political project has been about developing engineered systems, from road systems to electric grid systems to nuclear weapons systems, medical systems to electronic communication systems, in order to produce a particular way of living, a "high standard of living." A good definition of the modern political pact, held by almost every modern political community is, "By the development of engineered systems, our lives will become better."[1]

However, though some effects of engineered systems have been subject to debate and regulation (i.e., the Comprehensive Environmental Response, Compensation, and Liability Act regulating cleanup of superfund sites or the European Union's General Data Protection Regulation focusing on data privacy for internet users), the effect of engineered systems on politics itself has remained in the shadows, not subject to conscious political deliberation and regulation. Instead, dominant political culture seems to be premised upon an unquestioned reliance on engineered systems, which puts their effect on politics off-limits from conscious political deliberation and regulation (Ferkiss, 1980). As will be discussed below, the belief that engineered systems are apolitical (inherently good and therefore beyond political critique and contention) is especially strong among engineers (Cech, 2013). Even the supposedly extremely different politics of modernity—communism and capitalism—seem to converge on the need for more engineered systems that are bigger, faster, more permanent (at least as historically implemented) (Kemp, 1983; Scase, 1989). Thus it seems plausible that even before the "end of history" and the triumph of capitalism, there was an "end of politics" when the question over what constitutes the good life for all was definitively answered: the good life is the engineered life (Fukuyama, 1992; Zizek, 2008). As Langdon Winner puts it, "in our time *technē* has become *politeia*—our instruments are institutions in the making"

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[1] For a discussion of how this belief is fundamental to American politics, see my undergraduate thesis "Wilderness Subjugation in American Political Thought: The Dilemma of Technology" (2019) and Victor Ferkiss' "Technology and American Political Thought: The Hidden Variable and the Coming Crisis" (1980). For a more general discussion beyond American politics, see Bruno Latour's *We Have Never Been Modern* (1993).

(Winner 1986, 54). “Technology” seems to be the powerful, magical solution to everything—cancer, mental un-health, farming, love, food, movement, thought.

The dominant (a)political approach to engineered systems has therefore been to use political theories of government to regulate the “externalities” produced by many engineered systems—“dirty” air and water, carbon dioxide, discrimination, surveillance, exploitation, alienation. We use laws stemming from pre-industrial theories of government to regulate the externalities of engineered systems that violate privacy, cause “damages,” treat people unequally. Even if engineered systems themselves were seen as the proper subject of regulation, and therefore political study, the supposed inevitability of “technological progress” suggests that reform efforts be limited to slight adjustments to status-quo industry in order to prevent the most violent applications and externalities. Any fundamental adjustments or alternatives to the course of technological progress are off the dominant political table because they are “unrealistic.” Those who have considered such fundamental adjustments or alternatives, and raised questions about the benefit of categories of engineered systems have been a small minority of politically disempowered non-Western indigenous people or “backward” people within the Western tradition (Luddites, Amish, romantic poets, small farmers) (Harrington, 2009, 73-84).

Nonetheless, evidence is mounting that the dominant, modern regulatory approach to engineered systems is failing. In the face of a host of severely harmful “externalities” of engineered systems which threaten to unravel and subvert our collective worlds, it seems untenable to continue to limit engineered systems to the political shadows; they are increasingly, if sporadically, dragged into the political light. The scientific community has produced evidence that harmful climatic changes are caused by the engineered systems of fossil-fuel extraction and combustion (Lee et. al., 2023). Scientists are exploring how the engineered systems that produce nurdles (the pellets used to produce most plastics) and their plastic products are damaging ecological and human health (Murtazashvili, 2023). The EPA is regulating the systems that produce PFAS "forever chemicals" (Suran, 2022). The US Congress has summoned testimony over Facebook's political effects (Hu, 2020). The engineered systems that allow for genome editing have prompted a genome editing global observatory (Jasanoff & Hurlbut, 2018). Tristan Harris' *The Social Dilemma* attributes some mental illness to the engineered systems of social media (Du, 2022). Indigenous communities are resisting the exploitation and destruction of their homelands by engineered systems, and young people are resisting the generational injustices of such engineered systems (Radwin, 2022). Arguments have arisen for "degrowth" to a steady state and humane economies of small scale as a counterpoint to massive supply chains; these join arguments against high material/energy throughput and alienated production of engineered systems (Schmelzer et. al., 2022; Sol, 2019; Illich, 1973). Perhaps most importantly, there is increasing support from within the engineering community to think politically about engineered systems, in order to engage in more critical or self-conscious design (see especially the engineering justice literature discussed below).

Despite this recent surge in conscious political focus on the externalities produced by engineered systems, the politics of engineered systems themselves remain in the shadows. Though our understanding of how to regulate engineered systems is improving, we still analyze them on a case-by-case basis, and the category "engineered systems" does not seem to be a politically coherent, intelligible, or useful category—that is, as a political community we do not have a way to think holistically about governing bigfastforever systems or about the effect those systems have on our ability to self-govern.

What would it require to illuminate the shadowy politics of engineered systems? What would it mean to have deliberation about and regulation of engineered systems? What would it sound like? It would mean focusing on the general features of engineered systems rather than the idiosyncrasies of particular systems. It would require a political theory of engineered systems and the concomitant regulatory strategy. Perhaps most importantly, it would sound like a common political language being used to understand harms caused by, for example, "the Internet" system, nurdle systems, nuclear weapons systems, and internal combustion engine systems. By analogy, this language would sound something like the common political language that has emerged to design and regulate government. In the US, *The Federalist Papers* (1788) and the Constitution, along with state constitutions, formed the foundation for a language that can theorize, recognize, and measure governmental harms such as overly or underly concentrated power (allowing and limiting rule by "the people" is an institutional response to this); lack of recourse against abuse of power (judicial review and frequent elections are institutional responses to this); or arbitrary power (the "rule of law" is an institutional response to this). Consequently, when government action perpetrates some harm, we have a well-developed language that can be used to understand that harm and to develop the appropriate response. This allows us to avoid inefficient and ineffective case-by-case analysis and repair of harms in favor of recognizing categorical harms (here, harms uniquely caused by the category "government") and mustering effective categorical responses. Most political theory has been focused on developing and honing this language for government.

Any analogous language for engineered systems is severely underdeveloped. We largely analyze the harms that result from engineered systems on a case-by-case basis. In fact, it is difficult to imagine applying the logic of carbon dioxide emissions regulations to nurdles or "the Internet." To our existing political theory, phenomena such as the fossil fuel systems, nurdle systems, and "the Internet" system are not similar; rather, our existing political theory does not see these systems, but only sees their externalities. The e*ffects* of engineered systems have been a boon to modern political theory because they present constantly "emerging" conundrums; for example, political theory copiously discusses how digital electronic media changes democratic politics. But the technical *causes* of these effects—"technology"—is left a mystical, magical evolutionary process that is not clearly defined. In fact, given our casual understanding of "technology" as a "thing" that quickly obsolesces to be magically replaced by another "thing," a political theory of technology is impossible. Magical things and obsolescing things do not lend themselves to systematic understandings (even though if we looked more carefully we might see that these things represent systems that stretch far, in space and time, beyond our encounters with them). My working definition of engineered systems—systems that are big, fast, or long-enduring (what I call "bigfastforever" systems), or systems that use the mathematical methods and technics needed to build such systems—is not a politically known or relevant definition. This definition is a simple fusion of 1) a very common definition of engineered systems as physical systems that require advanced applied math (see Gross & Roppel, 2012) and 2) relatively unknown ideas about the political consequences of globally sized, fast-changing, and long-duration systems (see Dewey 1927). As I explain below, in Chapter 2, Timothy Morton's concept of hyperobjects—engineered objects that have taken on planetary-like space and time—and Benjamin Bratton's concept of The Stack—the infrastructure supporting and networks of interplanetary computing—come close to engineering/politics fusion that underlies my definition of engineered systems. However, neither of them explicitly focus on the category of artifacts commonly labeled engineered systems, nor are they as attuned to the political consequences of these bigfastforever systems. Further, my definition of bigfastforever systems supplies a heuristic by which to judge the effect of engineered systems on politics: I suggest that an engineered system has a corrosive effect on politics if it is big, fast, and forever, and that it does not corrode politics—and can even facilitate democratic deliberation—if it is small, slow, and current.

The reasons behind our failure to develop a political language that can illuminate the shadowy politics of engineered systems are discussed (if indirectly) in much scholarship, including Bruno Latour's *We Have Never Been Modern* and Victor Ferkiss' "Technology and American Political Thought: The Hidden Variable and the Coming Crisis" (Latour, 1993; Ferkiss, 1980). The basic argument Latour and Ferkiss make is that it has been so convenient for us to rely on technical solutions to political problems that our political culture now deeply resists recognizing that those technical solutions have an often-harmful politics. Put differently: we have been trying to escape politics via engineered systems—to replace the difficult, slow, messy work of deliberating and deciding how to live in community together with sleek technical workarounds—so we are loathe to accept that engineered systems are political (Ferkiss, 1980; Winner, 1986;

Latour, 1993; Carrese, 2019). For example, nitrogen fixation via the Haber Bosch process for synthetic fertilizers has historically been used as an engineered workaround of smaller, slower, shorter-duration nitrogen fixing processes (such as legume cover crops) (Hager, 2008). In doing so it provides a seemingly desirable technical solution to a political problem—how to live in community with each other and the land so that we are all fed—and is therefore a classic example of the quest to "relieve man's estate" (Hager, 2008; Berry & Wirzba, 2002; Bacon, 1605).[2] In the context of this politics that is paradoxically trying to escape politics, we are quick to believe that injustices caused by engineered systems (e.g., climate change, "mass destruction" with weapons systems, industrial accidents) can be solved by other engineered systems (e.g., monitoring, prevention, alarm, clean-up, or defense systems). To prove that engineered systems are good—and therefore that there is no need to bring them into the deliberative light of politics—it is often sufficient to invoke progress and list the triumphs of Science and Engineering: crop yields, high speed transportation, immunizations, surgeries, communication systems, efficient heating and cooling, digital electronic computing and communication and entertainment (See, e.g., Pinker, 2018; Goldin and Katurna, 2016). The conversation-ending question is: would you rather live in a time before all this progress (Pinker, 2018, p. 37)? Arguments against engineered systems are therefore often construed as arguments for conserving injustices. Because our political language for engineered systems is under-developed, it often has not given us the tools necessary to

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[2] In fact, one of the first early uses of the Haber Bosch process was to prolong war—the horrors of World War I—which could be defined, contra Carl Schmitt, as the antithesis of politics and the evidence of its complete absence (Hager, 2008; Mouffe & Wagner, 2013). In other words, insofar as engineered systems facilitate war, they facilitate the escape of politics.

theorize, recognize and measure the harms produced by engineered systems—one easy example is our current difficulty in reaching any political response to climatic changes caused by our use of engineered systems that rely on fossil fuels (e.g., roads, the electrical grid, the internet).

Two more likely reasons we have no political theory of engineered systems—reasons that are only very indirectly discussed in scholarship—are 1) the difficulty of understanding the "collective harms" that engineered systems facilitate and 2) the related lack of systems thinking. As to the first reason: collective harms are the category of harms for which the causes are distributed among many people (perhaps across many times). Reductively: assault is an individual harm; climate change is a collective harm. Collective harms are inherently difficult to understand—technically, politically, philosophically. Though there are promising approaches to regulating collective harms, such as the polycentric governance advocated by Elinor Ostrom (see Ostrom, 2015), in Chapter 2 I argue that many collective harms pose an insoluble challenge to justice and (therefore) democracy. A second fundamental reason that engineered systems have remained in the political shadows is that "systems thinking" is neither easy nor prevalent. Unlike life cycle assessment engineers or actor network theory scholars, at least when they are at work, most of us don't go beyond the "things" we experience in a particular time and space to understand that *things convene systems*. We are not in the habit of asking: what sort of system does a lightbulb convene? An LED versus a compact fluorescent versus an incandescent? How does the system convened by this lightbulb affect people in Shanghai and São Paolo and in the year 2050? As Bruno Latour reminds us, we do not but should interpret things in their etymological sense as "gatherings"—

sometimes gatherings of far-flung people and places across far-flung times (Latour, 2005; cf. Heidegger, 1967). Or as Wolfgang Sachs writes, "the tragic fallacy that modern technologies possess the innocence of tools" masks how most of our "things" are in fact the tip of an engineered system:

> As with a car, a pill, a computer, or a television, the electric mixer is dependent on the existence of a sprawling, interconnected system of organization and production. Someone who flicks a switch is not using a tool. They are plugging into a combine of running systems. (Sachs, 1999, pp. 13-14)

But such a systems perspective—that sees the thing (tool) for what it is—seems to be practically unattainable because of the sprawling and interconnected nature of such systems.

This thesis attempts to overcome these barriers and provide a preliminary political theory of engineered systems that could inform a common political language of engineered systems. It does so by developing a vocabulary that could be used to theorize, recognize, and measure the harms produced by some categories of engineered systems. This vocabulary builds on a descriptive vocabulary from engineering and a normative vocabulary (pertaining to what *should be* done) from political theory. For example, it uses the concept of systems boundaries from systems engineering and life cycle assessment as well as the normative concepts of political knowledge and empowerment from, among others, John Dewey's theory of publics, Ivan Illich's theory of tools for conviviality, and Benjamin Barber's theory of strong democracy.

Since developing such a political theory of engineered systems is antithetical to modern politics, and therefore not obviously necessary or valuable, before presenting the theory I provide a brief defense of why it is important to shed light on the as-yet shadowy politics of engineered systems. While the best defense for a political theory of engineered systems is the articulation of the theory itself in Chapter 2—it should be self-evidently worthy upon minimal reflection—the rest of this introductory chapter uses engineering and political theory scholarship to defend the theory in order to provide a more adequate introduction to the scholarly context.

Jon Leydens and Juan Lucena's *Engineering Justice* and Zeynep Pamuk's *Politics and Expertise* are especially useful in providing a preliminary defense of the need for a political theory of engineered systems. The former is written by engineering professors at the Colorado School of Mines and so should be especially useful for those approaching this thesis from within the context of an engineering institution. In my discussion of their work, I will focus on how Leydens and Lucena's politicization of engineering education and practice demonstrates the urgent need for a complementary politicization of engineered systems. (*Engineering Justice* also provides important pedagogical and curricular resources that I use in the Methods chapter.)

Zeynep Pamuk's *Politics and Expertise* develops, and simultaneously defends the need for, a political theory of "science." It therefore 1) is analogous to my attempt to develop, and simultaneously defend the need for, a political theory of engineered systems and 2) provides an excellent way to introduce my theory by way of comparison. Approaching my thesis by analogy to Pamuk's book should be especially useful for those approaching this thesis from a political theory background.

Leydens and Lucena's *Engineering Justice*: A Call from Engineering Educators to Appropriately Politicize Engineered Systems

John Leydens and Juan Lucena's 2018 *Engineering Justice: Transforming Engineering Education and Practice* is the most recent addition to "engineering justice" literature. This literature is largely written by engineers *cum* engineering educators, and includes Darshan Karwat et. al.'s "Activist Engineering: Changing Engineering Practice by Deploying Praxis," the 2013 collection of essays *Engineering Education for Social Justice*, Donna Riley's 2008 *Engineering and Social Justice,* and Caroline Baillie, Alice Pawley, and Donna Riley's 2008 *Engineering and Social Justice: In the University and Beyond.* Here I focus on Leydens and Lucena's book because of its recency and because it builds on previous literature to present curricular and pedagogical recommendations.

Engineering Justice is structured around three claims: 1) the vast majority of engineering education and practice is currently depoliticized, 2) engineering education and practice should be politicized, and 3) strategically infusing engineering for social justice (E4SJ) criteria into engineering curricula is a good way to politicize it. In this section I briefly discuss and affirm the first and second claims. I then more thoroughly discuss the third claim, explaining how, similar to other literature that attempts to politicize engineering, Leydens and Lucena's attempt is misleading if it stands alone, but immensely useful if it is complemented by a political understanding of engineered systems such as the one this thesis provides.

In order to argue that engineering education and practice is depoliticized, Leydens and Lucena rely mainly on Erin Cech's 2013 chapter "The (Mis)Framing of Social Justice: Why Ideologies of Depoliticization and Meritocracy Hinder Engineers' Ability to

Think About Social Injustices" (Cech, 2013); also discussed is Riley's section on "Positivism and the Myth of Objectivity" in her *Engineering and Social Justice* (Riley, 2008). Cech defines the ideology of depoliticization as "the belief that engineering work, by definition, should disconnect itself from social and cultural realms because such realms taint otherwise pure engineering design methodologies" (Cech, 2013, p. 71). Cech continues:

> Through the frame of depoliticization, the political and social foundations of all engineering work are culturally invisible in the meaning systems surrounding that work. More importantly, the ideology of depoliticization means that aspects of social life that have to do with conflicting perspectives, cultural values, or inequality are cast as "political" and thus irrelevant—perhaps even dangerous—to "real" engineering work. As a result, these concerns are defined as illegitimate to engineers' day-to-day work by the very culture of the profession. (Cech, 2013, p. 71)

Darshan Karwat et. al. similarly note that "apoliticism is what engineer and writer Samuel Florman would call an 'existential pleasure of engineering'" and that apolitical mindsets "form the cornerstones of modern engineering and technological development" (Karwat, 2014, p. 231).

Leydens, Lucena, Cech, Riley, Baillie, Karwat and other "engineering education leaders" (for names, see these sources, especially; also see my Methods chapter) all argue that such depoliticization of engineering is harmful (Leydens and Lucena, 2018, pp. 16-18). As Leydens and Lucena remind us:

> With great power, comes great responsibility… we need an engineering education that is tailored to the great responsibility engineers will assume in transforming life in the rest of the twenty-first century and beyond. (Leydens and Lucena, 2018, p. 1)

Engineers without a strong understanding of the political effects of their work are dangerous, Leydens and Lucena argue, and we need to address the mismatch between engineering education and practice that allows this danger to persist. As Riley argues in her Forward to Leydens and Lucena's text, we engineers "have a moral responsibility" to "work for justice" and "ask the central questions of social justice" (Riley, 2018, p. xviii).

These arguments are convincing and much needed. But they are misleading because they do not focus on the political effects of the category of engineered systems itself nor on what can be done to mitigate harmful effects. A useful caricature of Leydens and Lucena's argument is that "engineers are legislators: they should therefore strive to understand the effects of their potential legislation in the ways that the best legislators understand their legislation, which means using the political theories that those legislators use." This fits with the majority of approaches to understanding the politics of engineered systems. Perhaps the archetypical example of how engineered systems are political, given in Langdon Winner's classic essay "Do Artifacts Have Politics?," is low bridges built by Robert Moses in New York City. These bridges prevented buses from traveling to beaches, effectively excluding most Black and Brown people from traveling to beaches (Winner, 1980). This example demonstrates how artifacts can legislate in the same way that legislation does, just a bit more implicitly. The message is that we should think about engineered systems in the same way we think about legislation.

It is highly problematic, for two major reasons, to assert that because engineered systems are legislation, engineers should act like (good) legislators. First, in doing so engineers become "unelected delegates and representatives of the rest of us" (Winner, 1990). Of course, most *current* engineers are not to blame for engineers having disproportionate power, since that power has been given to and taken by *past* engineers (setting aside that past and present engineers are not mutually exclusive groups). But *recognition that current engineers thus can have outsized authority that subverts* *democratic authority should not be a comfortable, unquestioned acknowledgment*. As discussed in many sections of this thesis, and in an immense amount of political theory, there are very strong and generally accepted reasons why our world should be shaped democratically, and not by an oligarchy of engineers. Second, *in the uncritical engineers-as-legislators account there is no need for a new political theory of engineered systems—we can simply extend old political theories*. That's because there is nothing politically new about engineered systems, and since they are not categorically different, they do not need their own political category. This belief that engineered systems do not require new political theory may prevent an understanding of how engineered systems have usurped democratic authority—and how we recover a democratic politics.

It is therefore useful to distinguish between "the depoliticization of engineering" and "depoliticized engineered systems." Engineering justice literature so far has investigated the depoliticization of engineering as a cultural phenomenon—the result of individual and group failings, both within and outside of engineering institutions—but it does *not* investigate depoliticization as something intrinsic to the subject of engineering, namely, engineered systems. For example, while Cech does note that "the ideology of depoliticization is deeply rooted in engineering," and hints that it might be easier to depoliticize engineering than, for example, legislating or judging, she does not enter into a discussion of why it might be that engineering is so easy to depoliticize (Cech, 2013). And Riley simply concludes, "the central problem lies in engineers' tendency to compartmentalize" (Riley, 2018, xviii). The assumptions (by omission) are 1) that there is no need for a political theory of engineered systems that would help to politicize them and/or 2) that many engineered systems are *not* themselves depoliticized or inherently difficult to understand politically. As this thesis makes clear, there is a connection between these assumptions, since the political theory of engineered systems provided in Chapter 2 argues that many engineered systems are inherently difficult to understand politically, at least with enough knowledge to properly politicize, that is, regulate, them.

Although both depoliticized engineered systems and the depoliticization of engineering are immensely important to recognize and address, despite an extensive literature review I have found no emphasis on the former dimension in engineering justice or political theory literature. Relatedly, I have found no established political theory of engineered systems—instead, engineered systems are treated as nothing new, even if it is casually acknowledged that "something seems to be different." There may be intellectual movement toward understanding the politics of engineered systems, as exemplified by much of the engineering and justice literature, as well as a recent talk by Khalid Kadir, hosted by the Online Ethics Center for Engineering and Science, that calls for "rendering [problems] political" (Kadir, 2022). This movement might implicitly recognize that in order for the theoretical, pedagogical, curricular, and system design responses to "the depoliticization of engineering" to be effective, there needs to be a complementary set of responses that is focused on the problem of "depoliticized engineered systems." However, it seems there has been no explicit acknowledgement or discussion of the need for a political understanding of engineered systems to complement a political understanding of engineering culture, even though such a complement seems especially urgent in order to prevent further entrenching harms, in the way that "greenwashing" is said to further entrench unsustainable (dis)economics, or "wokewashing" could further entrench systemic racism. We don't want to inspire engineers (or those affected by engineered systems) with a false confidence in their ability to understand "how technology benefits and harms diverse groups" and "potential power issues"—a false confidence that would actively hide the most important harms, harms to our ability to shape our lives together (Leydens and Lucena, 80). In the same way that efforts to improve corporate sustainability need to be complemented by efforts to transcend extractive and exploitive capitalism, efforts to politicize engineering culture need to be complemented by efforts to politicize—to understand the political consequences of—engineered systems.

This thesis provides the beginnings of that necessary complement. I provide a theory of how the most influential engineered systems in our lives depoliticize with respect to knowledge and participation. I also document the design and testing of a pedagogical and curricular intervention meant to help engineering students understand the politics of engineered systems—importantly, *not* to understand all the political effects of particular engineered systems, since I argue this is impossible for most existing systems which are in essence depoliticized.[3]

Another useful way to articulate the complement I provide is in terms of Joseph Herkert's popular distinction between "macro/micro ethics" and Langdon Winner's critique of engineering ethics education, to which Herkert is responding (Winner, 1990;

[3] It's worth noting that that in the workshops conducted as part of this thesis it was effective to emphasize how the technical depoliticization of engineered systems (that is, the fact that engineered systems are inherently depoliticized) contributes to a cultural depoliticization of engineering (that is, the fact that some engineers do not cognize the political effects of their work)—this shifts "blame" from a culture with which students might identify to systems that are further removed from them. It also gives agency, because their professional work is explicitly technical—it involves designing engineered systems.

Herkert, 2001, 2005). Herkert, and many others following him, have used the term macroethics to describe a much needed focus in engineering ethics education:

> Microethical issues in engineering include such matters as designing safe products and not accepting bribes or participating in kickback schemes. Macroethics in engineering includes the social responsibilities of engineers and the engineering profession concerning such issues as sustainable development and product liability. (Herkert, 2005.)

I agree that such a distinction is important and that more emphasis should be placed on macroethical issues and education, as engineering justice literature emphasizes. Nonetheless I think Herkert's distinction misses the fundamental point of Winner's call to cultivate "political savvy and the capacity for political imagination": if there is "a logical juncture where ethics finds its limits and politics begins," then at that juncture there is a need to begin a political exploration of engineered systems (Winner, 1990, pp. 58, 57).

Winner's distinction between politics and ethics is important, and the historical focus on engineering *ethics* rather than engineering *politics* is telling. A widely accepted modern theory of the relation yet distinction between ethics and politics is Max Weber's delineation, in his 1919 lecture "Politics as a Vocation," between "the ethics of conviction" and "the ethics of responsibility." On the one hand, the individual moral actor can commit with conviction to the rightness of an action without regard for the wider social or political consequences of said choice, because the choice is (to paraphrase) "correct for me." On the other hand, the political actor by definition must account for—be responsible for—the wider and indeed systemic effects of a technical system, policy, or law on the lives and choices of others in that actor's political community (Bruun, 2019). For Weber, and in many modern definitions of politics, the essence of politics is the systemic organization of power relations in a given community, necessarily confining the individual choices of community members. This modern disjunction between ethics or morality per se and politics per se thus includes a distinction between scale of effect and systemic-ness of effect, or between degree and kind. A theory of micro and macro ethical choices addresses the scale or scope of the individual choices made by one, few, or many moral actors; but political choices ultimately are systemic in that they define the conditions for individual moral choices, whether of smaller or larger scale of impact. It is true that much political theory about democracy is not as "amoral" about politics as Weber's theory seems to be; indeed, this thesis employs a widely accepted definition of politics as ultimately concerning the justice of living together in community. Nonetheless, ethics primarily concerns right action regarding discrete choices, while politics primarily concerns how to constitute the polity.

Thus ethics and politics are related, but a working distinction between ethics or morality as concerning individual choices and their effects of smaller or greater scale, and politics as the systemic conditions and rules confining individual and communal choices, should be introduced into the theory and practice of engineering—and the understanding of engineered systems—*so that engineers can more adequately understand their craft and profession* given its obvious political, or systemic, consequences.

To understand both modern political life and the modern engineering profession we need a political theory of engineered systems to supplement the many ethical theories of engineered systems, even the macroethical ones. We need this so that we can develop a political understanding of engineered systems, and a political imagination of how they might (better) support justice. We need to supplement the literature on engineering justice and ethics, which does not deeply engage with political theory in general, or democratic theory in particular. (This also holds true for the closely related design and critical computing literature, such as Batya Friedman and David Hendry's 2019 *Value Sensitive Design* and the 2018 collection *Critical Theory and Interaction Design.*) For engineers, engaging with political theory may be difficult for various reasons, including that this theory comes in book form and does not directly address technics; but it is immensely valuable not only because it is often clear, well-argued, and offers action-oriented arguments, but also because it directly addresses the motivational realities, hard work, institutions and conditions of living well in community together.

Pamuk's *Expertise and Politics*: Analogies Between a Political Theory of Science and a Political Theory of Engineered Systems

Another way to introduce the contribution and scope of my political theory of engineered systems is by analogy to a political theory of science.

Zeynep Pamuk's 2021 *Politics and Expertise* provides the theory needed to give sciences a strong political existence. As Pamuk writes, "while other fields have studied the relationship between scientific expertise and democracy using their own theoretical and methodological frameworks, political theorists have largely neglected the subject … my book joins [a recent effort] to establish the problems of scientific inquiry as a vital area of inquiry for contemporary democratic theory" (Pamuk, 2021, p.17). In other words, Pamuk's goal is to provide a political theory of the sciences that will help us to understand their politics so that we can address the harms or goods caused by the sciences in a systematic way instead of on a case-by-case basis. (It is worth noting how extraordinary it is that until two years ago there was no strong political theory of the sciences, and that Pamuk's theory is not better known, despite the fundamental and immense influence of the sciences in shaping our worlds.)

Pamuk's proposed political theory of the sciences rejects interpreting science as a "black box" but instead starts from a "philosophically precise account" of the relationship between facts and values, science and politics (Pamuk, 2021, 11, 186). A careful description of the relationship between facts and values is needed precisely because they cannot be disentangled—the boundary between them is not clear but blurred. In other words, sciences themselves, not just the effects of scientific work, are political because they shape our lives in controversial ways:

> if scientific assessments incorporate judgements about what is significant, adequate, plausible, relevant, or useful, and political goals are determined in light of research that incorporates such judgments, the values and purposes of scientists will end up preempting or circumscribing democratic deliberation from the outset… [S]cience and scientists hold a crucial power to set the agenda, frame the debate, and determine beliefs about feasibility. (Pamuk, 2021, 47-48)

Such preemption and circumscription of democratic politics results when politics and political theory deal with the effects of science after the fact and assume (erroneously) that sciences are sufficiently understood by non-specific political theories that don't investigate the sciences in a deep, holistic, "ontological" way—a way that traces how sciences affect our being-in-the-world.

Specifically, Pamuk criticizes the use of a "Weberian model" of the division of labor between scientists and politicians, which posits that there is in fact a clear boundary between facts and values and that the production of facts and their use in value-laden decision-making can be cleanly separated:

> current institutional arrangements respond to this familiar dilemma [of increasing expert power] by reverting back to the traditional Weberian division of labor… [D]espite the practical challenges of drawing the boundaries between science and politics, this model still underlies both the formal mandate of scientific advisory committees and [the] self-understanding of scientists who serve on them. (Pamuk, 2021, 67)

Pamuk's fundamental observation is that the Weberian model—in which scientific facts and political values are presumed to be separate ingredients that can and should be combined at the last possible moment during legislative decision-making—is an outdated model that no longer produces good outcomes, if it ever did. Democratic politics has been subverted, often unintentionally, by "poorly approximating an ideal [the Weberian division of labor model] that cannot be attained" (Pamuk, 2021, p. 185). We need to update our model of the sciences, mainly by showing how facts and values are deeply entangled.

Pamuk's descriptive claim about the inseparability of facts and values in most situations is not novel. What is novel is her synthesis of that descriptive claim with a normative claim (a claim about what should be done). As Pamuk writes:

> The relationship between science and democracy has been examined mostly by scholars in science and technology studies (STS) and the sociology of science along with a few philosophers of science. As a political theorist, what distinguishes my approach is that I place political institutions at the center of my analysis. [By contrast,] [s]cholars in STS have usually avoided thinking in terms of institutions and been particularly wary of taking a normative stance. (Pamuk, 2021, p.15)

A reductive but helpful description of Pamuk's book is that it synthesizes ontologies of the sciences and theories of participatory democracy, or, STS and democratic theory. It's worth noting that this is truly pathbreaking: Pamuk is the first to develop a normative political argument, in the language of democratic theory, from fundamental observations about the operation of the sciences in our world. It is new to synthesize descriptive and normative claims about the sciences in the language of democratic theory.

That is, while there are others who make normative claims about the sciences, Pamuk is unique in 1) focusing her normative claim on actual or potential democratic institutions, processes and conditions, and 2) therefore, since that is also the focus of democratic theory in general, making her claims in the language of and in reference to democratic theory. The result is that Pamuk's normative claims—most prominently that scientific advisory committees should write dissenting opinions and that science courts should play a key role in providing recommendations for value-laden scientific decisions (or science-laden value decisions)—are uniquely actionable and well-defended. Because her normative claims are made in the language of democratic theory, Pamuk can rely on the wealth of democratic theory that makes strong and generally accepted arguments about the desirability (with respect to justice) of participatory democratic politics. Further, because reforming institutions seems to be a relatively tractable problem (compared to, say, eliminating inequality or racism, or more directly reducing corporate influence upon science) Pamuk's proposals for improving the use of the sciences in a democratic politics are pragmatic and realistic.

Similarities Between My Argument and Pamuk's

The political theory of engineered systems presented in this thesis is analogous to Pamuk's political theory of the sciences: I develop a normative political argument from fundamental observations about the operation of engineered systems in our world. Following Pamuk, I do not treat engineered systems as black boxes but instead actually examine them on their own terms, attempting to understand their categorical operation in the world. I argue that we should investigate engineered systems in a deep, holistic, "ontological" way—a way that traces how engineered systems affect our being-in-the-world.

Similar to Pamuk, I assume that this careful description of engineered systems is necessary because of the important and controversial ways in which engineered systems effect how we live in community together. I therefore take issue with what might be called the Lincolnian model of the relationship between engineered systems and democracy.[4] Similar to the Weberian model of the relationship between science and politics, the Lincolnian model assumes that engineered systems are not in themselves political and therefore can be the means to achieve democratic ends without any externalities or unintended consequences. To the contrary, I argue that democracy is preempted and circumscribed by most engineered systems, categorically so, and not just because of misapplication.

For example, I argue that the problem with cars is not most fundamentally a host of known physical effects—such as carbon dioxide emissions, which would be "solved" by using battery or hydrogen vehicles powered by renewable electricity—but rather the unknown, uncertain, temporally-and-spatially-distant physical, social, political, economic and ecological effects of this immensely complex transportation system. The fundamental problem with transportation by cars is that it has convened what I term a *bigfastforever system*—a vast infrastructural network extending out in time and space. Highways lock future generations into a particular way of living and relating to the world, and thus block their participation in shaping their world (intergenerational injustice). The car-road system convenes a global supply chain of mines and factories that distributes and distances harms relative to the people who cause them, and also allows for the people

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[4] This is also the "modern" model of engineered systems; I call it the Lincolnian model in reference to Abraham Lincoln's *Lecture on Discovery and Inventions* (1858) and *Address to Wisconsin Agricultural Fair* (1859) in which Lincoln suggests that technics and engineered systems can be used to achieve certain types of equality and freedom. Attaching Lincoln's name to a model that I argue is inadequate is meant to emphasize the good intentions and historically beneficial effects of that model while also gesturing to the immense influence, in American politics and beyond, of this model. See Carrese, 2019 for further discussion.

who cause them to be distributed. These collective, distributed, and/or distant causes and effects prevent deliberating communities and engineers alike from developing the understanding necessary to make the car-road system more just. The car-road system is so vast that almost every individual is blocked from shaping this system though it fundamentally shapes how we, moving beings, move. Its particular effects change so rapidly that democratic deliberation, which proceeds relatively slowly, is forever behind the "emerging technology." In sum, the nonlocal spatial and temporal boundaries of the car-road system subvert political participation and knowledge, and the engineered system is therefore unjust. Changing the way in which the system is energized does not solve the most fundamental political problem it introduces, and may make it worse *if* it is not seen as a transition step toward technics that support a democratic politics.[5] The many questions that this briefly sketched argument raises are more fully explored in Chapter 2.

If democracy is categorically subverted by systems with big, fast and forever system boundaries, the problem with the Lincolnian model is that, following it, "current institutional arrangements respond to the familiar dilemma" of harmful engineered systems by regulating them, but not regulating the category to which they belong (Pamuk, 2021, p. 67). Despite our long track record of failure with this model—including climate change, forever chemicals like PFAS, nuclear weapons, algorithmic bias, "Internet" interference in democratic institutions (such as elections), ecological destruction—"this model still underlies" legislative bodies' decisions about regulating the harmful effects of engineered systems as well as the self-understanding of engineers (Pamuk, 2021, p. 67; on the last point, see Cech, 2013 and Riley, 2008).

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[5] Technics are artificial systems or artifacts; see texts cited supra note 1.

Like Pamuk, my descriptive claim about harms caused by the big, fast, forever nature—that is, the non-local nature—of engineered systems is not novel. There are many theorists whose work explores the difficulties caused by non-local systems. Some of their names, followed by the terms they use to describe the harms of non-local systems, are: Julia Nefsky, David Zoller, et. al. (collective harms); Timothy Morton (hyperobjects); Arturo Escobar and John Law (designs for a One-World World); Judith Lichtenberg (new harms); Jonathan Benson (low-feedback goods); Garrett Hardin (tragedy of the commons); Ronald Beiner (apolitical technology); Robert Dahl (inordinately complex systems); Benjamin Barber (quantity and specificity of data); Hannah Arendt (automation, unstable machine world, banality of evil); Ivan Illich (industrial systems); Bruno Latour (hybrids). Of special note are Walter Lippmann (complex environment), John Dewey (indirect consequences), and William Scheuerman (the acceleration of time) who dedicate books to developing a democratic theory that responds to the reality of non-local systems. There are even some theorists who synthesize the descriptive claim about non-local systems with a normative claim about how we should intervene in that reality in order to nourish democratic communities, Illich and Escobar in particular. Helped by these theorists, the task of more fully synthesizing descriptive and normative claims about engineered systems using the language of democratic theory is a much easier, smaller step. My arguments begin as incremental modifications or syntheses of such existing arguments.

However, analogous to the important innovation of Pamuk's work, it is new to synthesize descriptive and normative claims about engineered systems in the language of democratic theory. While there are others who make normative claims about engineered systems, my normative claim is unique in its focus on democratic practices, and ways of life, with a careful attention to their limitations and prerequisite conditions. The result is that my normative claims are uniquely actionable and well-defended—most prominently that (a) political analysis of engineered systems should focus on their size, speed and duration (bigfastforever) and (b) we should attempt to reduce the size, speed and duration of engineered systems and transition to a set of more spatially and temporally localized technics wherever and however we can in ways that support the fundamental human capabilities central to social justice. Because my normative claims are made in the language of democratic theory, I can rely on a wealth of democratic theory that makes strong and generally accepted arguments about the desirability (with respect to justice) of participatory democratic politics. So I think it is possible to say of my work as of Pamuk's: Because reforming engineered systems seems to be a relatively tractable problem, my proposals for reducing the injustices caused by engineered systems are pragmatic and realistic, albeit immensely countercultural.

Differences Between My Argument and Pamuk's

My argument differs from Pamuk's in crucial ways. I emphasize the intrinsic value of participating in shaping the communal, or to use Benjamin Barber's term, that "strong democracy" is preferable to the "thin democracy" of the liberal tradition (Barber, 2003). I argue that the endemic political uncertainty (or unintelligibility) caused by engineered systems is more problematic to a democratic politics than Pamuk suggests, and argue that such uncertainty can and should be reduced. I don't provide institutional suggestions in the way that Pamuk does (while engineering courts and dissenting design opinions are worthy of exploration, that is for another project). Instead, I focus on providing the theory needed by engineers (and other powerful people making decisions about engineered systems) in order to think politically and make good decisions. Here I'll briefly discuss my position on uncertainty and institutional reform vis-a-vis Pamuk.

As I argue in Chapter 2, if an engineered system distributes causes and effects in space and time such that there is a high level of uncertainty about who is responsible for the system, who is affected by it, and if they are affected now or later, then that system prevents any given political community from developing the political knowledge necessary to make good, just decisions. I therefore argue we should not design, and should work to transition away from, engineered systems that produce such uncertainty. In contrast, Pamuk is more fatalistic about uncertainty and optimistic about democratic politics' ability to deal with it. She argues that "uncertainty and lack of knowledge … must be overcome through more research and deliberation" (Pamuk, 2021, p. 192). She does not suggest that the underlying condition of high uncertainty needs to change (nor does she discuss how this underlying condition has changed over time). Though she discusses at length whether high risk (that is, high uncertainty and high consequence) engineered systems are unjust, she ultimately concludes that the question needs to be left to democratic deliberation, and she does not recommend a substantive theory that might guide deliberation (Pamuk, 2021, pp. 162-184). My argument in Chapter 2 can be read as a different approach to the question of how much uncertainty or risk is admissible. I assume that democratic politics is not as adjustable to varying conditions (such as high-uncertainty engineered systems), and that current conditions need to change. I therefore provide a substantive theory to guide the design, reform and transition away from or elimination of particular engineered systems.

Unlike Pamuk, then, I focus on providing a theory for engineers to act on, instead of on providing a theory that asks scientists to step out of the way (not act) in order to allow deliberating democratic publics to act. While I agree with Pamuk that expecting engineers "to discern and use social and political values…would be to assign [engineers] a duty of political representation … a role for which they are neither qualified nor properly authorized," the reality is that engineers took on that role long ago, and that democratic publics now barely exist as a result (Pamuk, 2021, p. 54; see discussion of Dewey in Chapter 2). For now, the reality is that democratic publics *should* be the actors, but engineers *must* be the actors. Now, if engineers want to support justice they must attempt to transition out of their current role as unqualified, unauthorized political representatives by designing systems that are amenable to democratic publics taking back political power. For that transition, engineers need a political theory of engineered systems that is for them. Insofar as democratic publics may begin to reemerge and begin making decisions about engineered systems, that theory will also be for them (us).

Chapter Summaries

Chapter 2 provides an account of how unprecedented characteristics of some engineered systems—their large size, fast rate of change, and long duration—affect politics. Political knowledge—the knowledge necessary to progress toward justice—is inhibited by global systems that "local people" (people are by definition local) can't understand, by technological change that outpaces deliberation and by systems with highly uncertain future effects. Political empowerment—the capability to act on a deep human need to shape our world—is inhibited by systems that are so vast that individual actions are negligible; that change before people can act to intentionally change them; and that lock-in future generations to a particular path. The chapter concludes with a discussion of practical strategies and tools engineers can use to design engineered systems in ways that advance social justice, broadly understood. In support of this goal, I apply my general account of how engineered systems affect politics to the case of The Stack (the global computing network).

Chapter 3 is a description of the research questions and methods for a study of workshops on engineering and justice. Our three research questions are:

> **RQ1:** What is Dartmouth engineering students' baseline capability to understand how engineered systems affect politics and to develop systems that inform and empower?
>
> **RQ2:** Does the workshop immediately increase Dartmouth engineering students' capability to understand how engineered systems affect politics and to develop systems that inform and empower?
>
> **RQ3:** What about the workshop contributes to or detracts from Dartmouth engineering students' capability to understand how engineered systems affect politics and to develop systems that inform and empower?

We use a quasi-experimental pretest/posttest nonequivalent group study design to answer these questions. The study is "quasi" experimental because we do not randomly sample Dartmouth engineering students: we select workshop participants to ensure gender balance and we have a small sample size. The study has two conditions: a workshop group and a control group. Between pre- and post- surveys, the workshop group participated in a three-hour, five-person (four participants and one discussion leader) semi-structured conversation over dinner or lunch, while the control group had no suggested activity. Our survey instrument was designed to measure key attitudes, knowledge and intended actions. We use quantitative methods to test RQ2 (gain from workshops), and hypothesize that there is a statistically significant difference between workshop participant score change and control participant score change. We use the qualitative method of thematic analysis to answer RQ1 (baseline knowledge) and RQ3 (workshop features and bugs), as well as to provide insight about the degree of increase in students' capability to understand how engineered systems affect politics and to develop systems that inform and empower.

The second part of Chapter 3 is a presentation of results from and a discussion of that study. There were 32 participants in our study, split evenly between the workshop and the control group. As measured by surveys and interviews, we find that: 1) workshops produced a statistically significant immediate increase in students' knowledge, attitude, and empowerment scores; 2) a variety of different workshop aspects boost scores and create value for students, including that workshops are dialogue-based, small in cohort size, long in engagement duration, use a booklet and are led by a peer who guided conversation. Future work will address limitations of the current study, specifically its small sample size, biased sampling, early stage of curriculum development, and lack of basic related research.

Chapter 4 is a brief Conclusion that summarizes how the thesis answers its two main questions—how should we think politically about engineered systems? and how might we help engineering students to think politically about engineered systems, and act accordingly? The Conclusion also provides recommendations for future research and action, including how Thayer School of Engineering could support student exploration of the politics and ethics of engineered systems.

Chapter 2: A Political Theory of Engineered Systems

Introduction: The Need for Normative Heuristics

How might we measure the injustice or justice done by an engineered system? In other words, how should we think politically about engineered systems?

Answering this question is necessary to act well in our highly engineered world. But it is particularly important that two groups of people answer this question well: first, engineering practitioners, educators and students who have the most agency in forming and reforming engineered systems; and, second, political theorists, who have the most agency in developing strong answers to this question.

However, we (I belong to all of the above groups) have few tools that help us to answer this question in rigorous ways since no normative theories aim to answer that question directly (see Chapter 1). This is a problem since it seems that there is something peculiar and unique about the effects of engineered systems on our world, and that there are many harms and injustices caused by engineered systems that we fail to prevent. It seems we cannot rely on existing political theories to help us understand the political effects of engineered systems.

Instead, measuring the (in)justice done by a particular engineered system seems to require synthesizing descriptive and normative understandings of that system. A normative understanding requires a strong understanding of justice, and a descriptive understanding requires an ontological understanding of the given engineered system—knowing what it is to the world, its causes and effects, its relations. Each of these tasks is monumental in and of itself. Political theorists pass lifetimes attempting to hone an understanding of justice. Life cycle assessment engineers have had to develop techniques to simplify models of the systems they analyze since a complete understanding of their causes and effects is impossible, and partial understandings are often so difficult as to become prohibitive (Li et al., 2014; Beemsterboer, Baumann and Wallbaum, 2020).

Since simultaneously accomplishing the normative and descriptive tasks seems to be an impossibility, is there a way to focus each task so that it is possible to do both at once, and provide a feasible yet rigorous way to measure the (in)justice of an engineered system?

This chapter presents such a way to focus each task. It presents a political theory of engineered systems that argues there are categorical features of some engineered systems—their big, fast and/or long-term system boundaries—that produce particular injustices. Focusing on these categorical features is important because it allows for categorical regulation that transcends the case-by-case regulation typical of modern politics.

Since this argument might seem anti-engineering or unrealistic, a few preliminary clarifications are in order. This argument *is not* an argument for cancelling engineering—understood as the application of mathematical modeling to designing, forming and reforming our worlds. In fact, a key part of the argument is that engineered systems currently subvert precisely that meaningful activity of engineering. I argue that if an engineered system undermines human capability to form our worlds, it is unjust: this is the second normative heuristic discussed in this chapter. Most of the fundamental engineering and design techniques and practices that are used by engineering students, researchers and practitioners can be and are used for world-forming. Though they could be, most of these techniques and practices are largely *not* applied to making, tending and repairing spatially and temporally local systems. Much engineering is thus currently unsustainable and self-defeating. It does not make engineers more capable of designing, forming and reforming our world. It would be a huge, radical change from the status quo if engineering work resulted in politically healthy systems—that is, systems that promote political knowledge and empowerment. This change could and should happen.

This argument *is* an argument for cancelling—or at least transitioning away from—most existing engineered systems. The big, fast and/or forever system boundaries of engineered systems inhibit the possibility of democracy and meaningful human lives by subverting political knowledge and our capability to shape our communal lives. I hope this argument leads to future research on the system boundaries of engineered systems, but until we have more information I assume that almost all engineered systems have non-local system boundaries. Life cycle assessment (LCA) engineers support this assumption: Suh et. al. (2004) write that “considering the complex interdependence of processes in modern economies, it would be fair to assume that in general all processes are directly or indirectly connected” and Majeau-Bettez, Strømman and Hertwich (2011) write that “to accurately describe any value chain would require that the entire economy be inventoried.” It’s worth noting that this entanglement of all engineered systems in all other engineered systems has sparked a kind of existential debate (that stops far short of my arguments) among LCA engineers since they recognize that such global systems might require “economy-wide” system boundaries, and that this is a major problem for our understanding of those systems (Gibon and Schaubroeck, 2017; Schaubroeck and Gibon, 2017; Yang, 2017a, 2017b).

However, engineered systems could have local system boundaries, and I can envision road, water delivery, computing, and electric power systems with local system boundaries. But it will take immense restraint to *not* build systems that we are technically capable of building and instead to phase out bigfastforever systems, especially since the status quo depends on them. Perhaps the unlikelihood of such restraint will change if more people perceive the political harms imposed by engineered systems; for example, I think young people who are attracted to world-forming, as I have found most engineering students are, might be convinced to use their world-forming capabilities to make, tend and repair local systems that do not inhibit others' capability to form their worlds.

Towards a Political Understanding of Technics with Big, Fast and Long-Duration System Boundaries

This section discusses common-sense and scholarly approaches to contemporary problems that are useful introductions and inspirations to a political understanding of engineered systems. While I think these approaches help to understand my core argument and its significance, they are ancillary to my core argument. My core argument begins in the subsequent section, "First Normative Heuristic."

Globalization

"Globalization" is a familiar phenomenon to most. Many recognize that our most basic daily functions—including eating, moving, sleeping, playing, loving—are often affected by and affecting a global set of Others. Apples available in Hanover, NH are from Chile and New Zealand and their packaging is destined for the Pacific plastic gyre; global warming and mines and wars are produced by our cars, parts of which are produced who-knows-where; we experience sleep-deprivation from anxiety about global phenomena or sleep-augmentation from Prime-delivered physical and chemical soporifics; we mountain bike or game on East Asian-made products; we use “the Internet” to talk with family in other continents; subsistence farmers in Bangladesh are affected by flights and drives to a ski trip; all are affected by a global pandemic. Our fates, the shape of our individual and communal lives, seem determined by a huge web of interconnected and interdependent “actions.” Everyone seems to have a stake in every action.

Many people also seem to recognize that such global interrelations are not neutral, but have good or bad effects on their present and future selves and communities. Steel workers in Colorado, software engineers in cyberspace, investment bankers in New York, sweatshop workers in China, people in Bangladesh, frogs in Hanover, NH—all seem to have a stake in coal fired power plants in Tennessee and China, global supply chains for steel, trans-oceanic fiber optic cables, the operation of the Suez Canal, cobalt mining in the Democratic Republic of the Congo, PFAS contamination. Among all possible costs and benefits (including existential, moral, spiritual, financial, political, economic, aesthetic), some will win in many ways, and all will lose in some ways. It seems that the quantity of losers is large and increasing, though there is much debate on this; see, for example, the difference between Steven Pinker’s *Enlightenment Now* (2018) on the one hand and Feldman, Geisler and Menon’s *Accumulating Insecurity* (2011) or Ulrich Beck’s *Risk Society* (1991) on the other.

At the same time, most feel powerless to affect global interrelations. Though I might be affected by transoceanic fiber optic cables and CO_2 and PFAS emissions, what can I do? Furthermore, though I realize driving to ski or buying a new phone is part of a collection of similar actions that has a huge collective effect, I don't (or can't) think that my individual action or non-action will change that collective effect. We are fundamentally disempowered: we have a negligible influence on the artificial phenomena that most affect our lives.

It turns out that many scholars focus on the disempowering aspects of globalization. Below I discuss how their concepts and arguments can help refine and clarify our understandings of what is happening and what is at stake. But before discussing in more detail how common-sense perception of "globalization" can be analytically refined by related scholarship, it's useful to discuss two topics: 1) what is new and what is not new about globalization, and 2) how common-sense and scholarly accounts of globalization often ignore discussing particular engineered systems, and almost always ignore discussing the category of engineered systems.

First, "global" interactions, or artificial systems with non-local system boundaries, are not new (see Peeters, Bell, and Swaffield (2019) for further discussion). We know of long-distance interactions that occurred many centuries before industrialization, such as the overland trading and conquest via the Silk Road and Roman roads, and the overseas trading and conquest of the Columbian Exchange (and European colonialism in general). It's a possibility that the remarkably stable climate of the Holocene was caused by agriculture (Salinger, 2007). The wheel, the camel/horse/ox, and the galleon were key transportation innovations that facilitated such long-distance interactions. Further, *disempowered* global interactions are not new. In other words, being unable to change a life-forming artificial system because it is non-local is not new. Disempowerment seems to be the rule and not the exception in human history, particularly with respect to large artificial systems in which many actors are involved and only a small part of which is experienced in any given locality. (The heuristic rule, ignoring hierarchy, is: As the number of people involved in a system or action increases, the possible effect any one individual can have decreases proportionally.) Nonetheless, most people think of globalization and their experiences of it as new and unprecedented. What is new and unprecedented?

What does seem to be new is 1) the quantity and quality of such non-local systems and 2) a thick normative theory of democracy—that people should *not* be so politically disempowered.

In 2023, the number of non-local systems, and various emergent non-local systems-of-systems, is unprecedented. These systems are also qualitatively different in that they 1) allow inputs to be distributed in unprecedented ways, 2) often operate at much higher speeds, 3) have more distant-future consequences and 4) are existentially risky. “The Grid” and “the Internet” (insofar as they are separable) are good examples of systems with highly distributed inputs/outputs and immensely fast state change. While electric power and information networks are also forever systems, the more obvious example of a system with distant-future consequence is toxic “forever chemicals” that persist in the environment “forever” relative to the temporal locale of a human life. Such distributed inputs, high speeds, and forever outputs—big, fast, forever—are allowed by engineered technics that apply mathematics to model and control systems. Additionally, some of these global systems have existential global effects in the way that the ancient roads and ships did not. Oil extraction and combustion systems as well as nuclear weapons systems threaten to end the existence of many lifeforms, including human lifeforms. While exploitive colonial or trade systems of the past have been existentially threatening or destructive to various communities, it is new for a system or systems to have a globalized existential risk—that is, our peculiar “risk society” is new (Beck, 1992).

Additionally, in 2023 most subscribe to the democratic theory of justice that people should be empowered to shape their worlds. Though there are good arguments that in practice democracy is really about social equality, the theory holds that democracy is ideally about political empowerment, that people should have agency in their world. Believing that democracy does or can exist seems naïve in the face of disempowering non-local systems, but as I will argue, shaping our collective worlds is a necessary part of a meaningful life and so should be central to a theory of justice and fiercely enabled and defended in practice.

Finally, many casual and scholarly discussions of globalization rarely discuss how engineered systems enable globalization. Indeed, my use of the word “systems” above is actually rather unusual: most scholars focused on the ethical implications or problems caused by bigfastforever systems exclusively focus on their effects and leave the causes of those effects (that is, the systems themselves) as a “black box” that does not need to be interrogated. These scholars provide immensely useful ideas, some of which I discuss below, but their failure to interrogate systems, to focus on things and how we can change them, is a strange resignation to an “evolutionary” or “deterministic” theory of technological progress. We need to swap such an attitude of “techno-fatalism” for an attitude of "techno-constructivism" that pragmatically asks how particular engineered systems must be designed, redesigned, or eliminated in order to transition toward justice.

Hyperobjects

Though a careful ontology—a study of being—of engineered systems is still lacking, in this section I'll discuss literature that provides entry points into thinking about the problems caused by what I have called "bigfastforever systems" or "systems with nonlocal boundaries."

It's best to start with hyperobjects. In his 2013 *Hyperobjects* Timothy Morton writes: "I coined the term *hyperobjects* to refer to things that are massively distributed in time and space relative to humans" (Morton, 2013, p. 1). Hyperobjects include many phenomena that are not artificial, such as the "Lago Agrio oil field in Ecuador, or the Florida Everglades," or the Solar System, or "the sum total of all the nuclear materials on Earth, or just the plutonium, or the uranium" (Morton, 2013, p. 1). But hyperobjects also include artificial phenomena such as "Styrofoam or plastic bags, or the sum of all the whirring machinery of capitalism" (Morton, 2013, p. 1). The world used to consist of non-artificial hyperobjects (various ecosystems, or earth-systems) that contained a few human objects. Ancient ships and roads were systems that had nonlocal boundaries—they affected people and places far-off in space and time—but they were not quite (artificial) hyperobjects. That's because a world in which artificial hyperobjects exist has actually ceased to exist as "the world" that can be something stable and separate from us: "hyperobjects are directly responsible for what I [Morton] call *the end of the world*"

(Morton, 2013, p. 2, emphasis in original).[6] Morton uses two engineered systems to delineate the end of the world and the beginning of the Anthropocene, steam engines and nuclear weapons:

> The end of the world has already occurred. We can be uncannily precise about the date on which the world ended. Convenience is not readily associated with historiography, nor indeed with geological time. But in this case, it is uncannily clear. It was April 1784, when James Watt patented the steam engine, an act that commenced the depositing of carbon in Earth's crust—namely, the inception of humanity as a geophysical force on a planetary scale. Since for something to happen it often needs to happen twice, the world also ended in 1945, in Trinity, New Mexico, where the Manhattan Project tested the Gadget, the first of the atom bombs, and later that year when two nuclear bombs were dropped on Hiroshima and Nagasaki. (Morton, 2013, p. 7)

I do not dwell here on how hyperobjects have ended the world; while I do not disagree with Morton, I think it is helpful to be more analytically precise in order to provide an account of the conditions under which the world could again exist. Nonetheless, Morton's discussions of hyperobjects are useful because of a key analogy he develops and because of his subsequent descriptions of hyperobjects.

Morton's key analogy is between artificial and "Natural" systems.[7] The problem with artificial hyperobjects is that they resemble "Natural" systems in their size, duration, and speed. For example, anthropogenic global warming, Morton's archetypical example of an artificial hyperobject, is a problem precisely because it has taken on the speed, size,

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[6] Morton's use of "world" to describe a place that is (mostly) not conditioned by but rather conditions human life follows many other theorists' usage. It is particularly helpful to note that Morton's use is highly analogous to Hannah Arendt's in *The Human Condition* (1958) in which she notes, to fuse their languages, that the hyperobject of aerospace engineered systems have caused the end of the world.

[7] I follow Morton in capitalizing "Nature" and its derivatives "precisely to 'denature' it, as one would do to a protein by cooking it" (Morton, 2013, p. 4). However, I will also write "Nature" in quotation marks to indicate that I think something like previous understandings and functionings of "Nature" should be recovered precisely so that we might have a world. That is, unlike Morton, I assume that life is not worth living without a world to live it in, and that we therefore must figure out ways to recover our world. This will likely require developing moral and aesthetic relationships to our places and ecosystems that resemble ancient ways of being toward "Nature" (as opposed to the new Western way of subjugating "wilderness" for the relief of man's estate, to use Francis Bacon's world-transforming phrase). See Robin Wall Kimmerer's *Braiding Sweetgrass* for further discussion of these themes (Kimmerer, 2013).

and duration of the earth's climate. Morton uses the first half of the book to discuss characteristics of objects that are big, fast and/or long-duration. These descriptions are worth reading because they provide one of the best existing frameworks for an ontology of engineered systems—frameworks that help understand the physical or systemic causes of "globalization" and the concomitant class of moral, ethical and political problems.

However, Morton's theory of hyperobjects omits a discussion of how engineered systems are the necessary producers of hyperobjects. For example, Morton does not specify what precisely is artificial about his archetypical example of an artificial hyperobject—anthropogenic global warming. This is a key omission because, as Morton implicitly claims, it's only problematic when a system is a hyperobject *and* artificial. "Natural" hyperobjects, such as the pre-industrial climate, do not cause political crises, and are instead one of the requisite conditions of politics. In order to understand the (immense) political problem caused by global warming, and therefore how we might do something about it, we need to specify what is anthropogenic about global warming. We need to understand how the engineered systems of fossil fuel extraction and combustion have taken on the speed, size and duration of the earth's climate. We need case studies of how particular engineered systems are (or produce) hyperobjects so that we can develop normative heuristics and a general regulatory strategy.

We therefore need to build on, or deepen, Morton's theory of hyperobjects in order to arrive at a theory that provides an actionable approach to artificial hyperobjects.[8]

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[8] Future political ontologies of engineered systems might find discussions of "hybrids" in Bruno Latour's *We Have Never Been Modern* (1993), and discussions of infrastructure in design theory literature, to be similar and complementary to Morton's hyperobjects.

Collective Harms (and New Harms, Complicity, Banality of Evil)

Like Morton's *Hyperobjects*, literature that explicitly addresses categorical harms caused by "globalization" provides useful context for my own arguments. The literature that I think does this best—by focusing on how bigfastforever systems subvert strong democracy—is discussed below in the "Normative Heuristic" sections; in this section I'll address literature that is more focused on the moral problems caused by bigfastforever systems. While this literature is useful for establishing 1) how bigfastforever systems cause moral problems and 2) how those moral problems are severe and unlikely to be solved, it is most useful for 3) providing an analytic framework for thinking about how engineered systems can distribute harms to the extent that they are hidden and unrecognizable to our moral senses.

One such literature is focused on "collective harms." Though most of the philosophy and legal scholars who discuss collective harms simply take for granted that such categorical problems exist, most also implicitly gesture to how engineered systems are bringing about these problems. For example, in her 2019 paper "Collective Harm and the Inefficacy Problem," Julia Nefsky writes:

> Cases of 'collective harm' are ubiquitous. In these cases, when enough people act in a certain sort of way serious harm results, and yet no individual act of the relevant sort seems to itself make a difference.
>
> Climate change: Enough of us driving, flying, turning on our air-conditioners, etc., contributes to causing climate change, and its harmful consequences, but any one such act does not seem to make a difference. For instance, things will not go differently with respect to climate change depending on whether or not I fly to Europe this summer, or whether or not I take my car to work today.
>
> National election: Enough people voting in a large election for a bad political candidate (or failing to vote against them) could result in tremendous harm (e.g., increased poverty, environmental destruction, and unnecessary wars), but one vote won't make a difference. The winner will be the same give or take one vote.

> Consumer choices: Collective consumer choices affect global poverty, worker exploitation, animal welfare, and the environment, but it is often doubtful that a single purchase will make a difference. Will it make a difference, for instance, to chicken suffering on factory farms whether or not I buy a factory-farmed chicken at the butcher? A factory farm operates at such a large scale; one purchase more or less is surely not going to affect their production decisions. (Nefsky, 2019.)

In other words, the most pertinent cases of collective harm emerge when engineered systems have distributed the causes of a harm to the extent that any individual cause seems negligible. Although it's possible for cases of collective harm to emerge without the facilitation of engineered systems (Nefsky uses the example of how many people crossing grass can generate an undesired dirt path), it seems that more familiar, non-collective harms predominated before industrialization (Nefsky, 2019). Though Nefsky notes that discussions of some version of collective harms date back at least to Aristotle, she writes that "globalization, modern technologies, and massive increases in global population have made the inefficacy problem pervasive and of particularly pressing importance" (Nefsky, 2019, p. 11; see Ostrom, 2015, p. 2).

Judith Lichtenberg puts it this way:

> Over the past few decades, but especially in the past few years—with economic, environmental, and electronic globalization rapidly increasing; near consensus about the threat of severe climate change, whose effects will be felt most by the world's poorest people; knowledge that the provenance of products we use every day is compromised in a variety of ways; and, finally the growing impossibility of remaining ignorant of these phenomena—we have learned how our ordinary habits and conduct contribute to harming other people near and far, now and in the future. The model of harm underlying the classic formulation of the harm principle—discrete, individual actions with observable and measurable consequences for particular individuals—no longer suffices to explain the way our behavior impinges on the interests of other people. (Lichtenberg, 2010)

This echoes Samuel Scheffler, who writes that local ethics is challenged by "science and technology" and "the continuing revolutions in travel, communications, and information processing" (Scheffler, 1995, p. 228).

Other than "collective harms" and "new harms," terms used to describe the category of engineered harms are "complicity" and "banality of evil." (The many related concepts, not discussed here, include Elinor Ostrom's (2015) "common-pool resources" problems; Garrett Hardin's (1968) "tragedy of the commons"; Jonathon Benson's (2019) "low-feedback goods"; and "intergenerational justice" (see Yogi Hendlin, 2014).) Christopher Kutz's discussion of complicity in *Complicity: Ethics and Law for a Collective Age* (2000) seems to have jump-started the collective harm literature, and Hannah Arendt's use of "banality of evil" in *Eichmann in Jerusalem* (1963) has been widely used as fodder for thought about these contemporary moral and political problems.

While neither Arendt's nor Kutz's discussions are as focused as the collective harms literature on harms produced by engineered systems, it is clear that for them problems of complicity and banal evil only arise in the bureaucratized situations allowed by engineered systems. For example, while the "enormous and complicated crime" of the Holocaust in which Eichmann participated seems to be banal most obviously because of its organizational structure, such that the act of murder was far removed from all or most people who contributed to the murder, it was engineered systems that enable the existence of this bureaucratic, unthinking organizational structure (Arendt 1963, p. 225). Without the "technical devices" of gas chambers and railroads and the telegraph, Eichmann would not have been able to murder only by being dedicated to logistical quality—to murder without intent (Arendt 1963, pp. 250, 254). Without engineered systems that distribute the causes of harm, it is impossible for someone who participates in killing to be spatially, temporally, and psychologically "remote from the actual killer" on a routine basis (Arendt, 1963, p. 225).

While it is often not the point of literature on collective harms, new harms, complicity and banality of evil (hereafter "collective harms literature") to demonstrate the insolubility of the problems they discuss, the pragmatic thrust of this literature is that collective harms are politically insoluble. Though many authors conclude on optimistic notes about the possibility of regulating collective hams without changing their underlying causes—Lichtenberg suggests "acting collectively" while Nefsky suggests committing to right action even though it doesn't make a difference—this optimism does not follow from their arguments (Lichtenberg, 2010, pp. 576-577; Nefsky, 2019). Instead, their arguments suggest that just regulation is impossible when engineered systems distribute harms to the extent that they are hidden to our local, interpersonal ethics. However, because this provocative argument is never made central to collective harms literature, it is best to use the literature mainly to provide an analytic framework that can be used to build a version of that claim.

That is, the most important contribution of collective harms literature is to argue that *1) collective harms are the category of harms for which causes are distributed, and 2) by distributing the causes of some event, engineered systems effectively hide harms such that causes of harm are unrecognizable as causes of harm.*

On the first point, the distributed causes of collective harms distinguish them from other types of harm with which we are familiar, the causes of which are concentrated (see Table 1). Collective harms are caused be some inchoate group of strangers that do not strongly identify with the group, but nonetheless may be conscious of acting in concert with others. Strangers and I cause the carbon dioxide emissions that cause the harms of climate change, but we cannot be sure who is a part of this strange group with us, except by abstract analyses.[9] Agents that are a part of the acting group are only rarely conscious, if ever, of being part of the collective action. That's partly because the individual, partial causes of collective harms are negligible—no single action seems to make a difference to the harm, though a collection of many single actions is precisely what causes the harm (Zoller, 2015; Nefsky, 2019). When one's contribution to the harm seems to have no bearing on whether it occurs or not, the harm is "*causally overdetermined,* in that the effect has more partial causes than would have been required to bring this effect about" (Tiefensee, 2022; emphasis in original). The causally overdetermined nature of many collective harms is one of the mechanisms that allows us to cause collective harms with good intentions.

As Table 1 notes, collective harms can be further categorized by whether they result in distributed harms or concentrated harms, and whether those concentrated harms are close or far. Hannah Arendt's banality of evil is a type of collective harm for which the causes are distant; this is also Judith Lichtenberg's general interpretation of new harms. A "tragedy of the commons" harm is the type of collective harm for which the effects are also distributed. Collective harms always result in what Kutz (2000) calls complicity and are often produced by what Benson (2019) calls "low-feedback goods"—

[9] As Kutz (2000) points out, what I (following other scholars) call "collective harms" might best be thought of as "*unstructured* collective harms." That's because we are familiar with *structured* collective harms which are caused by a well-defined group intentionally coordinating their actions such that they know "we cause their harm" and therefore also "I cause their harm." Correspondingly, in Table 1 structured collective harms would be in the category of harms with non-distributed (concentrated) causes. Following Nefsky (2019) and others, I stick with using collective harms with no clarifying adjective since I think our common-sense understanding of "collective action" tends more towards the unstructured situation, and hence we only need to clarify with the extra adjective when we want to indicate the structured situation.

goods on some market that provide very little information about their effects. Further, Table 1 assumes that non-distributed causes of a distributed harms are impossible, since a distributed harm seems to require an engineered system that itself requires distributed causes; potential counterexamples, such as nuclear weapons, are quickly shown to be systems with distributed causes. It also assumes that the category of self-harm (when friends and I cause harm to me and friends) doesn't exist for practical (political) purposes.

Table 1. An analytic framework of harms suggested by collective harms literature.

	Collective Harms Distributed Causes (strangers and I cause)	**Conventional Harms** Non-Distributed Causes (friends and I cause)
Distributed Effects (harm to me and strangers)	• Climate change • Nurdles	*(assumption: non-distributed causes cannot have distributed effects)*
Non-Distrib. Near Effects (harm to me and friends)	• Industrial accidents • East Palestine, OH train fire (2023)	*(assumption: self-harm is practically nonexistent)*
Non-Distrib. Far Effects (harm to strangers)	• Sweatshops • CAFOS • Rare earth mining	• Conventional war • Murder • Colonialism

Because the causes of collective harms are distributed, we are unlikely to see each individual cause, each individual action, as one of the many causes of a harm. We are likely to see causes of collective harm exclusively as something else, such as driving to the ski area or buying socks or obediently doing our job, as Eichmann did. What Arendt and collective harms scholars point out is that we are actually quite justified in doing so:

systems that distribute the cause of some event make it easy *to do harm without intending to do so.* It is immensely difficult to "see" how our actions are part of a collective action that causes harm, so it is easy to intend to do good—to be nice and hard-working—while actually contributing to a harm. This provocative claim is why Arendt received so much criticism of her analysis of Eichmann's motivations: people were outraged and discombobulated by the proposition that someone could participate in mass murder without the intent to murder, only with the intent to do a good job. Though this claim is becoming less outrageous, it is still discombobulating to claim that somebody remote can participate in causing the harms of global warming or child labor or mass poisoning or animal cruelty. We are not well equipped to understand this sort of harm.

It turns out that our being ill-equipped to understand collective harms—or, more strongly, *that collective harms are insoluble*—is one of my two main arguments for why we should work to transition away from bigfastforever systems, or why justice requires that political community be conditioned mainly by relatively slow, small and short duration systems. But being ill-equipped to understand collective harms also makes this argument particularly difficult to understand.

To accentuate the difficulty: In order to understand why collective harms are impossible to understand, we need to understand collective harms. To put it in the most reductive terms, it seems I am paradoxically assuming that collective harms are and are not understandable.

It is therefore worth clarifying that I think the abstract, categorical features of collective harms are understandable, while actual collective harms are, for political purposes, impossible to understand. We can understand the systems that cause collective harms well enough to understand that they are politically inadmissible—precisely because we cannot understand them further. I am aware that it is risky to claim to know enough about unknowable phenomena that we should act in particular ways. However, the costs of not making this claim—an inability to think about collective harms and so a failure to develop a political theory of engineered systems—seem high enough to justify the risk. Further, this sort of claim is backed by one of the most prominent theorists of how to regulate collective harms, Elinor Ostrom, who suggests that individuals and groups can extricate themselves from collective harms dilemmas by "changing the rules" that cause the dilemma (Ostrom, 2015, p. 21). To use Ostrom's language, then, I am suggesting that we should strive to "change the rules" of our dilemma by developing sufficient political knowledge of collective harms situations in order to act on them.

First Normative Heuristic: Is an Engineered System Designed for Political Knowledge?

> *I want you to understand, though I'm not sure I do, completely—why [it] was so hard to say [that the Problem was a severe injustice]; why, even when all the evidence was there before us, it was still difficult to name. I think it had something to do with how much of our ethics were still built on the foundation of intent, reliant on the increasingly irrelevant language of person-to-person causality. Murder, theft, adultery—these were problems for which we had a script. Even typical human rights violations, perpetrated directly by a government on its people, were usually legible. But we'd been thrust into a world where the most influential moral currencies—data, carbon, capital—were circulating far above our heads, through networks of impossible speed and complexity. Our technological innovations had outpaced our moral innovations in both ingenuity and popular uptake, and so we were stuck wielding localized ethics in the face of globalized problems. Loosed from the boundaries of intuitive causality, then, sociopathy was easier to mask, harder to question.*
>
> — Daniel Sherrell, *Warmth* (2021) pp. 51-52

In this section I focus on the harms to political knowledge caused by engineered systems with nonlocal system boundaries. The basic argument can be phrased as a syllogism:

> Premise 1: It's impossible to have political knowledge of non-local constitutive artificial systems.
>
> Premise 2: Political knowledge of constitutive artificial systems is necessary to progress towards justice.
>
> Conclusion: Therefore, non-local constitutive artificial systems inhibit progress towards justice; they are unjust to the degree that they do so.

While this argument is new, there are strong arguments in defense of the second premise, and arguments that help contribute to the first premise. My goal in this section is provide defenses of both premises.

In order to do so it is useful to introduce the most thorough discussion of how political knowledge is subverted by nonlocal artificial systems: a century-old intellectual exchange between Walter Lippmann and John Dewey. In books written two years apart (it was a slow exchange), each took slightly different positions on the crisis of political knowledge caused by what Dewey called "the machine age" and Lippmann called "the Great Society." Both were concerned that the size and speed of early 20th century engineered systems were impossible for people to understand, even though those very same systems were responsible for the defining features of peoples' lives. In his 1925 book entitled *The Phantom Public* Lippmann writes:

> The environment is complex. Man's political capacity is simple. Can a bridge be built between them? The question has haunted political science ever since Aristotle first formulated it in the great seventh book of his Politics. He answered it by saying that the community must be kept simple and small enough to suit the faculties of its citizens. We who live in the Great Society are unable to follow his advice. The orthodox democrats answered Aristotle's question by assuming that a limitless capacity resides in public opinion. A century of experience compels us to deny this assumption. For us, then, the old question is unanswered; we can neither reject the Great Society as Aristotle did, nor exaggerate the political capacity of the citizen as the democrats did. We are forced to ask

> whether it is possible for men to find a way of acting effectively upon highly complex affairs by very simple means. (Lippmann, 1925, p. 33)

In his 1927 text *The Public and its Problems,* Dewey writes:

> Indirect, extensive, enduring and serious consequences of conjoint and interacting behavior call a public into existence having a common interest in controlling these consequences. But the machine age has so enormously expanded, multiplied, intensified, and complicated the scope of the indirect consequences, has formed such immense and consolidated unions in action, on an impersonal rather than a community basis, that the resultant public cannot identify and distinguish itself. And this discovery is obviously an antecedent condition of any effective organization on its part. (Dewey, 1927, p. 126)

Engineered systems had caused a crisis of political knowledge for democratic publics. Both Dewey and Lippmann assumed that "exaggerating the political capacity of the citizen" was not a solution. Therefore, as Lippmann makes explicit, there are two main ways forward: 1) assume that engineered systems cannot be changed in the relevant ways, but democratic institutions can be, and therefore focus on changing democracy to meet the unchanging reality of technology or 2) assume that democratic institutions cannot be changed in the relevant ways, but engineered systems can be, and therefore focus on changing technology to meet the unchanging reality of democracy. The problem of waning political knowledge seems to be a mismatch between potential knower and potential known; between citizen and system; between public and technic.[10] What contributes more to the problem: that the knower is ignorant, or that what is desired to be known is unknowable? That the citizen is unintelligent, or that the system is unintelligible? Do we need to focus on changing the public or the technic?

In accord with Lippmann, Dewey assumes we "cannot reject the Great Society" and chooses the first option—he assumes that engineered systems cannot be changed in

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[10] This is precisely the "democratic dilemma" addressed by Lupia and McCubbins in *The Democratic Dilemma* (1998). However, unlike Dewey and Lippmann, Lupia and McCubbins do not address how the strength or difficulty of this dilemma might be accentuated by engineered systems or "technology."

the relevant ways and therefore cannot be a focus of political reform. Both Lippmann and Dewey assume that the only relevant question is how to adjust democracy to the reality of engineered systems. As a result, both of their books are devoted to describing how democracy can and should adjust to "complex" systems and their "indirect consequences," how we can improve the public or the public's institutions.

This pattern holds for other political theory, which almost invariably assumes that better civic education, expert testimony, reform of political institutions, or some combination of all three can remedy the problem of public ignorance of the engineered systems that constitute our communal lives. No political theorist has carefully examined the second option and asked how engineered systems should be designed in order to allow for political knowledge. It seems that all political theorists have assumed that engineered systems can't be changed at all or enough to make worthwhile a careful inquiry into the constraints placed on engineered systems by the limits of political knowledge. As a result, no one has asked how we might design systems to be politically intelligible. No one has asked what sort of systems are inadmissible because they cannot be understood in the ways necessary to inform political decisions.

As discussed in Chapter 1, there are many possible reasons for a lack of focus on technics. Perhaps the most prominent are fallacies of techno-determinism, techno-neutrality, and techno-optimism. Against these fallacies, I believe that: we can form technical systems (the design of technics is not deterministic); technical systems constrain and allow all sorts of human doings and beings (the design of technics is not neutral, but has effects ranging from good to bad); we should not put all of our hopes in the technical solutions basket (technical designs are one particular, limited, if powerful, sort of design). Another potential reason that there has been insufficient discussion of what engineered systems are politically intelligible is that the “epistemic democracy” literature that focuses on understanding the relationship between political knowledge and democracy has a “preoccupation with knowledge exploitation” to the near exclusion of a discussion of knowledge creation (Müller, 2018). In other words, because epistemic democrats are only focused on how to make use of political knowledge, they have not asked how we can create political knowledge of the systems that shape our communal lives, and how certain engineered systems can support or inhibit that creation of political knowledge. This may be because there has historically been a relatively static world and a relatively static “knowledge stock,” but given the increased complexity of engineered systems it is naïve and misleading to exclude a discussion of the conditions for knowledge creation (Müller, 2018).

In this section I make a preliminary inquiry into the constraints the limits of our political knowledge should place on engineered systems. That is, against the assumptions that engineered systems *can't* be changed in the relevant ways and that democratic institutions *can* be changed in the relevant ways, I argue that engineered systems should be designed so as to provide the right conditions for the existence of political knowledge, which I argue is a conditional sort of knowledge. I disagree with Lippmann, Dewey, and the vast majority of theorists that the only relevant question is how to adjust democracy to the reality of engineered systems. Lippmann's and Dewey's accounts are useful in articulating the problem itself, but are misleading because they hastily assume that technology is inevitable and that democracy needs to adjust to a technological inevitability. Most people recognize that we no longer have the luxury of allowing technics to be inevitable, but that we must regulate them in some way. Many people recognize that certain technics are destroying environmental and social fabrics necessary for meaningful lives.

As a result, it is imperative that we develop a political understanding of such technics with the goal of eliminating unjust technics, supporting existing just technics and designing and building just technics that don't yet exist. We should ask the question that Dewey and Lippmann do not ask—how can we adjust engineered systems to the reality of democracy? And specifically with regards to political knowledge, about what sorts of phenomena is it possible to develop political knowledge, and therefore what engineered systems categorically subvert the possibility of progressing toward justice?

Characterizing Political Knowledge: Three Definitions, Democratic Premises

In order to answer the large question just posed it is useful to provide a preliminary definition of political knowledge, to understand what is special about it as compared to other types of knowledge.

> **First definition of political knowledge**: Knowledge of how system effects contribute to or detract from justice. Such effects might be categorized into environmental, economic, social, and political effects.

Such a definition is likely familiar to engineers and policy makers alike. It underlies engineering methodologies such as Life Cycle Assessment (LCA) and Techno-Economic Assessment (TEA). And it was the stated goal of the US Congress' Office of Technology Assessment, in operation from 1973 to 1996, to secure "information concerning physical, biological, economic, social, and political effects" of "technological applications" (PL 92-484, 1972). What these very broad categories suggest is that political knowledge is comprehensive or holistic—it is concerned with all phenomena that significantly affect how a community lives together. But it also different from a complete ontological knowledge because its ultimate end is to inform the shaping of a community. As Lupia and McCubbin note, knowledge is distinct from complete information: "reasoned choice does not require complete information. Instead, it requires *knowledge: the ability to predict the consequences of action*" (Lupia and McCubbin, 1998, p. 6). For example, technical knowledge of a tractor is only necessary for political knowledge insofar as it is helpful in understanding how that engineered system will affect communal life (some degree of technical knowledge is usually needed). This means that though political knowledge is holistic, it is also partial in the sense that it requires only that those phenomena pertinent to progressing toward justice or preventing injustice be investigated.

The above definition seems to describe much academic scholarship, including, with respect to engineered systems, Science and Technology Studies scholarship. However, political knowledge must be normative in a way that most academic scholarship explicitly avoids—it must be knowledge of system effects that is meant to inform normative judgement and the concomitant action. Political knowledge is essentially about prediction: it aims to provide a model of the justice-effects of implementing or eliminating or conserving a particular system (Lupia and McCubbin, 1998, p. 24). Political knowledge is therefore more explicitly prospective and action-oriented than most forms of knowledge. For example, while retrospective knowledge, or historical knowledge, about the political effects of a given system can be useful for informing action, much retrospective knowledge is not useful for action, and may actually subvert action by getting potential actors "lost in the weeds." Unlike historical knowledge, then, political knowledge is focused exclusively on the "constitutive" systems that significantly affect how we live in community together and is subject to time pressure so that it does not fail before the urgency of injustice.

It follows from political knowledge being action-oriented that it is only possible to have political knowledge of a reformable system. Knowledge of a non-reformable system, such as the system described by "the laws of physics," cannot be political knowledge because there is no action that can be taken on the system. Of course, apolitical knowledge might contribute to political knowledge. For example, to reform a road system, one might need to know about the unchangeable system described by Newton's Laws, but one would use that knowledge to develop an understanding of how the (changeable) road system should be changed. While it is useful at first to use a binary categorization—of changeable vs. unchangeable systems—it makes more sense to think about a spectrum or dimension of system reformability. For example, certain biological phenomena might be more reformable than the laws of physics, but still relatively non-reformable (and we might want to refrain from reforming them for important moral and political reasons); whereas the technical systems to supply space heating in cold climates might be highly reformable.

In addition to a dimension of system reformability that characterizes political knowledge, it is useful to add dimensions of system consequences and probability. Since risk is defined as the product of consequences and probability, or magnitude of potential harms weighted by the probability that those harms will occur, this amounts to adding a risk dimension. Assuming that every political community has a risk threshold, political knowledge is what allows systems to transition from beyond the acceptable risk threshold to within its boundaries. In other words, political knowledge is our risk mitigation tool. We develop political knowledge of systems we think might be worth conserving, eliminating, or implementing so that we can reduce the justice-risks of doing so.

The normative risk threshold is contested and conditional—there are different opinions about how much risk should be tolerated, and changing community circumstances likely change those opinions. In the extreme, communities that are existentially threatened are likely to take much higher risks than communities that are existentially secure. It seems unlikely that any community would refrain from developing political knowledge of the consequences of a certain system if they thought they could afford the time and resources to do so, so it is likely that existential threat either thwarts the development of political knowledge of a potentially knowable system or makes choosing a relatively unknowable system a possibility. Finally, it is worth noting that for any given system only the understanding of outcome-probability can be increased; the stakes, or consequences, remain fixed because changing the consequences would mean changing the system. (It follows that if uncertainty about outcomes cannot be reduced such that the product of harmful consequences and their probability are below the acceptable risk threshold, then the proposed reform, or even the system itself, should be abandoned; I discuss this further in the following section.)

Finally, political knowledge must be evaluated relative to results that cannot be known while the political knowledge is being built or used (Lupia and McCubbin, 1998, p. 24). Dewey writes that "there is a sense in which 'opinion' rather than knowledge … is the proper term to use … for in its strict sense, knowledge can refer only to what has happened and been done" (Dewey, 1927, p. 178). Benjamin Barber adds:

> Political knowledge is in any case always provisional. This is true in part because political knowledge shares in the evolutionary character of politics. The mutability that permits politics to adapt to history and to the evolving priorities that the expanding human consciousness discovers, as it moves from private to public modes of seeing and doing, also entails the mutability of the maxims and norms that govern that expanding consciousness. (Barber, 2003, p. 170)

The result is that one can only know provisionally and after-the-fact (and perhaps long after the fact) whether a person had the political knowledge necessary to make a good decision and act well in a given situation.

While this is all implicit in the definition of political knowledge given above, it's useful to make these characteristics of political knowledge explicit. I therefore offer a

> **Second definition of political knowledge**: Knowledge of how a reformable system's effects contribute to or detract from justice that is meant to inform a judgment about what action should be taken. This knowledge attempts to reduce to an acceptable level the risk of the proposed action. It is therefore holistic, partial, prospective and provisional.

It's worth noting, since this will become important, that the holistic nature of political knowledge makes it more difficult to obtain, while its partial, prospective and provisional characteristics make it less difficult to obtain. Under the right conditions, this apparent contradiction is actually a productive tension, one that provokes and invokes a political process that must decide when research, deliberation, and action are appropriate—that is, how and when to cut short the quest for omniscience.

It is crucial to note that one of the most conspicuous features of the first two definitions is that they are not necessarily democratic. In other words, these definitions do not specify by whom political knowledge is produced or held, and specifically whether political knowledge must be produced democratically, may be produced democratically, or should be produced democratically. Is the quotidian, situated knowledge of every person a necessary ingredient in political knowledge?

There are two arguments for thinking that true political knowledge must be knowledge of, by and for the people: 1) democracy as rule based on consent and self-governance is the best or least-unjust regime (for reasons other than that it produces the best political knowledge) and therefore political knowledge must be held or produced by the people to some degree; and 2) true, or the best, political knowledge is necessarily democratic and produced by the people. Here I'll focus on the second argument, for the instrumental value of a democratic politics, since it remains focused on the empirical and practical, and because I introduce the second argument, for the inherent value of a democratic politics, in the section on the Second Normative Heuristic.

The basic argument for political knowledge necessarily being the people's knowledge is that, as compared to viable alternatives, people who live in a particular community collectively 1) know best what's going on in that community and 2) know what's best for the community. (It's worth noting that this claim is not that "people collectively have perfect knowledge" but only that "people collectively have the least worst knowledge"; an analogous, famous formulation of the humble preeminence of democracy was given by Winston Churchill in 1947: "it has been said that democracy is the worst form of Government except for all those other forms that have been tried from time to time" (Churchill, 2008, p. 574).

Therefore the claim that political knowledge must be democratic might be described as having a descriptive and a normative element, and scholars often rank the importance or existence of these elements in some way.[11] For example, Dewey claims that while publics are not to be trusted with normative judgment, publics have descriptive powers that experts can't have:

> In the degree in which [experts] become a specialized class, they are shut off from knowledge of the needs which they are supposed to serve. The strongest point to be made on behalf of even such rudimentary political forms as democracy has already attained, popular voting, majority rule and so on, is that to some extent they involve a consultation and discussion which uncovers social needs and troubles … a class of experts is inevitably so removed from common interests as to become a class with private interests and private knowledge, which in social matters is not knowledge at all. (Dewey, 1927, pp. 206-207)

Individuals and people close to them have indispensable knowledge for improving their lives in community together, even if their knowledge is far from complete. It is unlikely that this knowledge can be fully communicated and translated to others who are engaged in political action; thus it is desirable that those who have this knowledge of the conditions of their own lives are also the people acting on this knowledge. Reforms made without involvement of the people with local knowledge are highly likely to overlook nuanced details of community being and system interactions.

Dewey's emphasis on the descriptive power of the people stands in contrast to Hélène Landemore's emphasis on the normative power of the people. In her 2013 *Democratic Reason: Politics, Collective Intelligence, and the Rule of the Many*, Landemore argues that "democracy is overall the smartest method for making group

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[11] See Müller 2018 for a similar distinction between knowledge creation and exploitation. Though this descriptive/normative (or creation/exploitation) dualism is useful and helps make sense of literature that emphasizes one over the other, it is worth noting that the descriptive and normative powers of democratic publics go together, either by virtue of their mutuality—that acting well requires a sufficient understanding of what is and might be, while describing well requires an understanding of what should be done (to prevent "getting lost in the weeds")—or their inextricability—that facts and values can't be separated (see Pamuk 2021).
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decisions" (Landemore, 2013, p. 8). This "epistemic defense of democracy" asserts that reforms made without the involvement of many community members are likely to miss out on the "collective intelligence" of judgments produced by a diversity of cognitive approaches (Landemore, 2013, p. 3). Landemore does occasionally confirm Dewey's view that there is fact-finding value to democracy, but her emphasis remains on fact-judging; and she shares this focus on the normative power of democracy with other epistemic democrats, according to her own review of that literature (Landemore, 2013, pp. 214, 209-231). Julian Müller affirms that epistemic democrats have been focused on normative power (what he calls "knowledge exploitation") as compared to descriptive powers (what he calls "knowledge creation") (Müller, 2018).

My goal is to understand the conditions that allow for political knowledge. For this reason, I am more interested in emphasizing the descriptive power of democratic publics. Descriptive power is highly contingent on what is being described—that is, we can describe a thing to the extent that it is intelligible. It seems intuitive that descriptions of a more "complex" thing will likely be harder to formulate and worse than descriptions of a less complex thing. But normative power is less contingent on the object being judged; it is highly contingent on good (moral) reasoning by the subject that is judging, not necessarily on the "complexity" of the thing being judged. That is, insofar as description and judgment can be separated, political knowledge is affected by conditions because *description is affected by conditions*, and not because judgment is affected by conditions (it isn't, in this reductive account). It is therefore more important, for my purpose, to understand how and why democratic publics have descriptive power.

A recognition that descriptive power is condition-dependent while normative power is condition-independent is implicit in both Dewey and Landemore's approaches. Dewey *is not* concerned that peoples' ability to judge is compromised by "the machine age" (regardless of his relatively low opinion of peoples' ability to judge), while he *is* concerned that peoples' ability to describe is compromised by bigfastforever systems. By contrast, Landemore has no need to investigate whether it is possible for people to describe the systems that constitute their worlds because she is only focused on peoples' collective ability to judge (which she perhaps artificially separates from their ability to describe). Though she devotes four pages to discussing Dewey's *The Public and Its Problems,* Landemore does not once mention, let alone discuss, Dewey's motivation to write about the epistemic value of democratic publics—his view that bigfastforever systems had subverted the possibility of developing political knowledge. Focusing on the normative epistemic power of democracy allows Landemore to "black box" the object of judgement and assume that the characteristics of the object inside the black box are not important.

Our descriptive power does not seem to be intuitive. We might have high opinions of our own knowledge, but we're unlikely to think that people in general are capable of high-quality political knowledge. As Joseph Schumpeter comments in his famous *Capitalism, Socialism and Democracy,* most people probably think that in politics "the sense of reality is so completely lost … [that] the typical citizen drops down to a lower level of mental performance as soon as he enters the political field" (Schumpeter, 1950, pp. 261-262). And Landemore dedicates a section to documenting scholarly versions of the argument that "citizens are ignorant," and therefore true democracy will fail

(Landemore, 2013, pp. 36-38). However, if at least since Dewey's time democratic publics have failed to exist because bigfastforever systems are politically unintelligible (as I reasonably assume), empirical accounts are bound to discover that citizens are ignorant. As Landemore notes, empirical accounts of citizen ignorance unjustifiably and implicitly assume that citizens can and should understand nonlocal systems: "the design of factual political questionnaires smacks of elitism, measuring a type of knowledge relevant to policy analysts and journalists, but not necessarily the only one conducive to smart political choices" (Landemore, 2013, p. 199).

Empirical studies that consider the counterfactual scenario of political knowledge of local constitutive systems are much needed. Unfortunately, these sorts of studies face three barriers: 1) there are very few or no contemporary counterfactuals—communities not constituted by systems far beyond the spatial and temporal scales of quotidian life (bigfastforever systems) seem to be nonexistent; 2) most assume that counterfactuals are now impossible and not worth studying; and 3) experimental studies seem impossible, while it's unclear whether empirical (historical) studies would provide meaningful, let alone conclusive data. Frank Bryan's 2004 book *Real Democracy* provides perhaps the best account of a counterfactual situation (town meeting democracy in Vermont), but Bryan doesn't provide a comparative account of the descriptive power of people in the local system he studies and in nonlocal political systems, and in any case the communities he studies are highly influenced by bigfastforever systems, such as the Grid and the Road.

It seems the descriptive power of the people will always be open to question and needs to be asserted cautiously. That is, although assertions of the descriptive power of the people are common—even the democracy-skeptical Schumpeter concedes that "in the realm of public affairs there are sectors that are more within the reach of the citizen's mind than others … this is true, first, of local affairs" (Schumpeter, 1950, p. 260)—it remains an abstract, untested proposition. Along with Landemore, I aim to avoid begging the question "to whom does political knowledge belong?" by asserting that the benchmark for political knowledge is the sort of local knowledge that only "the people" can collectively achieve (Landemore, 2013, p. 203). However, since there is no conclusive evidence about who are the necessary producers of political knowledge, it seems wise to at least keep open the possibility that everyone contributes to political knowledge and not to prematurely exclude some (for further discussion of the lack of conclusive evidence, see Landemore, 2013, p. 198-206).

One particularly good (and famous) argument for the descriptive power of the people is Friedrich Hayek's theory of knowledge. In his highly influential 1945 essay "The Use of Knowledge in Society" Hayek writes:

> Today it is almost heresy to suggest that scientific knowledge is not the sum of all knowledge. But a little reflection will show that there is beyond question a body of very important but unorganized knowledge which cannot possibly be called scientific in the sense of knowledge of general rules: the knowledge of the particular circumstances of time and place. It is with respect to this that practically every individual has some advantage over all others in that he possesses unique information of which beneficial use might be made, but of which use can be made only if the decisions depending on it are left to him or are made with his active coöperation. We need to remember only how much we have to learn in any occupation after we have completed our theoretical training, how big a part of our working life we spend learning particular jobs, and how valuable an asset in all walks of life is knowledge of people, of local conditions, and special circumstances. (Hayek, 1945, p. 521-522)

Although Hayek's immediate application of this observation was a defense of the price system's role in mediating transactions, his observations form the basis for the epistemic defense of democracy undertaken by Dewey, Landemore and others. Interestingly, scholars have usually interpreted Dewey and Hayek's observations about the value of the people's knowledge as incompatible or "orthogonal" (Landemore, 2013, p. 88; Ralston, 2012, p. 94). In Landemore's case, this can be explained because she is focused on the normative phase of democratic deliberation that requires the rational, intentional decisions of planned order (Hayek's *taxis*), not of spontaneous order (Hayek's *cosmos*) (Landemore, 2013, pp. 86-88). However, it seems clear that Hayek's observations hold true for the descriptive, pre-decision-making phase in which deliberators must attempt to aggregate "dispersed and local knowledge of individuals" into some sort of factual "truth" (Landemore, 2013, p. 88). This descriptive phase *is* a spontaneous order—that is then used to inform the planned order of political decisions. In Landemore's terms: collective description is coextensive with collective intelligence. I am therefore in accord with Ralston's argument that "Dewey's and Hayek's ideas are more compatible than most democratic theorists and political philosophers will admit" (Ralston, 2012, p. 94).

However, descriptive political knowledge cannot be as dispersed, or as tacit, as descriptive economic knowledge. As Dewey observes, democratic publics cannot form when individual knowledge of effects is so dispersed that it prevents any sort of coherent deliberation (Dewey, 1927, p. 33). Though individual political knowledge is necessarily incomplete political knowledge because it is not in the first instance collective (that is, it is the knowledge of a collective of individuals), individual political knowledge must be *relatively complete* in order for effective deliberation and decision-making. A group of ten thousand people that each knows one different fact about a system's effects cannot possibly use that knowledge to understand how to shape the system for communal good. Conversely, most individuals among the ten thousand need to have an understanding of most of the system's important effects in order for good deliberation and decisions to be possible.[12] Unlike the price system, political knowledge cannot be composed of fragmented individual knowledges, but must instead emerge from relatively complete individual knowledges.

Incorporating the collective nature of political knowledge into our definition, we have a

> **Final, democratic definition of political knowledge:** Knowledge of, by, and for the people of how a reformable system's effects contribute to or detract from justice. It is meant to inform a judgment about what action should be taken and therefore to reduce to an acceptable level the risk of the proposed action. It is therefore holistic, partial, prospective, provisional and collective.[13]

Absence of Political Knowledge is Unjust

To motivate a further discussion of "Premise 1: It's not possible to have political knowledge of non-local constitutive artificial systems," it's worth briefly defending "Premise 2: Political knowledge of constitutive artificial systems is necessary to progress towards justice." What is the effect of the absence of political knowledge?

If a community doesn't have political knowledge—the knowledge essential to intentionally make systems more just, less unjust, justice being the traditionally-understood aim of politics—then the absence of political knowledge will perpetuate and produce injustice; hence, absence of political knowledge is unjust. Further, the absence of

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[12] The difficulty of defining the "mosts"—i.e. the proportion of individuals who must have a good understanding of a system—in this sentence is a question for further research; current democratic theory literature only provides the most general, binary answers.

[13] Since this definition is close to Barber's definition of political knowledge that "conceiv[es] of politics *as* epistemology and thereby invert[s] the classical liberal priority of epistemology over politics," it's worth noting that because my definition focuses on descriptive power, it does not invert that priority (Barber, 2003, p. 166).

political knowledge is an existential injustice for political communities: total political ignorance is incompatible with the existence of a community seeking to improve itself within a justice metric. If a public lacks political knowledge, there is *no way* for it to progress toward justice. Without solving the problem of political ignorance, it is futile to attempt to solve any other political problem; a community would be left to hope that uninformed action or non-action—chance—would provide desirable results. Obtaining political knowledge and conserving the conditions for obtaining political knowledge, then, is the primary prerequisite, the *sine qua non*, of political community.

Given the existential injustice of a public's political ignorance, it makes sense logical that Dewey and Lippmann were so concerned with the problem of political knowledge and the destruction of democratic publics. Insofar as the problem still exists, it makes logical sense that many political theorists have continued to focus on the problem. And it makes *historical* but not *logical* sense that political theorists have attempted to solve the public's political ignorance by adjusting democracy to engineered systems to the exclusion of any discussion of how to adjust engineered systems to democracy.

Limits to Capacity for Political Knowledge

Returning to Premise 1, the next question is: what reformable systems can people to know politically? Put differently, what are the limits to peoples' capacity for political knowledge? (These questions are among the most important derivatives of the first question of this thesis: how should we think politically about engineered systems?).

Both questions assume that peoples' capacity to understand systems is limited. That seems to be a reasonable assumption, especially when we consider Lippman's argument that the "omnicompetent citizen" seems to be a false ideal:

> I have not happened to meet anybody, from a President of the United States to a professor of political science, who came anywhere near to embodying the accepted ideal of the sovereign and omnicompetent citizen (Lippmann, 1927, p. 11)

If peoples' capacity for political knowledge is limited, then the systems about which we need to know to participate in political deliberation should be correspondingly limited, or "knowable." To use the definition of political knowledge given above, if our understandings of the probabilities of a system's consequences (risks) can't be improved beyond certain limits, then the potential consequences of the system must be limited in accord with our limited understanding. Or, in terms of uncertainty, if we can't become more certain about the consequences of a given system, then system consequences must be limited in a way that corresponds with tolerable uncertainty.[14]

Limited cognitive, or "processing," capacity is the obvious cause of the limits of political knowledge.[15] The practical consequence of a limited cognitive capacity is that it forces us to select as objects for our attention a limited set of phenomena, of the

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[14] Engineers (and scientists) have developed sophisticated methods to understand their knowledge limitations, or uncertainty, in describing and predicting events. Engineers have always had an interest in answering questions about uncertainty such as: how certain are we that the steam engine won't explode, the bridge won't collapse, the bit won't flip? how about in various conditions? But recently, engineers have needed to respond to a "deeper" form of uncertainty that is itself produced by engineered systems (for a discussion of this irony see Funtowicz and Ravetz, 1993). For example, climate change mitigation engineers are interested in how high to elevate houses given climate changes caused by bigfastforever engineered systems (Zarekarizi et. al., 2020). It's becoming increasingly apparent to scientists and engineers that good advice, good designs, good decisions are affected by deep and dynamic uncertainties that cannot be decreased and are difficult to characterize. However, sophisticated methods for quantifying such deep and dynamic uncertainties can be misleading and prevent us from focusing on the root problem—that we have produced politically unintelligible systems, systems that necessarily prevent us from collectively cognizing and deciding about risk. In other words, such approaches must be careful not to normalize or even celebrate that we live in a "risk society" of "accumulating uncertainty," but should instead clearly articulate when an underlying condition they study should not exist, and hopefully how we might work to eliminate that underlying condition (Beck, 1992; Feldman, Geisler and Menon, 2011).

[15] For a discussion of how experience limits capacity for political knowledge, see Barber's *Strong Democracy* (2003) at pp. 169 and 237. Here I limit my discussion to motivation since it is the motivation to develop a political knowledge of constitutive artificial systems, and not our experience in deliberating about them, that is most, or first, affected by those systems becoming non-local.

seemingly infinite possibilities. Finding the focus of our selective attention is therefore the most practical approach to understanding of the limits on capacity for political knowledge. As Lupia and McCubbins write:

> Relative to our ability to comprehend it, our environment is very complex… As much as you might like to pay attention to many factors at once, you cannot. You must develop a means for choosing among stimuli. (Lupi and Mccubins, 1998, p. 22)

In other words, if we are going to develop political knowledge about something, we need to be motivated to do so. And if we don't want to know about something, we won't know about it even if we have the capacity to do so. So what is our means for choosing among stimuli? About what phenomena are we motivated to develop political knowledge?

The obvious and common answer is: local phenomena. We are most motivated to pay attention to what's closest to us. We are not motivated to understand the (in)justice of phenomena that's not local to us. Scholars have given this answer again and again, and I discuss a few accounts below. But before doing so it's worth noting this answer's apparent simplicity is deceiving: it's actually not so simple to define what "local" is, except tautologically as those phenomena to which we pay attention. What's close need not necessarily be what's spatially and temporally close; I think I'm close to my family though they live thousands of miles away. Some engineers and policy makers might be close to bigfastforever systems while very far from a spatially local ecosystem. As Schumpeter writes, the "narrower field" of local phenomena is "widely differing in extent as between different groups and individuals and bounded by a broad zone rather than a sharp line" (Schumpeter, 1950, p. 259). However, as will be explored below, this difficulty of defining "local" can and should be framed as a generative problem. Contested definitions of "local" should initiate and fuel democratic deliberation about appropriate system boundaries. My thoughts offered here, in conversation with other scholars, will hopefully inform such deliberation.

As Schumpeter writes, a person is most motivated to know about “the decisions of daily life,” less so “the problems of a town,” less so “national issues,” and even less so “those regions of national and international affairs that lack a direct and unmistakable link with those private concerns [of the family and business office]” (Schumpeter, 1950, p. 258-261). There is experimental evidence using fMRI methods that “up close and personal” harms increase emotional engagement and influence moral judgements by making us less likely to participate in a positive harm (Greene, 2001). Lichtenberg writes that although we might contribute to a nonlocal system (via a collective action) that produces new harms, because nonlocal systems “do not produce palpable, immediate, visible effects, we are likely to feel no regret, no guilt, no shame, and no drive to act differently” (Licthenberg, 2014, p. 77).

In sum: most people most of the time are not motivated to perceive system effects that are distributed or far away (spatially or temporally, or distanced by social class or income or race, etc.). Insofar as political knowledge requires sustained attention to effects, this means that we can only have political knowledge of systems with effects local to us. This basic observation is the foundation for a “political motivation argument” against cosmopolitanism that is analogous to my own argument (see Erez 2020 and Erez 2017). Borrowing from the general form of this argument, my argument is: Because social justice requires a stable motivation to develop political knowledge of constitutive reformable systems, and because there is no stable motivation to develop political knowledge of nonlocal engineered systems, nonlocal engineered systems are unjust. (As addressed in my discussion of cosmolocalism below in this chapter, the argument against nonlocal politics and engineering is not an argument against openness or interconnection).

Even if we do perceive distant effects and they become more "up close and personal"—as is possible with global news coverage and modelling of harms to future generations allowed by global, powerful computing networks—lack of ability to change systems prevents us from developing political knowledge. As Samuel Scheffler writes in his 1995 "Individual Responsibility in a Global Age":

> The primacy of near effects over remote effects means that we tend to experience our causal influence as inversely related to spatial and temporal distance. Of course, we know that we can do things that will have effects in distant lands and remote times, and sometimes these effects matter greatly to us. The phenomenology of agency, however, is such that our influence on our local surroundings in the present and the near future tends, as we say, to seem more real to us. This is both because the relevant causal connections are ordinarily easier to discern in these circumstances and because we are more likely to witness the effects of our acts firsthand. (Scheffler, 1995, p. 228)

Since we (likely correctly) don't perceive that we have the ability to effect change on non-local systems—including systems with distributed causes, systems with long term effects, and systems that change too fast for deliberation—we will fail to develop political knowledge of them (see Barber, 2003, p. 272). My discussion thus far has focused on spatially distributed systems since it is most difficult to understand how they inhibit political knowledge. It is relatively easy, additionally, to understand this issue in temporal terms: that systems that change before they can be known inhibit political knowledge (assuming that developing political knowledge takes some amount of time that can't be significantly decreased; see Scheurman, 2004), and that systems with highly uncertain long-term effects inhibit political knowledge because we would need to time-travel in order to understand their effects.

Because the proto-political knowledge of individuals is necessary for complete collective political knowledge to emerge in deliberation, this means that we (the people) only have a capacity for political knowledge of local systems.

BigFastForever Systems Inhibit Political Knowledge

To phrase the foregoing argument positively as a design constraint or imperative: Because we are practically limited to developing political knowledge of local systems, and political knowledge of something is necessary to (without eliminating it) make it more just, non-local artificial systems inhibit progress towards justice and likely cause injustices. Insofar as bigfastforever systems may be politically necessary to achieve some other element of justice, there may be a tradeoff that justifies the existence of a bigfastforever system and the high risk that comes with it, at least for a time, and certainly as part of a nonviolent transition away from now-entrenched bigfastforever systems; these points are discussed more below in the section on the capabilities approach theory of justice and transition design. Though optimizing with respect to social justice is a difficult process indeed, the high risks we take and the massive harms we have already accrued with nonlocal engineered systems suggest that a heuristic approach focused on localization can reduce uncertainty, promote knowledge, and lead to more just decisions and actions.

But what are non-local and local systems? Since answering that question in this thesis, or as a small team of engineers, sidesteps the democratic process and the superior knowledge that comes with it, it is necessary to be cautious. However, since as engineers we find ourselves with outsize power to shape our world, we have to attempt to develop *some* understanding of the designs that might allow for a better, *democratic* understanding to emerge. To not attempt such understanding would be a negligence more harmful than facing the contradiction head on and doing our best to resolve it. Therefore the following definitions should be seen in part as provocations to awareness of the problematically immense political power of engineers.

In order to provide preliminary definitions, I've found it useful to focus on temporal and spatial system boundaries, as well as to use a binary categorization—although there is an infinitely diverse spectrum of size, speed, and duration, as my definitions indicate. Using the first normative heuristic—is an engineered system designed for political knowledge? —we have preliminary definitions of big, fast, and forever engineered systems:

> **Big System**—a system that interacts with so many people and places that 1) the causes of its systemic harms are spatially distributed, and/or 2) its harmful system effects are spatially distanced or distributed, to a degree that people who use or cause the system to exist are not motivated to develop a political knowledge of it.
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> **Fast System**—a system whose state changes so frequently that understanding its effects in order to change it (i.e. developing political knowledge of it) seems futile since "understood old versions" will be replaced by "not yet understood new versions" before any deliberative decision can be made.
>
> **Forever System**—a system with harmful system effects that are temporally distanced or distributed to a degree that people who cause the system to exist are not motivated to—and even if they were, could not—develop a political knowledge of it.

A few notes on these definitions are in order. First, they are meant to indicate a threshold beyond which political knowledge is definitely inhibited. These definitions are therefore heuristic definitions, adequate for dealing with systems that are grossly beyond the acceptable thresholds—as it seems nearly all current engineered systems are (see Morton, 2014; Lichtenberg 2014; Suh et. al., 2004). However, it will be necessary to fine tune these definitions as we progress towards systems with small, slower and shorter-duration system boundaries. Second, these definitions require moving beyond conventional engineering approaches, including LCA and Systems Engineering, to a political approach to systems and system boundaries, such as Actor Network Theory. This is not to minimize the use of those approaches. LCA, for example, far surpasses the limited approach to system boundaries of systems engineering, which focuses on developmental control, operational control, functional allocation and unity of purpose with the result that the system boundary is purely technical (Kossiakoff et al., 2011). Instead, LCA attempts to consider all non-negligible causal relations, but has had to develop elaborate and sometimes not theoretically justified methods to identify system boundaries since "non-negligible" needs to be clearly defined in a quantitative analysis (Li et al., 2014). Further, LCA approaches do not take into account collective harms scenarios where the sum of negligible system effects may be non-negligible (see Table 1). In order to properly identify when a system with which we are working is partially responsible for convening a bigfastforever system, and therefore to identify important harms, it is necessary to take into account such non-negligible effects. Actor Network Theory (ANT) provides one possible approach to establishing politically relevant system boundaries (Latour, 2005). However, if ANT scholars tend to focus too much on non-physical (social) processes convened by engineered systems, they might fail to describe physical system boundaries, which is necessary for a political analysis of those systems. Careful, politically relevant descriptions of system boundaries that go beyond LCA toward an ANT approach are much needed and, conversely, ANT scholarship could learn from the aim of LCA to focus on physical system boundaries.

Though careful descriptions of system boundaries are lacking, examples of systems that are big, fast and/or forever—Morton's analogous term for these systems is hyperobjects, but I think my description is more precise—abound. The systems on which I have focused are The Road (our massive system of paved high speed roads), The Grid (any one of the massive interconnected electric power systems on Earth), and The Stack (the accidental megastructure of planetary scale computation, as described by Bratton (2015)). As explained above, paradoxically, these systems are often not recognizable to us, since we've had no incentive to develop political knowledge of them. For example, we interact with The Stack on a daily basis (like it or not), but most people have very little, if any, understanding of it. Of course this is excusable since attempting to develop even a proto-political knowledge of these systems would be an immense task. Scholars have tried—see Benjamin Bratton (2015) with The Stack, Zack Furness (2010) and Henry Petroski (2016) with The Road, and Thomas Hughes (1993) and Julie Cohn (2017) with The Grid—but they all admit their limitations and are more or less clear about the simplifications and excisions they accept in order to make their task manageable.

In a world of bigfastforever systems, we are indeed stuck "wielding localized ethics in the face of globalized problems" (Sherrell, 2021, p. 52). We are stuck without political knowledge of the artificial systems that constitute our communal lives.

A set of normative heuristic questions to guide the design of just engineered systems, or to prevent the design of unjust engineered systems, should therefore focus on spatial and temporal system boundaries: Is the system big? Is the system fast? Is the system forever? These questions amount to asking: Is the system designed for political knowledge?

Answering these questions with respect to a given design is not easy, especially since it's categorically not obvious when we're participating in or supporting bigfastforever systems. Good answers require thinking in terms of collective actions, distributed harms, nonlocal speeds and durations—something that I've argued is inherently difficult. Thinking in terms of collective actions requires each engineer to ask: What is the emergent system which my system co-creates?

In other words, one formulation of the task for engineers is that an impossible task (asking "is this system designed for political knowledge?) must be done in order to prevent an impossible task (wielding localized ethics in the face of globalized problems) from needing to be done. But engineers should not think that we can do the impossible; we should be humble (especially because engineers are nowhere near to resembling a democratic public) about our ability to develop political knowledge of bigfastforever systems and therefore make good decisions about them. Until systems are local, it will be inherently unclear what is the best path forward. This is frustrating, but it provides useful clarity about the sort of change that is needed regarding existing systems and system design processes: we need change to *far more local* systems, since without that transition it will be impossible to ascertain the injustices done by the sorts of bigfastforever systems that we have now (this is discussed further in the below section on Transition Design).

Second Normative Heuristic: Is an Engineered System Designed for Political Empowerment?

> *The principal source of injustice in our epoch is political approval for the existence of tools that by their very nature restrict to a very few the liberty to use them in an autonomous way.*
>
> — Ivan Illich, *Tools for Conviviality* (1973) p. 43

In this section I focus on the harms to political empowerment caused by engineered systems with nonlocal system boundaries. Like the argument for the political knowledge (or first normative) heuristic, the argument for the political empowerment (or second normative) heuristic can be formulated in a syllogism:

> Premise 1: The capability to act politically—to form, make, tend, and repair—the systems that constitute one's world is meaningful and fulfilling; a life without political action is bleak and incapable of full human flourishing.
>
> Premise 2: Bigfastforever systems inhibit peoples' capability to act politically.
>
> Conclusion: Therefore, bigfastforever systems inhibit the possibility of meaningful lives; they are unjust to the degree that they do so.

My goal in this section will be to defend both premises. Throughout this section I alternatively use "the world forming capability" and "capability to act politically" and "political empowerment" interchangeably since I consider those terms synonymous. I've found each useful in different contexts: the first two since they explicitly gesture to the capabilities approach theory of justice developed, most notably, by Martha Nussbaum; the first over the second when the word "politically" is a barrier to understanding what I mean (as I have found can be the case in an engineering school where we are often still bound by the idea that engineering should be apolitical); and the third as a way to tie the idea to the intuitively normative concept of empowerment (and because, of course, I am part of Thayer's Empower Lab!).

There are two ways, an *intrinsic* way and *instrumental* way, to approach the world-forming capability.

The instrumental idea of the world-forming capability posits that a systematic inability to world-form is unjust because being able to change reformable constitutive systems—that is, systems that constitute our life together—is necessary to progress toward justice. This view quickly converges with the argument for political knowledge and intelligible, local systems: World-forming requires political knowledge, which requires the collective descriptive power of a political community, and this in turn requires that the object of description be local; therefore, only local engineered systems are just in the sense of political empowerment. Insofar as the instrumental idea of the world-forming capability and the argument for political knowledge are the same, any further discussion of the instrumental value of the world-forming capability is redundant.

I therefore omit that further discussion except to make the important point that it seems the most recent influential uses of the world-forming capability of it have been self-defeating. The modern techno-scientific world-forming project, the development of engineered systems, has alienated most people from their world-forming capability at the same time as it has improved many human lives in other ways. Our techno-scientific project for "the relief of man's estate" (Sir Francis Bacon's famous phrase in his 1605 *The Advancement of Learning*) has resulted in existential physical threats or disruptions that prevent present and future people from forming our worlds: we are instead faced with territorial dispossession for mining, oil and gas extraction, big agriculture, industrial transportation and massive dams, and the resulting climate change over which individuals and even, apparently nation-states have little control; poisoning by various industrial processes that we cannot avoid; the threat of weapons of mass destruction, use of which we have little say over; and accumulating insecurity as a result of these central features of our lives that are not ours to shape (Bacon, 1605; Feldman, Geisler and Menon, 2011).[16]

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[16] An introduction to how this technoscientific project of "development" has been gendered (true to Bacon's focus on *man*'s estate), and the important implications of such gendered "development," is in Merchant's 1980 *The Death of Nature: Women, Ecology, and the Scientific Revolution.*

But disempowerment is not always so obvious as physical destruction, dislocation or poisoning. People in the most “developed” countries are not just increasingly dying of cancer, heart disease, diabetes attributed to various toxins. Empirical studies show we are also succumbing to more intentional deaths of despair—suicide, alcoholism, overdose (Case, 2021). Ann Case attributes rising deaths of despair among people without a college degree to their feeling that “their ability to contribute to society has been terribly thwarted” (Case and Frueh, 2022). In *Bullshit Jobs*, David Graeber shows how the dominant occupation in developed countries—jobs in which blue- and white-collar workers are cogs in an industrial process—subverts the fundamental delight of making an impact on the world and thus does spiritual violence to people (Graeber, 2018, pp. 67-99).

These empirical accounts of disempowerment are only motivational since neither Case nor Graeber gives much attention to the technical phenomena that allow for the emergence of the cultural phenomena on which they focus. It’s worth noting that even had they wanted to focus on the technical conditions that facilitate certain cultural conditions, it’s likely that their economic and anthropological epistemologies would prevent them from doing so. For Case, the causal chain from bigfastforever systems to deaths of despair seems far too noisy for a testable economic theory of the situation. Graeber’s focus on short-term self-reporting is unlikely to uncover underlying causes because those causes are long-term, culturally invisible and seem very difficult to understand. But just because we can’t know about the relationship between bigfastforever systems and disempowerment from those epistemologies, doesn’t mean that we can’t know about the relationship in another way.

Following other scholars, in this section I provide an account of the relationship between bigfastforever systems and disempowerment through a political epistemology. Unlike my account of the political knowledge heuristic, which stays more squarely in a positivist epistemology familiar to engineers and (analytic) philosophers, the following account does not present a "problem" or a "puzzle" with a clean solution that can be tested, logically or empirically. Although, as my syllogistic framing of the argument suggests, at the most abstract level the account can be subjected to logical testing for validity, the premises cannot be subjected to logical or scientific testing. Instead, the truth of the premises emerges from a political understanding of our world. This political epistemology, or way of knowing about the world is familiar to political theorists and likely to many scholars in their "daily lives," outside of their academic roles. In the experimental workshops I held with fellow engineering students (Chapters 3 and 4), as I (the discussion leader) introduced political participation, I asked that we take off our "engineering/problem solving hat" and put on our "political/human hat"—the hat that allows us to reflect on the meaning that comes from making, tending and repairing the systems that constitute our world—more crudely, "making an impact"—without scientifically testing the existence of such a meaning. Trading in the positivist for the human worldview is necessary to understand the argument about the importance of political participation and how it is subverted by bigfastforever systems. I find that this approach is also especially intuitive for engineers, who often have chosen their profession because of early, formative, often playful experiences with building, tending, repairing artifacts in their world.

Therefore my main use of Case's and Graeber's observations about the rise of deaths of despair and bullshit jobs is suggestive—to suggest that even if the *physical* harms and "accumulating insecurity" of our current industrial systems were mitigated, there are more fundamental pathologies. The subsequent section explores what I believe is the most fundamental pathology of bigfastforever systems: that it disempowers people (who have the potential to be political actors given the right conditions).

Characterizing Political Empowerment

In order to understand why we should care about political empowerment and how bigfastforever systems affect it, it is useful to provide a definition, discuss it and refine it.

> **First definition of political empowerment:** The capability to act on a deep human need to shape our world in important ways.

This definition follows from my understanding of politics as the sum of deliberation, decisions and actions to reform and form the artificial systems that shape our worlds. Political empowerment is therefore the power to do politics. What is new in this definition is the value that I assign to *doing* politics.

One way to think about the importance of doing politics, or world-forming, is through the Crystal Palace thought experiment Dostoevsky explores in *Notes from the Underground.*

> Crystal Palace thought experiment: You live in the perfect Crystal Palace, which through the rational perfection of ingenious engineered systems fulfills absolutely *all* possible needs and desires *except* for your desire to shape your world in an important way, since to engage in such world-forming would alter the perfect world in which you live. Would you want to live in the Crystal Palace? (Adapted from Dostoyevsky, 1864)

In the context of global injustices, accumulating insecurities and the widespread and tragic inability of many humans to achieve basic needs and desires, I want to immediately clarify that such a thought experiment is a vast reduction and oversimplification. But it is nonetheless useful because it allows us to disentangle the harms that are usually associated with a loss of autonomy (such as in the cases of slavery and colonialism) from the harm associated with loss of autonomy itself.[17] That is, it allows us to carefully examine a fundamental aspect of dignified, meaningful lives—and therefore a fundamental aspect of justice—that the modern technological project overlooks: political empowerment.

Since the Crystal Palace became a conceivable reality after the industrial revolution, the "perfect" situation it describes has become a theme in much literature, and a few political theories. The most direct addresses of the Crystal Palace theme focus on the human meaning that is lost, or the angry "acting out" that occurs, when the capability for political action is thwarted. For example, Dostoevsky writes that in the Crystal Palace:

> boredom may lead you to anything … I, for instance, would not be in the least surprised if all of a sudden, a propos of nothing, in the midst of general prosperity a gentleman with an ignoble, or rather with a reactionary and ironical, countenance were to arise and, putting his arms akimbo, say to us all: "I say, gentleman, hadn't we better kick over the whole show and scatter rationalism to the winds, simply to send these logarithms to the devil, and to enable us to live once more at our own sweet foolish will!"
>
> …
>
> One's own free unfettered choice, one's own caprice, however wild it may be, one's own fancy worked up at times to frenzy—is that very "most advantageous advantage" which we have overlooked, which comes under no classification and against which all systems and theories are continually being shattered to atoms. (Dostoyevsky, 1864)

[17] Some approaches, such as Arturo Escobar's in *Designs for the Pluriverse,* do not try to isolate the value of autonomy ("*autonomía*") from the value of physical safety ("non-exploitation") (Escobar, 2018). But these approaches are usually more focused on the Global South, where the immediate need to protect physical safety is most pressing; the benefit of isolating the value of political empowerment comes only after physical safety is mostly achieved, as it arguably is for most in the Global North, and may possibly become in the Global South. See Illich (1973) pp. 48-51 for a discussion of why and how we should distinguish between different "environmental imbalances."

Since it provides a grounding analogy, it's useful to note that the destructive, impetuous tendencies of Dostoevsky's reactionary gentleman are reminiscent of recent populist politicians and many of their followers. Could it be that a significant part of the "populist" politics in Europe and the US are driven by frustration at being in the Crystal Palace, without an opportunity to contribute, such that the basic drive to "make an impact" can only be manifest destructively? Dostoevsky suggests we consider that our desire to make an impact should be taken seriously and considered more than "just" a childish desire to want to kick over the blocks, perfectly stacked by someone else, that we've been told not to touch. In Aldous Huxley's *Brave New World*, John the Savage expresses a similar objection to perfect comfort: "I don't want comfort. I want God, I want poetry, I want real danger, I want freedom, I want goodness. I want sin" (Huxley, 1946, p. 148). By expressing their need to act out against the boredom of perfection, to establish their importance in the world rather than to be merely happy or comfortable, the Underground Man and John the Savage highlight the central, hidden tension of technological progress as it has been conceived—the tension between satisfying physical needs and desires and satisfying the "metaphysical" need to shape our world.

This tension of course has political implications, and some political theorists have recognized the need for, and sometimes the loss of, the world-forming capability.[18] In his essay "How to Understand Politics" Harvey Mansfield argues that "political science … ought to be sensitive to importance, the importance of importance" (Mansfield, 2007). That's because *thumos*—the Greek word that Plato and Aristotle use to describe "the part

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[18] It's worth noting that discussions of "alienation" and "mass-man" are very related, but do not focus on political empowerment as do the texts I refer to here as "political theory." Cf. Richard Schacht's 1970 *Alienation* and Romano Guardini's 1956 *The End of the Modern World.*

of the soul that makes us want to insist on our own importance"—is a fundamental political reality (Mansfield, 2007). Mansfield cautions that "participation" can have an empty meaning that does not get to the heart of the human ambition for importance:

> The political science of our day almost entirely ignores ambition. It is, for example, anxious over the problem of how to recover our spirit of civil engagement, but it looks mostly at what moves most people to vote, which it calls by the vague term *participation*. (Mansfield, 2007)

Complementing Mansfield's observation, Benjamin Barber argues for a democratic way of life that goes beyond "thin" accounts of participation to a "strong" account of participation that is about realizing individual and community flourishing: "in strong democratic politics, participation is a way of defining the self" and "participation and community are aspects of one single mode of social being" (Barber, 2003, pp. 153, 155). In *The Human Condition* Hannah Arendt similarly argues for the fundamental value of political action to the human condition; Martha Nussbaum makes "control over one's environment" one of ten central capabilities in her theory of justice; and Amartya Sen and Jean Drèze write that political participation has "intrinsic value for the quality of life" (Arendt, 1958; Nussbaum, 2011; Sen and Drèze, 2002). Finally, Ivan Illich provides the most holistic defense of the world forming capability in his 1973 *Tools for Conviviality.* One of his most forceful examples, only barely different from the Crystal Palace, involves rich prisoners:

> People need not only to obtain things, they need above all the freedom to make things among which they can live, to give shape to them according to their own tastes, and to put them to use in caring for and about others. Prisoners in rich countries often have access to more things and services than members of their families, but they have no say in how things are to be made and cannot decide what to do with them. Their punishment consists in being deprived of what I shall call "conviviality." They are degraded to mere consumers. (Illich, 1973, p. 11)

Two comments on political theory accounts of world forming are in order. First, they usefully, albeit mostly implicitly, make the distinction between apolitical and political forming—between the agency to decorate the fundamental infrastructure of our lives as we please and the agency to shape that fundamental infrastructure. Political forming (world-forming) is impossible when the artificial systems that fundamentally constitute one's world cannot be formed, whereas apolitical world forming (a kind of "toy" world forming) is possible when those constitutive systems cannot be formed. There are two particularly conspicuous sorts of toy world forming: voting and crafting. Voting seems to be an increasingly meaningless exercise of power when it is obvious to most that the real power is not held by voters, but by a relatively small number of elite political actors, by corporations enabled by engineered systems, and (perhaps most fundamentally) by the systems themselves. As Illich writes, we should not hastily equate the capability to vote with political empowerment: "the pompous rituals by which each man is given a vote to choose between factions only cover up the fact that the imperialism of industrial tools is both arbitrary and growing" (Illich, 1973, p. 43). Similarly, we should not let increased desire and ability to craft cover up political disempowerment. That is, the resurgence of craft, maker, handmade, artisan, DIY and homesteading cultures, practices and tools—documented in (just to list books) *The Good Life*; *Return of the Artisan*; *Makers*; *Shop Class as Soulcraft*; *The Creative Citizen Unbound*; *Taking [A]part*; *Tinkering*; and *Animal Vegetable Miracle*—should not necessarily be taken as evidence that people are politically empowered, that is, capable of world-forming. Depending on the conditions in which one lives, such activities could be world forming—in fact, my argument is that we should create the conditions such that those activities *are* world forming activities. But in present conditions, when bigfastforever systems constitute our world, crafting hobbies often further entrench disempowering systems (Black and Burisch, 2021). This seems especially true for crafting enabled by status quo digital electronic networks, or “the Internet.”

Second, political theorists, except for Illich (who in any case does not comfortably fit in that category), avoid a discussion of the relationship between political empowerment and technics. Even Arendt, who provides a sort of genealogy of how bigfastforever systems have come to restrict the possibility of political empowerment, does not systematically address how some tools also foster political empowerment. Benjamin Barber briefly discusses how “technology” can allow for political participation despite large-scale political units, but invokes “technology” as a magical solution with no discussion of tradeoffs, let alone a systematic inquiry into how big technologies that allow for fast communication with far off places might cause problems for political participation (Barber, 2003, pp. 245-47). In contrast, Illich directly addresses the role of technics, including engineered systems, in disempowerment:

> People feel joy, as opposed to mere pleasure, to the extent that their activities are creative; while the growth of tools beyond a certain point increases regimentation, dependence, exploitation, and impotence … An individual relates himself in action to his society through the use of tools that he actively masters, or by which he is passively acted upon. To the degree that he masters his tools, he can invest the world with his meaning; to the degree that he is mastered by his tools, the shape of the tool determines his own self-image. (Illich, 1973, pp. 20-21)

Illich’s strong advocacy for the value of the world forming capability is deeply tied to his observation of the fundamental relationship between technics (tools) and world-forming. That is, tools both give and take away the capability to form our world. As Illich writes “tools for a convivial yet efficient society could not have been designed at any other stage of history” than the modern since we did not previously have the engineering knowledge necessary to do so (Illich, 1973, p. 33). Yet it is also at this stage in history that certain tools are the “principal source of injustice” (Illich, 1973, p. 43).

Illich reminds us that science and engineering could be otherwise, that we might change the course of technological "progress." Science and engineering need not inhibit the world forming capability, but could actually enhance it:

> The unqualified identification of scientific advance with the replacement of human initiative by programmed tools springs from an ideological prejudice and is not the result of scientific analysis. Science *could* be applied for precisely the opposite purpose. Advanced or "high" technology *could* become identified with labor-sparing, work-intensive decentralized productivity. (Illich, 1973, pp. 33-34; my emphasis)

The convivial communities that make up Illich's vision of justice hinge on the *presence* of tools (including engineered systems) that allow for good work and environmental relationships, including with other humans, and the concomitant *absence* of tools that prevent good work and corrode environmental relationships (bigfastforever engineered systems). Tools and their makers, engineered systems and engineers, play the pivotal role in determining whether this central element of justice—political empowerment—exists or not.

Collecting these elements of political empowerment into a definition we have a

> **Final definition of political empowerment:** The capability to act on a deep human need to shape our world that is highly dependent on the tools that already constitute our world.

Bigfastforever Systems Inhibit Political Empowerment

Nonlocal engineered systems inhibit political empowerment because they 1) are caused by so many people that any individual has a very low probability of making a meaningful contribution; and/or 2) change too fast for individuals to have the chance of shaping them; and/or 3) lock-in future people to certain scenarios that are virtually unchangeable. A reductive summary of these mechanisms and the complementary systems for political knowledge is shown in Figure 1.

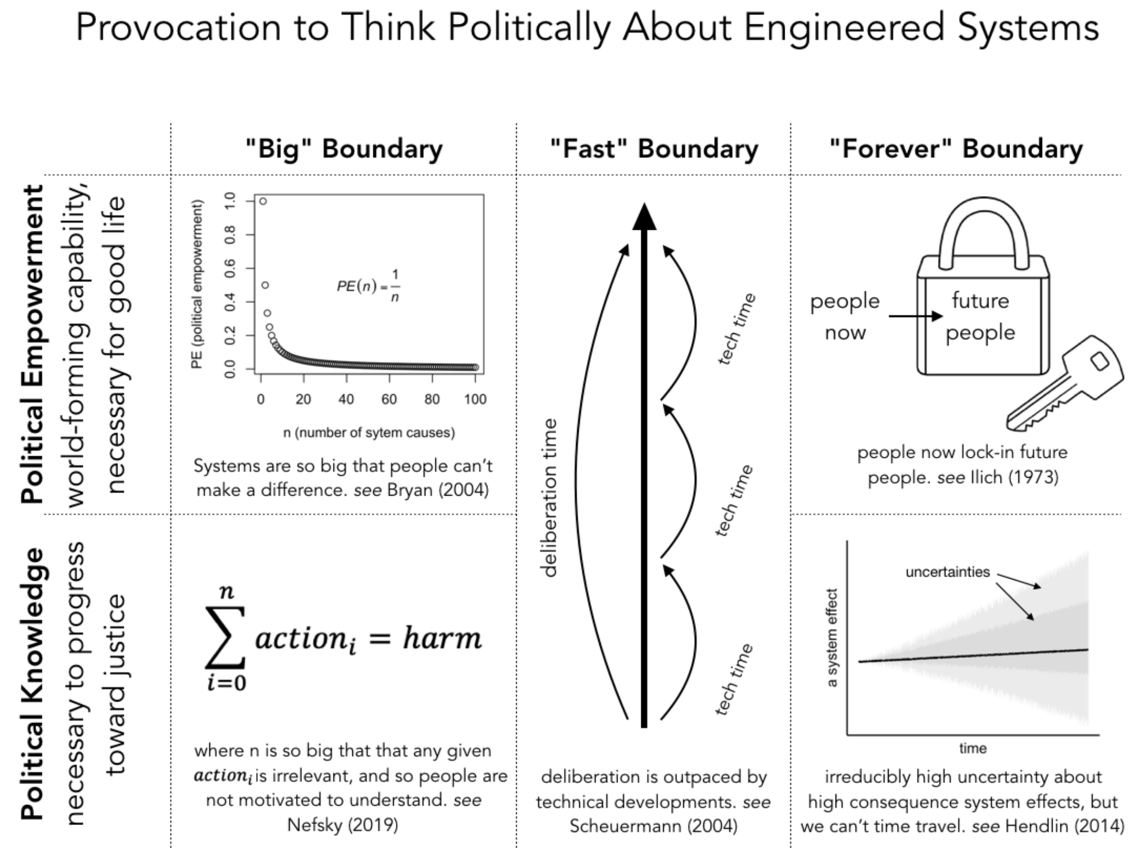

Figure 1. This reductive summary of the mechanisms by which bigfastforever systems inhibit democracy is meant as a provocation to think politically about engineered systems. Further reading is listed along with each graphic.

Capabilities Approach and Cosmolocalism

If the goal in providing normative heuristics is to support the choice and design of just engineered systems, the political knowledge and empowerment heuristics that I've introduced need to be 1) framed in terms of a holistic theory of justice and 2) qualified by more nuanced ideas of what local systems might be. That is, although on balance I think more just outcomes would be produced simply by choosing and building smaller, slower and shorter-duration engineered systems, optimally just outcomes require a more nuanced, less reductive, approach. Though local engineered systems are far more likely to be just than their nonlocal counterparts, local engineered systems are not necessarily just. Fortunately, there is a wealth of literature that, while not providing the political arguments for how nonlocal engineered systems inhibit justice, provide a vision and criteria for what just localism might be. Here I'll present a selection of what I think are the most important sources and ideas: Martha Nussbaum's capabilities approach theory of justice; Wolfgang Sachs, Ezio Manzini and Gideon Kossoff's cosmolocalism; and Wendell Berry's idea of a local economy.

The capabilities approach is a theory of justice that argues justice is about ensuring all people can attain at least the threshold levels of the capabilities necessary for living a dignified life. Martha Nussbaum and Amartya Sen are its initiating and most well-known proponents. Here I focus on Nussbaum's articulation since it provides the useful, though problematically reductive and prescriptive, list of ten central capabilities that must be protected and enabled in a just community.[19] Nussbaum argues that a useful provisional list of the ten central capabilities necessary for a dignified life are: life; bodily health; bodily integrity; thoughts, senses, imagination; emotions; practical reason; affiliation; other species; play; control over one's environment (Nussbaum, 2011, pp. 33-34). In engineering terms, these ten central capabilities are the objectives of the "multi-objective optimization" that is the path toward justice. Although it is reductive to think of the pursuit of justice as such a multi-objective optimization, the analogy is useful since it is clear that instead of simply optimizing for two variables—political knowledge and

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[19] Another benefit of Nussbaum's approach is that it is concisely yet holistically summarized in her must-read *Creating Capabilities* (2011); the central tenets are summarized on pp. 18-19 of that text. Further, as I will explain, the capabilities approach in general lends itself well to thinking about just technologies, and a significant literature has developed on the capabilities approach and technology. See Ilse Oosterlaken's 2015 *Technology and Human Development* and Marco Haenssgen and Proochista Ariana's 2018 "The Place of Technology in the Capability Approach."

political empowerment—there is a need to balance those objectives with a more holistic set of objectives. I think engineers should heavily weight political empowerment and knowledge, certainly relative to the negligible feather weight they have been given in historic engineered designs, but engineers should ultimately be guided by a holistic theory of justice such as the capabilities approach. For that reason, a just society would likely rely on a few engineered systems with nonlocal system boundaries, though it is highly unlikely that justice would require that such systems be as big, fast or forever as current systems. As Illich writes,

> It is possible that not every means of desirable production in a postindustrial society would fit the criteria of conviviality. It is probable that even in an overwhelmingly convivial world some communities would choose greater affluence at the cost of some restrictions on creativity. (Illich, 1973, p. 23)

Even the most vociferous critic of bigfastforever systems recognizes that the solution is not a totalizing switch to small-slow-now systems that fail to account for all of the capabilities central to a dignified human life.

It's worth noting that it would be revolutionary for engineers to focus on objectives beyond Nussbaum's first three capabilities—so as to include the capabilities of "practical reason" and "control over one's environment" that I see as roughly equivalent to political knowledge and political empowerment. This is especially so since it already seems rare for engineers to think about the first three capabilities; given that most "real world" design projects optimize for profit and not for such lofty objectives as life, bodily health and bodily integrity. However, in engineering schools such as Dartmouth's, new paradigms are emerging that suggest engineers should be more attuned to the social consequences of their designs. This is a move in the right direction, as I discussed in Chapter 1 with respect to engineering justice and engineering ethics approaches; it should be celebrated that Leydens and Lucena list and briefly discuss the capabilities approach in *Engineering and Justice*. But what is even more fundamentally needed is the deeper (and even more unlikely…) transition by which engineers begin to think politically about designs, rather than grabbing a handy list of objectives over which to optimize. This requires thinking about the categorical political harms that engineered systems can cause—harms to political knowledge and political empowerment—as well as situating that thinking in a holistic theory of justice such as the capabilities approach.

More specific guides to envisioning just local systems come from scholars who write about "cosmolocalism" (which is highly similar to "designs for the pluriverse" as described by Escobar (2018)). By combining cosmopolitanism and localism, these scholars intend to clarify that their localism is not an atavistic regression to an historical antecedent; they're not arguing for a return to life as it was in say, 1491. (That said, many places in 1491 were not "walled off" but already had linkages to far-off places that were enabled by the powerful technics (proto-engineered systems) of ships and roads and wheels.) Ezio Manzini and Mugendi M'Rithaa define cosmolocalism as "a creative balance between being rooted in a given place and community, and being open to global flows of ideas, information, people, things and money" (Manzini and M'Rithaa, 2016). Gideon Kossoff writes of "multi-scalar, or nested, networks of self-organizing, semi-autonomous, and place-based communities that are empowered to create the good life in the image of their own cultures and histories" (Kossoff, 2019). The basic point is that there is a need to think about local engineered systems in terms of a local economy *that is interconnected with other local economies.* The antidote to bigfastforever systems is not small-slow-now systems that are isolationist, disconnected, and selfish. Wolfgang Sachs, the initiator of the specific phrase cosmopolitan localism (and whose *Planet Dialectics* (1999) contains the most theoretically rich discussion of it and related themes), reminds us that a localism without interconnections is necessarily a broken localism:

> Cosmopolitan localism seeks to amplify the richness of a place while keeping in mind the rights of a multi-faceted world. It cherishes a particular place, yet at the same time knows about the relativity of all places. It results from a broken globalism as well as a broken localism. (Sachs, 1999, p. 107)

Though perhaps new to the community of designers and design scholars, such nuanced, qualified discussions of localism are not so new. They have a long history, amid which Wendell Berry's writing about the idea of a local economy stands out. Berry, too, emphasizes that "the principle of neighborhood at home always implies the principle of charity abroad" in an effort to avoid the broken, provincial forms of localism (Berry & Wirzba, 2002). In other words, literature on cosmolocalism is the tip of the iceberg, and a vast literature on the importance and structures of a local economy can help provide a normative vision and a pragmatic strategy for a transition away from bigfastforever systems.

Barriers to Thinking Politically About Engineered Systems

The main barrier to understanding the politics of engineered systems is most obviously "not thinking"; closely followed by "not thinking politically." Beyond the more specific barrier of failing to account for political knowledge and empowerment, here I want to emphasize two barriers that pose particular difficulties for current engineering design practices: adaptive preferences and the (unintended) violence of humanitarian design. I highlight these because engineering ethics, engineering justice, human centered design and value sensitive design literature and approaches fail to address and mitigate the problems caused by these phenomena, especially adaptive preferences. Further, it's useful that these concepts are independent of my particular arguments. In fact, I've found that adaptive preferences and the violence of humanitarian design can be good ways to motivate students to do the hard work to think politically about engineered systems—since they are relatively simple concepts with obvious, relatable examples.

"Adaptive preferences" refers to preferences for unjust conditions that are caused by an adaptation to those unjust conditions. Jessica Begon provides the examples of "those who choose to stay with an abusive partner, or sufferers of Stockholm syndrome (wherein a kidnap victim feels trust or affection for their captor)" (Begon, 2015). Martha Nussbaum provides the example of women who prefer to be uneducated and live in a culture where women's education is not a possibility (Nussbaum, 2011, p. 84). Adaptive preferences pose a significant problem for design methods such as Human Centered Design that focus on soliciting "user" needs without reference to a theory of justice. Even Value Sensitive Design, which at least provides a theoretical framework that addresses important questions of justice, fails to provide any account of adaptive preferences (Friedman and Hendry, 2019). This is a serious omission that undermines the validity of these approaches. As Begon writes, adaptive preferences are "a longstanding problem for theorists of justice" that have generated much scholarly debate and have no easy solution (Begon, 2015). It seems engineers would be negligent to avoid such a central issue of justice: insofar as our approaches to designing engineered systems fail to account for adaptive preferences, it is very likely that we will unintentionally produce harms.

One important way to think about such unintentionally produced harms, that may often be the result of adaptive preferences, is with reference to Mahmoud Keshavarz' discussion of "the violence of humanitarian design" (Keshavarz, 2019). The violence of humanitarian design refers to well-intentioned "humanitarian" solutions that perpetuate the problem they mean to solve. In the extreme, the solution is just more of the problem, such as when the NRA (with good intentions, we naïvely assume) proposes more guns as a solution to the crisis of mass shootings. Typically, however, the violence of humanitarian design is more difficult to see because it is the *logic* of the solution that perpetuates the problem; or, most difficult to see, it is the *logic* of the solution that perpetuates the *logic* of the problem. For example, many scholars argue that geoengineering perpetuates the logic of nature-control and human-nature dualism that is at the heart of our ecological crisis (Foster, 2018; Schneider, 2019). Keshavarz emphasizes how this violent logic is especially possible when a given situation is framed as a "humanitarian crisis" such that the long term effects (potential harms) of an intervention are overshadowed by the immediate benefits. In this way, "design solutions to emergency crises … move beyond the site and moment of emergency and turn temporary status into a permanent condition" thus perpetuating "'the crisis' that humanitarians in fact try to address" (Keshavarz, 2019, p. 124). But the problem extends beyond the crisis intervention, or "lifeboat" design, on which Keshavarz focuses. As Illich notes, in his characteristically provocative tone, "it has become fashionable to say that where science and technology have created problems, it is only more scientific understanding and better technology that can carry us past them" (Illich, 1973, p. 8). Such reductive techno-solutionism is often not so obvious as Illich makes it seem, but can occur even when engineers make efforts to use non-technoscientific methods to understand community needs or perhaps even co-design. Keshavarz argues that we need to go beyond such superficial efforts to address the political effects of our designs:

> Against the background of a prevailing critical discourse—one that presents design as an agent of social, political, and environmental change, it is important to remember that it is *not* enough to design "for" or even "with" the other. Designers and design researchers in the Global North must also recognize *how* and *why* they carry their acts of designing from the positions they occupy. In promoting the conceptualization of design as a change agent for political and social problems without considering the politics of designing, we risk depoliticizing the context in which the design interventions take place. (Keshavarz, 2020)

Thinking politically about our engineered systems is necessary in order to recognize or, better, avoid adaptive preferences and the related violence of humanitarian design.

Transition Thinking and Design

Any political theory needs to be actionable. Though this initial stage of the project is mostly about exploring the particular harms caused by engineered systems and not recommending particular solutions, it is still worth providing a theoretical framework for how engineers should think about "solutions." Such a framework is especially useful since the harms explored in this chapter are caused by ubiquitous, entrenched systems that seem impossible to avoid and seem here to stay. That is, without a framework to think about how we might transition toward local (i.e. just) engineered systems, and a set of tools for helping to implement a strategy, my critique is impotent and naïve. Fortunately, excellent frameworks, tools and strategies have been developed in the contexts of other transitions, perhaps especially what is often labeled "the energy transition" away from fossil fuels. Some of these tools and strategies, such as Cradle to Cradle framework and Degrowth strategy, are explicitly focused on localizing systems.

Design theorists have further elaborated on business and institution oriented strategies to develop a “transition design” framework (Transition Design Seminar, n.d.). Here I will highlight some of the most important elements of those frameworks that can help engineers support a transition towards more local engineered systems.

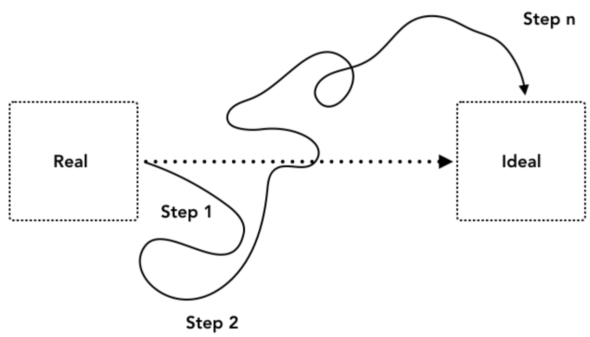

Figure 1. A transition pathway, with stepwise progression, from a real situation to an ideal situation. Each step should represent a change for the better (there should be no regression), and the rate of change might be nonlinear.

The most essential use of a transition framework is to take the paralyzing tension between real and ideal and instead to render it a productive tension. That is, a transition framework can help us to think in terms of some ideal for which we are aiming while also recognizing that from our current real position that ideal is relatively unachievable, and the best we can do is to take incremental steps towards the ideal (Figure 2). The steps may be larger or smaller, and “necessary” steps may be feasible only in a future far beyond current peoples’ lives. For example, even though backyard production of electricity is desirable, “it is almost certain that in a period of transition from the present to the future mode of production in certain countries electricity would not commonly be produced in the backyard” (Illich, 1973, p. 23). This stepwise approach to progress (etymologically, “stepping forward”) means that each step should be positive. Planning a step that has extreme negative consequences, such as a reign of terror in order to achieve a political revolution, should be out of the question. Each positive step should be acknowledged as insufficient in itself, as progress *relative* to a real and an ideal, but far from absolute progress. Doing better is not doing best. This means that we should articulate the position as well as the rate of change. (For engineers, this should be a familiar concept—it is a derivative!). Understanding the rate of change, or speed of progression, means looking to past positions and projected future positions. Also, as represented in Figure 2, change might be nonlinear and convoluted. Further, there will always be uncertainty about whether steps are actually progress since evaluating change, especially when the goal is holistic, as is justice, is very difficult.

There are many existing resources to help conceptualize and implement transitions toward more local engineered systems. Beyond the most basic theoretical task of rendering productive the tension between real and ideal, transition design theory develops a more sophisticated account of the needed approach. (Transition Design Seminar, n.d.; Irwin, Kossoff and Tonkinwise, 2015). The strategies and plans of many communities, institutions, and businesses provide practical guidance. For example, Cradle to Cradle provides a certification program and product design checklists that emphasize using local material and energy sources (McDonough and Braungart, 2002; *Cradle to Cradle Certified® Version 4.0*, 2021). As William McDonough and Michael Braungart write, "we recognize that all sustainability (just like all politics) is local" (McDonough and Braungart, 2002, p. 123). Degrowth and steady state economy frameworks similarly provide practical guidelines (Schmelzer et. al., 2022; Sol, 2019).

Finally, any effective transition framework must acknowledge the necessity of epistemic pluralism. Getting stuck in a particular knowledge rut is not a good strategy for imagining the best way to transition away from status quo injustices. For engineers, this means recognizing that the engineering way of knowing about and acting on the world is one particular, *limited* way of knowing and acting—even if it is currently the most powerful. Additionally, engineers should recognize that their power to influence transitions is part of the problem and part of the solution. Though engineers should use their power well, they should attempt to divest themselves of disproportionate power and reinvest that power in others, thus enabling a return to (or simply progress toward) a democratic politics.

Case Study: The Stack

The Stack, the computing "system of systems"—"the Internet" plus everything needed to build, energize, and dispose of "the Internet"—that fundamentally structures our lives, is the consummate example of a system with extremely large, rapid and long-duration system boundaries. I'll illustrate this by discussing the engineered system of material, energy and data flows that is necessary for my "single" computing action of accessing Benjamin Bratton's 2015 *The Stack*. In what follows I am not attempting to understand the effects of this computing action or the system it convenes—I think that's impossible—but I'll attempt to present *enough* evidence to demonstrate why it's impossible for me to understand that system politically, and also why that system disempowers me (and everyone else).

What is the "Internet plus" system or "The Stack" system that I need to read Bratton's ebook? One way to begin understanding the system behind my "internet action" is to trace the physical path of the data signals. The Traceroute program available through my Mac's terminal app reports that my request to get the ebook data at "direct-mit-edu.dartmouth.idm.oclc.org" takes 9 router hops, starting at Baker Berry library in

Hanover, NH and ending at a server in New York City, identified using its Internet Protocol (IP) address of 152.179.19.254 and an IP geolocator app. (Yes, servers and "the cloud" have physical locations in datacenters.) These hops are routed along fiber optic cables, and though there are academic studies of the locations of these cables, including Durairajan et al. (2015), my research finds that high resolution maps of fiberoptic cables are proprietary; I'd need such proprietary maps to identify the specific cables used by my request (note that there are relatively detailed non-proprietary maps of *submarine* fiberoptics, e.g. at submarinecablemap.com).

Life cycle assessments of fiberoptic cables and datacenters would be a good way to begin understanding the system boundaries of interest. However only one of these life cycle assessments, of datacenters, is available—there are no published life cycle assessments of the fiber-optic internet network, which fits with the "extreme invisibility of cable infrastructure" (Furlong, 2021). Datacenters are slightly more visible, and have been assessed by lifecycle engineers; I chose to use Whitehead, Andrews and Shah's 2015 paper "The Life Cycle Assessment of a UK Data Centre." The paper details the various physical effects of a datacenter (likely similar to the one where 152.179.19.254 lives), using the "damage categories" of climate change, ecosystem quality, human health and resources (Whitehead, Andrews and Shah, 2015) Like most other LCAs, the paper draws explicit system boundaries that are focused on abstract system operations. Figure 1 in the paper shows a representation of these system boundaries, and indicates that there is a huge industrial system that is convened in order to mine, manufacture, transport, power, maintain and dispose of a data center (including the computing from the same or other datacenters that help manage the logistics and optimization of the data center lifecycle).

That Figure 1 reveals that analysis of such “cradle to grave” system boundaries is a useful entry point into understanding that the data center system is far more than a sleek warehouse full of chilled blinking servers; it extends far in time and space beyond that “operational phase.” But this approach also is misleading in that it leaves the temporal and spatial dimensions of the system implicit—nowhere is it noted *where* or *on what timescale* the various stages of a data center’s life occur. Nowhere is it discussed how *the rapid change* in various parts of the system of interest inhibit knowledge and action. In this narrow engineering analysis, there is no mention of where or on what timescale the “emissions to air, water, and ground” occur (Whitehead, Andrews and Shah, 2015). Making these dimensions explicit would help us understand the political effects of the datacenter system.

To help see the spatial and temporal dimensions of “the engineered system that allows me to read Bratton’s ebook,” we can turn to that very book itself. (While here I focus on *The Stack*, useful related studies include Kathyrn Furlong’s 2021 “Geographies of Infrastructure II: Concrete, Cloud and Layered (In)Visibilities,” Nicole Starosielski’s 2015 *The Undersea Network*, and the 2015 collection of essays *Signal Traffic: Critical Studies of Media Infrastructures*.) Bratton’s book is especially useful in that it takes a whole-system approach that attempts to describe the vast and fast boundaries of “The Stack”—which he defines as the system on which the Internet depends and of which the Internet is the most central part. The layers of The Stack include the mining and manufacturing and energy conversion needed to build and power cables and servers and power grids; the network of cables and repeaters and routers and datacenters of “the cloud”; and the many interfaces of The Stack from the cityscape to the iPhone (Bratton, 2015, p. 5). Bratton argues that in order to understand the political consequences (his focus is on "sovereignty") of these many layers, we need to consider them for the integrated system that they are:

> Instead of seeing all of these as a hodgepodge of different species of computing, spinning out on their own at different scales and tempos, we should see them as forming a coherent and interdependent whole. These technologies align, layer by layer, into something like a vast, if also incomplete, pervasive if also irregular, software and hardware *Stack*. (Bratton, 2015, p. 5.)

The coherent and interdependent whole of The Stack has more expansive and nuanced system boundaries than those identified by Whitehead, Andrews and Shah (2015). According to Bratton's analysis, and corroborated by our common-sense experience of the Internet, The Stack's system bounds are truly global by virtue of the cable- and satellite-enabled Internet, but also the global mining and manufacture and energy conversion industries. The Stack's effects extend far into the future, via persistent infrastructures, emissions and toxins, as well as via social media's effects on mental health, persistent television culture, locked-in governmental reliance on electronic data and surveillance and long-term damage to political practice via ignorance and disempowerment. This global, long-duration system also evolves extremely rapidly as cables and servers and software and mines are changed, such that The Stack in any given moment is always already a new Stack, even though it is perpetually grafted on to previous Stacks (and the technologies on which those Stacks were built).[20]

The relatively big, fast and forever system bounds of The Stack severely inhibit our political knowledge of its effects and our capability to shape it. If Bratton's book

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[20] While this brief ontology is sufficient for my purposes, the curious reader will find in-depth description of The Stack system, and will be able to hone system boundaries somewhat, by reading Bratton's book; despite what Ian Bogost calls its "abstruse" style, Bratton's ambitious 500-page attempt at a political ontology of The Stack is the most plausible account of the system that allows the Internet (Bogost, 2017).

represents the best attempt to develop a political understanding of The Stack, and he had many years and full attention devoted to the task, we are very clearly far off from knowledge—of, by and for the people—of how The Stack contributes to or detracts from justice. The Stack is so immensely globally distributed, its workings so complex and hidden (intentionally and not), that no individual can hope to develop an understanding of the system necessary to regulate it. We *can* have the proto-political knowledge of The Stack that allows us to recognize it as inherently unintelligible; to use Donald Rumsfeld's typology of unknowns, this thesis argues that we can have enough knowledge to categorize The Stack as a "known unknown." Further, we can recognize that The Stack severely inhibits political empowerment. Though The Stack constitutes the world in which we live to a very high degree—by way of computational finance, e-commerce, ecological destruction as a result of datacenters, destruction of humans for conflict minerals, surveillance, military operations, social media, 24-hour news, computer modelling, the emerging Internet of Things, *ad nauseum*—individuals have no chance of shaping it. *It is a constitution without possibility of amendment that locks in current and future people to a certain way of life.* One example: with its proud statement that "in any one year, over 6000 people actively participate in the IETF," the Internet Engineering Task Force unintentionally confirms that this part of the Stack, which effects more than 7,000,000,000 people, is highly non-democratic (Introduction to the IETF, n.d.).

In sum, the Stack causes harms to politics that can only be caused by engineered systems. Like any other engineered system with big, fast and forever system bounds, it inhibits political knowledge and participation. These harms occur in addition to the many other cultural and political harms detailed by Bratton, Furlong (2019), Starosielski

(2015), the authors of *Signal Traffic* (2015), life cycle assessment engineers, and many others. And of course it is true that harms to political knowledge and empowerment—especially disempowerment—would persist even if we miraculously solved those many problems and engineered an “environmentally friendly,” fair trade, non-discriminatory, equal access, private, secure and demilitarized version of The Stack. Yet, in a way that might puzzle us and is especially harmful, The Stack is often portrayed as the vehicle of knowledge and empowerment, a champion of democracy. Article 19, an organization that advocates for a democratic internet, explicitly aims to protect “the Freedom to Speak, and the Freedom to Know” it asserts the Internet can provide, but it only proposes peer-to-peer reform for one small part of The Stack (Article 19). Cris LeDantec’s research on how to develop knowledgeable, empowered publics using networked computing systems is much needed because it introduces Dewey’s *The Public and its Problems* into the critical computing literature, but LeDantec’s 2016 *Designing Publics* never discusses the fundamental problem described by Dewey—disintegration of publics caused by big, fast and forever engineered systems—and it proposes “democratic” solutions that only further entrench a fundamentally undemocratic Stack (LeDantec and DiSalvo, 2013; LeDantec, 2016). Information and communications technology (ICT) solutions to declining participation in and declining opportunities for political engagement similarly ring hollow. Such solutions are proposed by many democratic theorists (including Benjamin Barber in *Strong Democracy*) and by researchers working on technology and the Capabilities Approach—but without any discussion of whether the underlying software and hardware as well as energy and labor infrastructure is also democratic. The tradeoff between means and disempowering system effects is not made explicit. And on closer examination, it seems like the optimal solution requires a transition away from The Stack, rather than a counterproductive reliance on The Stack.[21]

That is, rather than focus on the sensational effects of The Stack's frontend—including "generative artificial intelligence" such as ChatGPT—we should be focused on the "boring," hidden effects of The Stack's backend. ChatGPT is harmful mostly because it's part of The Stack, not because of the sensational ethical dilemmas that have produced a profusion of AI ethics papers. The Stack with ChatGPT is not much more unintelligible and alienating than The Stack without it, and if we are to be concerned about ChatGPT in particular it should be mostly because it further inhibits political knowledge and empowerment. Unfortunately, moving from thinking about the sensational frontend to the boring backend of ChatGPT and other Stack phenomena is hard since it means overcoming a fundamental bias of modern ethics. The Trolley Problem, for example, focuses on the frontend ethical dilemmas—to switch the tracks or not? To push the fat man off or not?—and totally ignores the backend political dilemmas, such as, to have the train or not? To have the train in what form? These pressing ethical dilemmas are important to address, but addressing them is meaningless unless we also commit to changing the underlying conditions that cause them in the first place. Fixating on a tragic dilemma can subvert the effort to change the conditions that cause the tragic dilemma. Fortunately, recognition of this need to focus on infrastructure is not new, as indicated by the emergence of "infrastructure studies," but it is certainly not popular. It has not been

[21] Many critical computing and computing infrastructure scholars acknowledge the counterproductive logic of many "Stack solutions." One of Bratton's formulations is: "it is only through the medium of The Stack itself that we know so precisely how the carbon appetite of The Stack is contributing so decisively to our Anthropogenic predicament in the first place" (Bratton, 2015, p. 305).

present in political theory nor engineering education; I hope this thesis contributes to changing that reality.

What would a transition away from The Stack toward more local computing look like? Is local computing possible? What are the tradeoffs of computing systems, as evaluated by a holistic theory of justice? How would local computing systems repurpose existing infrastructures, such as fiber optics and data centers? What is peer-to-peer computing, all the way down to the Earth level of the Stack? These are important questions for future research, and important questions for engineers to be asking—especially since modern engineering methods, and an increasing number of products, are highly reliant on if not explicitly built for The Stack. If the arguments presented in this thesis are sound, we have enough knowledge to know that these are important questions. We have enough proto-political knowledge to know that the non-local computing systems we have severely inhibit political knowledge and empowerment. We have enough knowledge to realize that asking how to transition toward just computing systems means asking how to transition toward more local computing systems. Further, we have a basic idea of the engineering goals, challenges, and tradeoffs. Cosmolocal computing systems would be radically different from the computing systems that we know. They would likely be slower and larger in order to be more intelligible and formable. They would use more local materials and energy sources—no coltan mining in the DRC to make a computing system for Hanover NH, no coal from West Virginia burned in a New York power plant to power the ISO New England grid. Cosmolocal computing systems would be more repairable, biodegradable, recyclable. They would support a cosmolocal economy, and perhaps be networked—via engineered systems with local system boundaries (such as locally manufactured fiber optics)—to other local computing networks.

Chapter 3: A Study of Engineering and Justice Workshops

The theory presented in Chapter 2 is meant to inform action. Of course it is meant to inform scholarly action—continued debate about and research into aspects of the argument—but it is mainly meant to inform action by people who currently have, or are training to acquire, the power to influence what sort of engineered systems constitute our lives in community together. In order to develop an understanding of how to teach engineers to think politically about engineered systems and act accordingly, it is necessary to establish a baseline understanding of engineering students' capability to think and act politically on engineered systems. Not only do we care about a baseline, but we also care about how we can *improve* engineering students' capability to think and act politically on engineered systems. Both of these tasks require designing an instrument that can measure "the capability to think and act politically on engineered systems." The second task requires testing ways to communicate the theory and its practical implications to engineering students and engineers.

In collaboration with my thesis committee and a team of engineering undergraduates (see acknowledgements), I designed a study to establish a baseline understanding of, and test a method to improve, the capability of engineering students at Dartmouth's Thayer School of Engineering to think and act politically on engineered systems.[22] The study occurred in Spring 2023 and had 32 participants, all Dartmouth undergraduate engineering students. All participants took pre- and post- surveys at the

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[22] Since the work done for this Chapter was the collective effort of Kate Pimentel, Wells Willett, Heather Wang, Sophie Inkster and myself, I will use the first person plural throughout.

beginning and end of a 4-hour window. In between, 16 students participated in 4-hour, 4-student engineering and justice workshops (the workshop group), while the other 16 students were given no instruction about what to do (the control group). Follow-up interviews were conducted with half of the workshop participants.

This chapter presents the methods for and results of that study—a study of engineering and justice workshops for Thayer undergraduates. The precise goals of the study, or research questions we want to answer, are therefore also presented. A literature review is incorporated throughout the section.[23] Approval for this study, STUDY00032662, was obtained from the Center for the Protection of Human Subjects on February 7, 2023.

Research Questions

The NIH stage model for behavioral intervention development is a useful tool for understanding the position of this study in a larger scientific process and therefore what type of research questions are appropriate for this study, and which for follow-up studies (NIH Stage Model, n.d.). Though our ultimate goal is to develop an intervention that empowers designers and modifiers of engineered systems to think and act politically, and not to develop an intervention that produces behavior change, the stage model is still applicable to our research.[24] The NIH classifies Stage 0 and Stage I in the following way:

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[23] For a more comprehensive account of studies and papers on teaching engineering ethics, see Hess and Fore (2018) as well as the journals *Science and Engineering Ethics* and *Engineering Education* in general.
[24] See Hannah Arendt's *The Human Condition* at pp. 43-45 for a precis on how understanding humans in terms of behavior, and attempts to manage behavior, is antithetical to action and a healthy politics. Though there may be a fine line between a behavioral intervention on the one hand and persuasive argument and deliberation on the other, we see this as a very important difference. As educators, we think it is counter-productive to attempt to manipulate "the psychology" and behavior of students without their consent; instead, we intend to treat them as agents who can be persuaded by "the unforced force of the better

> **Stage 0** involves basic science that occurs *prior to* intervention development, but is relevant (ultimately translatable) to intervention development. Another type of basic science research—research on mechanisms of change—is an integral part of all other stages of intervention development. Such research involves asking basic science questions about behavior change *within the context of* intervention development studies. Questions of mechanisms of behavior change are relevant to every Stage of behavioral intervention development.
>
> **Stage I** encompasses all activities related to the creation and preliminary testing of a new behavioral intervention. Stage I can include the generation of new behavioral interventions as well as the modification, adaptation, or refinement of existing interventions (Stage IA), and it culminates in feasibility and pilot testing (Stage 1B). Stage I can also include modification of an intervention for the purpose of making it more easily implementable. In addition, also in the service of increasing implementability, Stage I can include, as appropriate and necessary, the development of training materials. Finally, note that one can conduct Stage I studies in research settings, with research providers and research subjects; or in community settings with community providers or caregivers. (NIH Stage Model, n.d.)

Stages II through V—pure and real-world efficacy (II and III), effectiveness (IV) and implementation and dissemination (V)—are not presented here since this thesis encompasses Stage 0 and I only. Stages II through V are tasks for future research.

The theory presented in Chapter 2 is part of the "basic science" of Stage 0. Also part of Stage 0 is establishing a baseline understanding of *Thayer undergraduate engineering students*' attitude toward and knowledge of, as well as intention to act on, a *political theory of engineered systems*. Since our political theory of engineered systems is new, there is necessarily no baseline of engineering students' attitude/knowledge/action with respect to a political theory of engineered systems. However, a major part of our research for Stage 0 was developing that baseline understanding via our own participation and interactions in engineering institutions and cultures, as well by analyzing literature on teaching engineering justice and engineering ethics to understand how their findings

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argument" via consensual deliberation, and that therefore our goal should be to encourage right action, and not right behavior (Arendt, 1958; Habermas, 1981). There is therefore a fundamental tension between the statistical methods employed in this study and the goals that those statistical methods are meant to help measure. This tension should be more fully accounted for in future work.

might inform our research. Finally, an important element of Stage 0 is research on mechanisms of change, which we briefly review below.

The work that went into designing our study, including our “modification, adaptation, or refinement” of existing engineering ethics teaching methods, is Stage IA. This methods section presents the results of Stage IA. Stage IB is the pilot testing of our intervention. The results sections in the second part of this chapter presents the results of Stage IB.

Our study combined the “baseline establishment” part of Stage 0 with stage IA and IB because we are relatively confident 1) that our new political theory of engineered systems is sound and unlikely to change much in its essential elements; 2) that the population of engineering students should understand and act on that theory; and 3) that seminar-style interventions are the best method for fostering the latter. That is, we determined that the “basic science” is well-enough established to ask more focused questions about a *particular method X* to improve attitude/knowledge/action of a *particular population Y* of Thayer undergraduate engineering students with respect to the *particular content Z* of a political theory of engineered systems. We were not interested in the efficacy of seminar-style workshops in the abstract, nor seminar-style workshops for engineering students, nor engineering ethics seminar-style workshops for engineering students. Instead, we aimed to begin a process of fine-tuning a particular method *X* to communicate particular content *Z* to a particular population *Y*. That means our research questions could be focused on pilot testing a specific intervention.

Finally, it’s worth noting that we see the stage model as iterative and not sequential—we expect our findings in Stage I to further clarify the “basic science” of

Stage 0, including our theory and baseline understanding of engineers' political thought and action capability. This will then inform further studies in Stage I (we assume that there will need to be quite a few more Stage I studies in this research program before there can be studies in Stage II).

The most general knowledge we want to produce in Stage I is *the generalizable features of the best way to empower engineering students to think and act on a normative theory of engineered systems*. Our most general research question for that stage is therefore: what is that best way? Our general hypothesis about that best way is that it involves 1) seminar courses, or a series of long conversations focused by a set of questions and readings; 2) integrating ethics or justice into technical courses via "micro-insertions" of critical material that foregrounds the political context of engineering problem solving (per Davis (2006) and Leydens and Lucena (2018)); and 3) the "real-world pedagogical strategies" of codesigning systems with communities (Hess and Fore, 2018). Ideally these different educational strategies will work in tandem. However, in this study we chose to focus on the seminar strategy in large part because it seems to be the most essential and most needed component of empowering students to think and act on a normative theory of engineered systems.

That is, research suggests that seminar courses are the best way to empower students to think and act politically on engineered systems. Rob Lawlor writes in his 2021 article *Teaching Engineering Ethics: A Dissenting Voice* that in designing methods for teaching engineering ethics:

> it would be worth considering what methods of teaching are used by philosophy departments . . . almost all philosophy teaching has four core elements:
>
> 1) Reading—which introduces students *directly* to high quality philosophical argument and counter-argument …

2) Lectures—which can serve a number of purposes, but notably helping students with the interpretation of readings that they might struggle with … presenting additional argument and perspectives … [and finally] an alternative to 1) …

3) Discussion — … discussions allow the lecturer (or tutor) to help students with their interpretations … and allow students to develop their own skill at reasoning and constructing arguments. And the discussions expose students to other people's attitudes, such that they realize that not everyone reached the same conclusion they did, and that maybe the answer is not obvious …

4) Assessment … (Lawlor, 2021, pp. 43-44)

This "content-centric" approach is different from the many other approaches to teaching engineering ethics, including teaching professional ethics codes and—the approach studies have found to be most popular approach—using case studies (Lawlor, Hess and Fore 2018; Haws, 2001).[25]

The problem with case studies and teaching to ethical codes is that they do not foster the attitudes and knowledge necessary for deep, dynamic thought—and therefore reading and conversation—about the politics of engineered systems (Lawlor, 2021). Yet it is precisely this sort of thought that is necessary for just engineering designs. As Haws writes:

> The six pedagogical approaches (professional codes, humanist readings, theoretical grounding, ethical heuristics, case studies, and service learning) may all have value in engineering education. However, they are not all of equal value for the implicit goals of enhancing divergent thinking, helping engineers to see their work through the eyes of the broader community, and giving students access to the language of ethics. This last objective, helping our students to formulate, articulate and defend their ethical resolutions to the broader community, can only be achieved with theoretical grounding. Theoretical grounding, combined with service learning to make it "real" and case studies to make that reality sufficiently broad, should optimize engineering ethics instruction. (Haws, 2001)

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[25] There are many different professional codes of ethics for engineers; prominent codes include those of the Institute of Electrical and Electronics Engineers (IEEE) and the National Society of Professional Engineers (NSPE). Ethics trainings based on case studies emphasize peer-to-peer learning via discussion about how individuals should make ethical choices in a particular, bounded scenario (Lawlor, 2021). Charles Harris et. al.'s 2009 *Engineering Ethics: Concepts and Cases* and Robert McGinn's 2018 *The Ethical Engineer: Contemporary Concepts and Cases* each list a huge number of example case studies. Frequently used case studies include the Manhattan Project and the Challenger explosion; McGinn's book includes the Union Carbide pesticide plant in Bhopal, the Citicorp Center Tower, and Google Street View.

Facing a depoliticized engineering culture and practice that is attractive to "convergent thinkers who tend to become oblivious to the wider ramifications of their work," we have an urgent need to cultivate divergent thinking via content-centric methods (Haws, 2001). Our study therefore focuses on testing the seminar strategy with the aim of quickly developing an effective, workable curriculum and approach; future research should test more holistic curricular approaches.

However, a few conditions prevented us from testing our ideal seminar courses in this study and in the near future. Most obviously, the study needed to be much shorter than a semester-long seminar course in order to be incorporated into this thesis. Further, while piloting an extracurricular seminar course on engineering and justice might be possible relatively soon, a course *in* an engineering school curriculum will take time to develop and may face cultural barriers; I am doubtful that a proposal for an engineering course on "political theory of engineered systems" will be quickly accepted.

Therefore, in this study we decided to test the abbreviated version of a seminar—a seminar crash-course or "workshop." While reducing the time committed to studying a certain set of questions fundamentally changes the character of a seminar and may eliminate many of its important long-term effects, we aimed to preserve enough of the core elements of a seminar such that our workshops would be content-centric guided discussions that encouraged divergent thinking. In some ways, our workshops resemble a single seminar meeting and our study can be seen as testing the short-term effects of a single seminar meeting. I hope that this study might be the beginning of a research program that will culminate in testing and integrating curricular seminar courses.

Accordingly, the more specific knowledge we want to produce at this point in Stage I is *the generalizable features of the best seminar-style workshop for empowering engineering students to think and act on a normative theory of engineered systems*. The concomitant research question is, what is that best seminar-style workshop? However, since in this pilot study we cannot hope to produce specific knowledge about the best workshop, we instead ask about whether the delivered workshop produces some increase in desired capabilities.

Our specific research questions are:

> **RQ1:** What is Dartmouth engineering students' baseline capability to understand how engineered systems affect politics and to develop systems that inform and empower?
>
> **RQ2:** Does the specific workshop delivered immediately increase Dartmouth engineering students' capability to understand how engineered systems affect politics and to develop systems that inform and empower?
>
> **RQ3:** What about the specific workshop delivered contributes to or detracts from Dartmouth engineering students' capability to understand how engineered systems affect politics and to develop systems that inform and empower?

We chose to use the phrase "develop systems that inform and empower" to positively frame these questions, even though realistically most of the work for current engineering students will be the "negative" task of making engineered systems less-worse, that is, developing systems that are less inhibitory of political knowledge and empowerment, less conducive to ignorance and disempowerment.

RQ1 is answered by qualitative analysis survey results, supplemented by minimal quantitative analysis. RQ2 is answered by quantitative hypothesis testing. RQ3 is answered by qualitative analysis of student participation in workshops.

Study Design: Pretest-Posttest Nonequivalent Group

The study design we used to answer our research questions can be described as a quasi-experimental, pretest/posttest nonequivalent group design (Mark and Reichardt, 2009, p. 189). The design is *quasi*-experimental since we did not randomly assign participants to our two conditions (workshop or control, discussed below) (Mark and Reichardt, 2009, p. 183). Although our scheduling process resulted in at least semi-random assignment to different conditions (and our results show that there was no significant difference between pretests for the workshop and control groups), we could not assume before we conducted the study that the different groups in our study started as "equivalent." Additionally, our presumed small sample size contributed to our assumption that we should have a quasi-experimental design and therefore use pre- and posttesting (as well as the appropriate hypothesis tests for analysis).

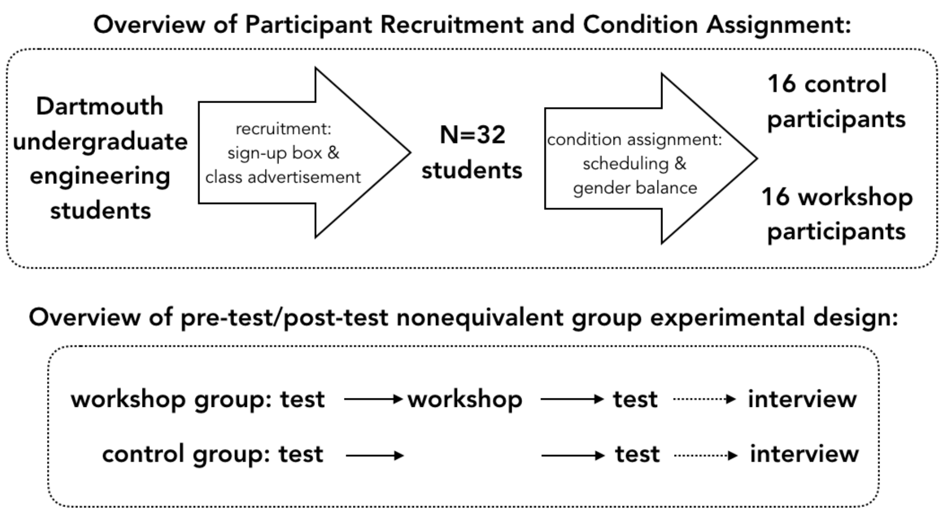

Figure 3. Diagram of our "pretest-posttest nonequivalent group" study design. The lower half of the figure is redrawn from Mark and Reichardt, 2009, p. 189. The groups were not "equivalent" because of our non-random sampling.

Our basic pretest/posttest nonequivalent group design is represented in Figure 3. This design is useful since it allows for "gain score analysis"—analysis of how much capability to think and act politically the workshop group gains as compared to the control group (Mark and Reichardt, 2009, p. 189). Gain score analysis can rule out the threat to study validity (a "validity threat") that occurs when one group starts out with a higher score than the other group. It does this by avoiding a direct comparison between posttests, but instead comparing the difference in score *change* between the two groups. While there are other validity threats that occur with this study design, such as "selection by maturation," we planned to and did use appropriate statistical and qualitative techniques to ensure our conclusions were valid (Mark and Reichardt, 2009, p. 189).

Conditions

The study had two different conditions, a workshop condition and a control condition. The workshops condition consisted of a three-hour, semi-structured discussion on the politics of engineered systems based on Chapter 1 and Chapter 2 of this thesis. (See Appendices D and E for an outline of workshop curriculum that includes the key topics and questions we asked in each workshop, as well as the workshop booklet.) The control condition consisted of no suggested activity in between taking the pre- and posttest surveys. Surveys were administered in the same way to both the workshop and control groups.

The control condition was meant to control for the effect of the surveys themselves and any effect that time considering questions about how engineered systems affect politics might have had on participants' posttest score. This study design (and our use of pre and post surveys) closely follows Borenstein et. al.'s study of an engineering-specific approach to assessing moral judgment. Borenstein et. al. "compared the mean change in scores of students in the experimental groups to that of students in the control groups in order to ensure that what [was measured was] the effect of pedagogy rather than other effects such as the effect of retaking the test." Like Borenstein et. al., since we were introducing a new survey intsrument it made sense to use our control group to control for survey-taking effect rather than to test against an possible "state of the art" curricula on the politics of engineered systems. (Also, it's worth noting that, prior to this study, I could not find any comparable state of the art for teaching about the *politics* of engineered systems; as discussed in Chapter 3, we encourage future studies that compare against a state of the art intervention, since this thesis creates such a benchmark that would allow for future comparison.)

Survey Instrument and Validation

Our survey instrument (see Appendix A for the full instrument) is one of the most important contributions of this study. Though we have a long way to go in developing the understanding of our survey instrument compared to work done by Borenstein, Drake, Kirkmann and Swann to develop the Engineering and Science Issues Test, we think that our survey provides the as yet most theoretically substantiated approach to assessing the needed thinking in engineering students (Borenstein et al., 2010). Unlike Borenstein et. al. who aim to develop an assessment of "moral judgment" among engineering students, we aim to assess "political thinking on engineered systems" because, following the arguments made in Chapter 1 and Chapter 2, that is what is needed most. Further, we also aim to assess students' capability for "political action on engineered systems" since, as argued in Chapter 2, there is a clear need for engineering students and engineers to become part of a movement to develop just, local engineered systems, and refrain from developing or supporting unjust, non-local engineered systems.

We developed our survey questions with two main goals in mind: 1) measuring, through scoring, our random variables of attitude, knowledge and action (see Quantitative Methods section below) and 2) providing rich information for qualitative analysis (see Qualitative Methods section below). We were also aware of the limits that cognitive fatigue placed on the length of the survey questions, so we limited our survey questions to four or five Likert scale questions and one open-ended question for each random variable, for a total of 17 questions. We developed a scoring rubric for the open ended questions in order to maximize our consistency in scoring participants (see Appendix A).

Preliminary validation of our survey construct was an iterative team effort. First, in collaboration with Liz Murnane, I developed a laundry list of potential survey questions a few months before the study ran, as part of the CPHS approval process. I then made minor modifications to the wording of these questions and began to work on developing the smallest subset of them that I thought still measured the key attitude, knowledge and intended action scores. As the theory in Chapter 1 and Chapter 2 matured, survey questions were accordingly deleted, added, and modified in this minor sense. In the few weeks before the study, Wells Willett and Hannah Carrese (in separate sessions) provided thorough feedback for each question that included a search of the "diction space" for each question; these sessions resulted in more clearly worded questions (though, as discussed in the latter part of this chapter, there are improvements to be made). Some of the alternative questions considered are presented in Appendix A. During this process, members of our research team took an early version of the survey. After I had evaluated each response with sensitivity to my knowledge of the team member we convened to discuss particular survey questions that I had flagged as seeming unrepresentative of a particular team member's actual attitude, knowledge, or intended action. We adjusted the survey accordingly.

This testing gives reason to assume that the survey is responsive to important attitudes, knowledges, and intentions—such as techno-fatalist and apolitical attitudes; knowledge of collective harms, political knowledge, and political empowerment; and intentions to continue conversations write transition statements (see Appendix A for a more complete overview). However, we assume that it could be much more responsive, and that the iterative process of fine-tuning the survey instrument, and/or customizing it to particular contexts, will be necessarily ongoing. For example, evaluating responses from the study and discussions with workshop participants has provided important new data that helps us to understand those parts of the survey that worked well and those that did not. Our use of a new and untested survey instrument was another reason for employing pre- and posttesting, since we were unsure of what the effect size would be and of how different students might respond.

Because our study was designed to measure change in score before and after a three hour workshop, we used an additional post-survey for workshop participants that asked them one general and three specific questions about the workshop content, instructor, and curricular integration. Both post-workshop surveys included demographic questions. This meant that we had three different surveys: a pretest, a post-workshop test, and a post-control test. Our completion times were approximately: 20-25 minutes for the pretest survey and the post-control survey, and 25-30 minutes for the post-workshop survey.

Population of Interest

From one perspective, it would be ideal if the results from a study like this could generalize to as large a population as possible—engineering students in general, or perhaps even engineers in general. But we have high uncertainty about our ability to generalize to the first population, let alone the second. Dartmouth engineering students are likely different from other engineering students for at least four reasons. First, we students at Thayer School of are situated within a (supposedly) liberal arts institution, and there are not many other engineering schools at (supposedly) liberal arts colleges. Second, Thayer has a relatively unstructured curriculum, with loose "concentrations" substituting for well-defined electrical/mechanical/civil/biomedical tracks. Third and fourth, Thayer has relatively high levels of diversity and a few courses that teach human centered design and design thinking, both of which presumably predispose our engineering students to be more aware of "others," a key prerequisite for thinking politically.

We can assume our inferences are valid for the Thayer student population, but there is high uncertainty about their validity for the engineering student population in general. Further, workshops and surveys were tailored to reference elements of the Dartmouth engineering curriculum, so future studies would need to adjust their interventions and measurement instruments accordingly.

Quantitative Methods

Random Variables

We decided to define three random variables to help guide analysis of this study: participant attitude A, participant knowledge K, participant action E (for Empowerment). These variables correspond to the desired outcomes for engineering students—right attitude, right knowledge, right action. These outcomes are informed by Bloom's taxonomy of desired educational outcomes, Hannah Arendt's arguments about the importance of thought and action, the scholarship discussed in Chapter 2 on the necessity of motivation to know (Arendt, 1958; Armstrong, 2010). The distinction between these variables is somewhat arbitrary since it is highly unlikely that they are independent, especially given the way we are measuring them on our survey instrument. For example, our first and second questions used to measure E on the survey—1) "I intend to talk with a friend at least once a week about how engineering education and practice can change to support people who are blocked from shaping their worlds" and 2) "I intend to be part of a movement to build engineered systems that use local material and energy sources"—are likely to depend participants' knowledge, K, of why it is important to discuss and change how some people are blocked from shaping their worlds, and why using local material and energy sources is important. However, for constructing the survey questions and for interpreting our results we assumed that it would be useful to group questions such that their response contributed to these distinct random variables.

These random variables are defined by the statements and questions on our pre- and post- surveys such that:

$$A = \{a \in \frac{1}{2}\mathbb{Z} | (5 \leq a \leq 35)\} \tag{1}$$

$$K = \{k \in \frac{1}{2}\mathbb{Z} | (4 \leq k \leq 35)\} \tag{2}$$

$$E = \{e \in \frac{1}{2}\mathbb{Z} | (5 \leq e \leq 35)\} \tag{3}$$

These random variables are ordinal since we cannot be certain that there is an equal gap between answers of, for example, “strongly agree,” “agree” and “neither,” nor that gaps encoded by a difference of 1 point for Likert questions are equal to gaps of 1 point for free response questions. Further, their values are elements in the set of integer and half-integer values, $\frac{1}{2}\mathbb{Z}$, since free response scoring allowed for half-points to be awarded. Their ranges are dictated by the possible high and low scores on our surveys.

Since these variables are measured on our pre- and post- surveys, it is useful to further summarize them using two more random variables such that X is the sum of the attitude, knowledge and action scores on the pre-survey while Y is the sum of the attitude, knowledge and action scores on the post-survey:

$$X = A_{pre} + K_{pre} + E_{pre} \tag{4}$$

$$Y = A_{post} + K_{post} + E_{post} \tag{5}$$

Hypotheses

We had three hypotheses: two about how scores would change within each group, and one about how score change would be different between the groups.

Our first within group hypothesis was that the sum of participant attitude, knowledge, action scores will be higher after workshops than before workshops. This general hypothesis can be broken down into sub hypotheses for the three random variables A, K and E —we hypothesized that all three would increase after workshops.

We assumed increase in workshop scores was an important difference to test because it is possible that the difference between pre- and post-workshop scores *is not* significant, while the difference between the workshop group score change and the control group score change *is* significant. Such a situation is simulated in our R code (see Appendix C) where there are small but statistically insignificant ($\alpha = .05$, Brunner-Munzel test) score increases from pre-control to post-control to pre-workshop to post-workshop that results in a significant ($\alpha = .05$, Brunner-Munzel test) increase in score change between workshop and control groups.[26] In other words, without testing this hypothesis we might conclude that there is a statistically significant difference between the workshop and control group score changes, even though the workshop wasn't successful in producing a statistically significant score change among the workshop participants. However, on closer analysis, we determined that this hypothesis was redundant since the reason for a study design with the control group was precisely so that we could answer RQ2 *relative to the control group.* In other words, the "immediate increase" about which we care is not workshop participants' change in score, but workshop participants' change in score *relative* to the control group's change in score. Therefore, given our study design, the situation discussed above and simulated in R would not require that we test this hypothesis; the between group hypothesis below is

[26] In mathematical terms, this is similar to a statement that the "insignificant difference relation" is not transitive. In logical terms, this is similar to the sorites paradox. The situation is only *similar* since we assumed we needed to test "the difference between the difference between" pre- and post-scores for workshop and control groups (or the difference of score change between groups), rather than just the difference between post-control and post-workshop.

sufficient to test RQ2. Further, in future studies that can assume there is no significant difference between pre-control scores and post-control scores (as we found in this study; see Quantitative Results), there would be no need for a pre/post study design (the post-workshop scores could be directly compared to the control scores) and this hypothesis would not be needed. Nonetheless, we present this hypothesis since it was one of our original hypotheses.

Mathematically, where μ represents the central tendency of the data, the null and alternative hypotheses about an increase in scores within workshop participants is:

$$\text{Within Workshops } H_0\colon \mu_X = \mu_Y \quad (6)$$

$$\text{Within Workshops } H_1\colon \mu_X < \mu_Y \quad (7)$$

The above mathematical formulation represents our original formulation *before* we had fully considered the need for non-parametric rank-sum tests. If we had more fully considered the implication of our small sample size, likely unequal variance between sample distributions, and unknown population distribution, we would have chosen to formulate these hypotheses in terms of "stochastic superiority" of a rank test, such as the Brunner-Munzel test eventually used (Karch, 2021). As discussed in the Quantitative Results section, however, we can reformulate these hypotheses in terms of the Brunner-Munzel test while preserving the general hypothesis that workshop scores will be higher than control scores. Therefore, throughout this section we present our original hypotheses, in terms of a difference between central tendencies rather than stochastic superiority, since they represent the general relationship that we tested.

Our second within participant hypothesis was that there will be an increase in attitude scores but not knowledge and action scores for the control group. The hypothesis about attitude is:

$$\text{Within Control } H_0\text{: } \mu_{A\_pre} = \mu_{A_{post}} \quad (8)$$
$$\text{Within Control } H_1\text{: } \mu_{A\_pre} < \mu_{A_{post}} \quad (9)$$

The hypothesis about attitude, and the general hypothesis that there is no change in score for the control group, is important to test because it will help determine whether there is a need for the pre/post *and* control design of this study. If there is no significant change in control group scores then the survey taking itself does not have a significant effect and it would make sense to either eliminate the control group—participants' post scores could be compared directly to their pre scores—*or* to eliminate the pre/posttesting for the workshop group—participants' post scores could be compared directly to their own pre-scores (a virtual control). Each of these study designs (no control or no pre/post) would have significant advantages in particular situations; see Discussion.

Finally, our third between group hypothesis was that the mean change between pre and post responses will be larger for the workshop condition than the control condition:

$$\text{Between Groups } H_0\text{: } \Delta_{control} = \Delta_{workshop} \quad (10)$$
$$\text{Between Groups } H_1\text{: } \Delta_{control} < \Delta_{workshop} \quad (11)$$

Where:

$$\Delta_{control} = \mu_{Ycontrol} - \mu_{Xcontrol} \quad (12)$$
$$\Delta_{workshop} = \mu_{Yworkshop} - \mu_{Xworkshop} \quad (13)$$

This hypothesis is the hypothesis that will allow us to answer RQ2 about the success of the workshops in terms of a relative increase in score change that they produce.

Qualitative Methods

Qualitative methods included thematic analysis and less structured synthesis and interpretation of data. Data is from workshop notes and observations, post-workshop surveys, and follow-up interviews. Kate Pimentel, Heather Wang, and Sophie Inkster took notes during the workshops, and I conducted seven total 30-60+ minute semi-structured interviews.

Qualitative analysis was a key part of this study that allowed us to develop much deeper answers to our research questions. This value of qualitative analysis may not be obvious, since as Baillie and Douglass note "commonly in engineering education work, engineers adopt a positivist epistemology because it feels more 'rigorous,' sometimes without even being aware that they are doing so" (Baillie and Douglas, 2014). Fortunately, Baillie, Douglass, and many other engineering ethics education researchers are recognizing that quantitative methods necessarily simplify and reduce in ways that qualitative methods do not, and that at the very least there needs to be a complement between quantitative and qualitative methods if we are to develop an understanding of how to teach engineering students about ethics or, in our case, politics. As Hess and Fore write in their recent literature review of studies of engineering ethics education, "we would encourage more scholars to identify and utilize qualitative methods to explore ethical becoming within the context of engineering education" (Hess and Fore, 2018).

Our thematic analysis methods were both deductive and inductive. That is, we had an idea of themes to look out for before we started analyzing our data, but we also let themes emerge from the data. Following Braun and Clarke, we did not use theme-frequency to rank theme-importance (Braun and Clarke, 2006). This is mostly because we do not assume there is a direct relationship between quantity and importance; we therefore discuss themes that we believe are important for explaining the successes, failures and limitations of our study regardless of the number of supporting occurrences. Additionally, it's worth noting that since our written dataset did not "capture" workshops (workshops were not recorded), a large amount of data came from "deductive" interview questions that prompted student responses focusing on particular themes that were then used as part of our "inductive" coding scheme. In this way, we embraced an iterative process of thematic analysis that follows Braun and Clarke's description of best practices and allowed for participants to cocreate the knowledge that we produced in this study (Braun and Clarke, 2006).

Lastly, although Hashemian and Loui (2010) suggest that best practice for interviews is to have non-instructors conduct the interviews so as to mitigate the bias of offense-avoidance (where people being interviewed don't want to be "overly" critical of the instructor), I decided to conduct interviews myself in order to gain the most rich data about workshops and future workshop-like ideas. I tried to mitigate students' potential unwillingness to criticize workshops "in front of me" by starting interviews with my own brief criticism of the workshops and then by focusing our conversation on brainstorming future workshops and courses. By discussing what would and would not work about future workshops, I gained much indirect evidence about what did and did not work about the workshops conducted for this study. Further, from these interviews I gained an excellent set of ideas for how to institutionalize courses/seminars/workshops on engineering and justice, some of which are presented in the discussion below. In that way, participants provided much more than "data to be analyzed," but themselves engaged in the analysis and synthesis to create knowledge of what worked and didn't about the workshops and (therefore) how a future seminar series should be structured.

Results

RQ1: What's the Baseline?

Dartmouth engineering students' baseline capability to understand how engineered systems affect politics and to develop systems that inform and empower is characterized by: a semi-open *attitude* to doing so, relatively little of the necessary *knowledge* to do so and relatively little *empowerment* to do so. That is, the themes of attitude, knowledge and empowerment emerge from and are useful for analyzing our data. This is likely a result, in large part, of the surveys being divided into those themes.

Attitude

Dartmouth engineering students have a semi-open attitude to thinking politically about engineered systems. A semi-open attitude is semi-fatalistic: a fully open attitude would be characterized by a desire to explore the radical alternatives, suggested by a theory of justice, to the status quo course of technological progress; a fully closed attitude would be characterized by a total unwillingness to explore any alternative to the status quo course of technological progress. While the average answer to the survey statement "I think we can change the course of technological progress" was "agree," qualitative data suggests that students do not believe that the course of technological progress can or should be changed by much. This is partly because students are generally excellent at recognizing systemic cultural and institutional barriers to thinking politically about engineered systems, and so are realistic about the possibility for systemic change. On question 17 of our survey most survey respondents identified that institutional focus on profit and rapid deadlines, as well as a generally politically uninformed or resistant-to-polticization engineering culture, would inhibit thought and action. For example, P1 wrote, “I think money and time are the biggest challenges to supporting a transition towards social justice through engineering” and P7 wrote “not everyone shares the priority of advancing social justice.” Some went further. P29 noted that “on the computer hardware side, every piece of hardware is proprietary and doesn’t allow users the freedom to reasonably understand it.” P3 wrote “one challenge I see is not prioritizing a transition toward social justice. I can see myself engaging in project for fun, interest, etc.” P5 invoked the “‘still born knowledge’ panel” of the Orozco mural at Dartmouth to describe how learning at Dartmouth can be a “bubble” out of touch with the real world. P23 wrote about the “difficulty of REAL ethical work in engineering, not just lip service and greenwashing.” These astute and colorful descriptions indicate that Dartmouth students are very aware of the challenges to designing for social justice.

What is more important to focus on, however, is that participants seemed to let this realism influence the ideas they were willing to consider. In other words, most participants seemed at least slightly resistant to considering fundamentally different engineered systems (smallslownow systems) that did not seem immediately realistic. This was most obviously manifest in the workshops in which students were very quick to invoke “reality” as a reason for not thinking about “ideal” engineered systems that didn’t subvert social justice (that is, cause preventable harm). We think this is probably closely tied to most students’ discomfort with considering normative arguments (discussed further in the section on RQ3). Since part of what is needed to think politically about engineered systems is the political imagination to consider fundamentally different alternatives to the engineered systems that now constitute our worlds, many Dartmouth students' attitudes would need to change in order for them to engage in the sustained thought and action necessary to choose, form and reform systems that support a transition toward social justice. (As discussed in the section on RQ3, the good news is that all workshop participants were open to changing their attitude to some degree). Here it's worth noting that a better survey question that would more accurately measure the needed attitude is "I think we can *fundamentally* change the course of technological progress." It's also worth noting, as I did in workshops, that realism and fatalism are not equivalent—in fact I think there are good arguments that the most hopeful and empowered attitude is also the most realistic attitude.

Our study participants mostly believed that *engineers should think politically.* That is, very few students thought it best to leave political thinking to legislators. The motivation for many was the recognition that, at least currently, "technology moves faster than laws" and therefore legislators can't possibly develop the necessary knowledge, so engineers have a responsibility to try (P19). There were two exceptions. One was a student who was humble about his own ignorance. P9 penned:

> I still agree [with the hypothetical teammate posited by the survey question] that there is no need to think about the political effects. While it is nice to, I don't believe it is a necessity. Engineers are not politicians/we have not received adequate training for politics. I worry that the Engineers do not have enough training in politics to have an unbiased opinion about the subject.

While the humility in this response is admirable, it shows the general social-technical dualism that is one of the main barriers to thinking politically. P8's response is similar, but was not based on an explicit recognition of ignorance:

> As long as my design is legal there is no need to think about political effects. As an engineer, I should be focused on the product and its efficacy instead of its political consequences.

As discussed in our RQ3 section, below, our experience in workshops makes us optimistic that these attitudes can change quickly, at least in the short term.

The flip side to students' belief that engineers should think politically was their lack of discomfort with engineers' disproportionate power. The full-points response to question 6 on our survey would have acknowledged that having outsized power requires thinking politically *and* attempting to reinvest others with that power. Not a single response mentioned the latter. Though it is impossible to tease apart whether this is the product of techno-fatalism (we can't change the status quo) or a normalization of engineers' disproportionate power, for whatever reason there is a lack of discomfort with this unjust situation. This is one of the main attitudinal barriers to thinking politically about engineered systems that needs to be addressed.

Most students are not techno-optimists, and all workshop participants were quickly open to conversations about the flaws of technical systems. Our mean score in response to the statement "I think every problem has a technical solution" was 3.3, or slightly on the disagree side of neutral. The workshop experience indicated that students who have a slight tendency toward techno-optimism and are not quickly convinced otherwise are still open to actively discussing the injustices produced by engineered systems and how we can ameliorate them—this was experienced most strongly with P21, and to a lesser extent with P29 and P24.. The evidence for this comes from workshop notes and interviews, as well as from the fact that the three workshop participants who were neutral about or agreed that "every problem has a technical solution," as indicated by their responses to that Likert scale question, were still active workshop participants.

Perhaps most importantly, all workshop participants came to workshops willing to listen and engage. However, this is likely a product (to some degree) of self-selection for workshops—students' attitudes in future seminars that engage a less self-selecting, broader cross section of the student population will be a better indicator. For example, P21, the low outlier in the workshop group, was in general resistant to the ideas of the workshop (including the most basic assumption that not every problem has a technical solution) but nonetheless had an open attitude and enthusiastically engaged in the workshop conversation. However, I assume such an attitude of "resistance yet openness" was highly influenced by P21's established friendly relationship with me and another student in that workshop—I had been the TA for one of P21's classes and he'd recently helped me with a bicycle repair. That openness to discussing the politics of engineered systems is condition dependent (is positively influenced by preexisting positive relationships) fits with our findings in RQ3 that it was important for the workshop to be peer-led, and the generalization that winning hearts is a prerequisite to winning minds.

Knowledge

Most students knew that engineered systems are political, and many knew that the rapid pace of technical innovation is a problem. As self-reported during our conversations about these topics, most students did not know about: system boundaries, collective harms, political knowledge, political participation, engineers' outsize authority, the violence of humanitarian design or resources where they could deepen their understanding of these ideas. Students were not familiar with substantive sources that could help them to understand these ideas Since very few students mentioned, in conversations or surveys, engineering specific resources for designing local systems, or the theories of change that might help them structure their design and design documentation approaches, it is unlikely that they know about them.

Students seemed to know that engineered systems have political effects. For example, most students agreed (mean response of 3.9) that “it’s possible that some types of engineered systems inherently undermine democratic politics.” When discussing the difference between politics and ethics in workshops with the help of Winner (1990), students agreed with the idea that we should move beyond thinking about the ethics of our actions as engineers to considering the political implications of the systems we help design. However, there was resistance to the idea that engineered systems *affect politics,* and can inhibit political knowledge and political empowerment. P21 said, “it’s a foreign concept to me that engineered systems are political” and our survey and interview data indicate that he is referring to the effects of engineered systems on political knowledge and empowerment. Though P21 is an outlier in many respects, our conversations indicate that he is not an outlier in this respect. Most students did not know, and struggled to understand, that some types of engineered systems might inhibit political knowledge and empowerment.

Many students knew rapid innovation is politically problematic. P11 provided a detailed example of the difficulties that arise from engineers’ desire to build innovative systems that are “new and previously unpatented.” P15 wrote “engineers should consider consequences of designs before implementation, because it takes time for democratic systems to catch up to science, and in that time harm can be done by the invention.”

However, most students did not know about the concept of system boundaries, which among other benefits provides an analytic tool to identify systems that change rapidly. Students did provide good guesses about what “system bounds” meant but were unfamiliar with the systems engineering and life cycle assessment approaches that are key entry points to thinking politically about system boundaries. It should be noted that part of their confusion may have come from the fact that we used the term “system bounds” instead of “system boundaries” on our surveys and in workshops, which we have since found to be more ambiguous and less approachable than “system boundaries;” the conclusions we can draw from survey data are therefore not very strong, but we discussed “system bounds” extensively in workshops, such that terminology was likely not a barrier to workshop participants, and it seems that students also lack knowledge of system boundaries. In response to our survey question 11, P22 wrote “I am a bit unclear on what ‘non-local system bounds’ are -> ig [I guess] this is sourcing material energy from elsewhere.” P3 wrote “maybe I’m not understanding what the questions are asking in regards to local system bounds.” These responses are also representative of an exclusive focus on spatial system boundaries (size). Though students could identify the problems of rapid innovation, they neglected to mention temporal system boundaries (duration or speed) in pre-surveys.

Students were unfamiliar with collective harms. Though the mean of 3.6 (between neither and agree) in response to the pre-survey statement “I can explain how certain types of engineered systems do or do not produce collective harms” indicates that on average students thought they could explain collective harms and their relationship to engineered systems, our discussions in the workshop suggest otherwise. It seems students in workshops had an intuitive understanding of how collective harms produce the need for collective action, a more popularly discussed concept, but no student was familiar with the analytic formulation of collective harms. In our conversations about Nefsky (2019), most students were unfamiliar with arguments that the majority of collective harms situations seem to be caused by engineered systems. The nuances of collective harms are a difficult topic of active research in philosophy, and in our conversation of collective harms students did not exhibit the background knowledge or intuition necessary to understand how they could avoid designing systems that might contribute to collective harms.

Political knowledge and political participation were foreign concepts to students. Again, though there was a mean of 3.6 (between neither and agree) in response to the statement on the pre-survey “I can explain why political participation/political knowledge is or is not necessary for social justice,” workshop discussion suggested that students lacked depth of understanding. For example, many students struggled to understand the argument for why political knowledge is necessarily democratic. Though this is a contested claim, it is important to know the arguments for and against this claim, as well as to understand the significance of political knowledge—its necessity for intentionally progressing towards justice. Students were also unfamiliar with the deeper meaning and significance of political participation. Most students, especially the older students who had worked through human-centered design projects in Engs21 and Engs89/90 understood the importance of involving the community affected by their design, often called the “target population,” in the design process. However, such co-design was mostly seen as a way to improve the design outcome or the community’s use of the design, and not as an inherently valuable way to allow people to form their world. Many workshop participants did acknowledge that living in the perfect Crystal Palace without the possibility of shaping one's world would be dull, but were not quick to see this state of affairs as unjust in the way that Illich, Escobar and I argue it is.

Students were unfamiliar with the violence of humanitarian design. The mean of 2 (disagree) in response to the collective harms question on the pre-survey that "I can explain 'the violence of humanitarian design'" is corroborated by our experience in workshops. Students were quick to recognize that it is likely problematic when a "solution" follows the same logic as the problem, or in the extreme is simply more of the problem, but did not have the analytic toolset or know of resources that could help them identify such problematic "solutions" and explain them to colleagues.

In general, we found that students did not know of resources on specific content that could aid them in developing and encouraging "designs that support a transition toward social justice." Students mostly named important but content-neutral resources such as "funding, literature, mentorship, and peer to peer collaboration," "professors," "my assets of being an effective communicator and a good listener" or "my liberal arts education" (P20, P23, P7, P4). Combining this evidence of 1) the mismatch in students' Likert responses to the collective harms, political knowledge and political participation questions with their lack of knowledge as demonstrated in the workshops and 2) the match between students' Likert response to the violence of humanitarian design question and their lack of knowledge as demonstrated in workshops suggests that students' general knowledge (and knowledge of general resources) does not correspond to specific knowledge (and knowledge of specific resources). Because collective harms, political knowledge, and political participation are "general terms," students were confident in their knowledge of them, while students were not confident in their knowledge of the "specific term" the "the violence of humanitarian design." This suggests that, insofar as we think it is important to have specific knowledge and understand specific terms—mostly since there might be a particular language that is necessary to engage with conversations on certain themes (such as democratic theory or design theory)—survey questions should be redesigned to ensure such *specific* knowledge is being measured, rather than general knowledge.

In conclusion, students in our sample do not have the baseline knowledge of adequate to understand how engineered systems affect politics.

Empowerment

Students in our sample are generally empowered to act within existing institutional and cultural constraints, but are not empowered to change those institutions and cultures. Students were quick to identify general challenges to, and general assets to aid in, choosing and designing systems that "support a transition towards social justice." P11 identified the "liberal arts," "collaboration" and "research" critique as important assets to overcoming the challenges of the discrepancy between the intended and actual effect of a system, unjust working conditions or markets caused by certain designs, a failure to design systems consciously, and the primacy of "economic value." P19 identified good partners, "existing strategies," "mentors," and their own personal time and effort as assets that could help overcome challenges of "time," "money," "trends" and bad partners. P23 identified "philosophy & social science profs," "research online &

in library" and "thoughtful ENGS profs & grad students" as assets in overcoming challenges of "incentive misalignment," "resistance to extra effort," "lack of understanding," "getting mired in disagreements" and "difficulty of REAL ethical work in engineering, not just lip service & greenwashing & the like." In workshops we found that students were generally skeptical of institutional and cultural change and lacked practical strategies to work towards that change. P24 seemed to reflect a general sentiment when they wrote "still a bit unsure about how we'd get the general public to care or feel passionately about this," and during our transitions statement exercise students worried about the "greenwashing/wokewashing" that would occur when they can't follow through on their intentions. Though Dartmouth students are highly empowered compared to most, workshop participants voiced skepticism that change can occur "bottom up" and seemed to consider themselves on the bottom. This is likely a product of their "early career positions"—it would be very helpful to know if experienced engineers and engineering educators with more influence in their respective institutions feel more empowered, or whether they also feel disempowered to enact systemic change, for example because they are "beholden to the consumer."

Most students did not acknowledge their own ignorance, which could be a big barrier to being empowered to develop systems that inform and empower. There were only three students who explicitly acknowledged their ignorance and their need to keep learning, and seven whose answers to question 17 on the survey implied that their own lack of knowledge was a problem. In retrospect, in workshops we should have done more to emphasize our relative ignorance and need to keep learning. We want to find the right balance the humility like that of P4—who wrote "I foresee that I will not recognize all potential issues, and subsequently not take the appropriate actions towards social justice"—with the optimism and confidence of most other students.

Most students intend to act in ways that will support a trend toward engineered systems that are less inhibitory of political knowledge and political empowerment, but it is unclear how to interpret this intention. Our mean responses to the empowerment statements on our survey (E1-E5; see Appendix A) were 3.0, 4.0, 3.5, 3.1, and 4.8 respectively, indicating that in general students from our sample intend to act in specific ways that are likely to support their efforts to design, and the actual achievement of, systems that support political knowledge and empowerment. Many students left the workshop feeling inspired and empowered to act. P23 wrote "felt very inspired, intellectually stimulated, & motivated to do & learn more!" and P26 wrote "it made an impact on how I will think when making a design." P19 wrote "I came away with action steps I can take to help others learn more, and help myself learn more." But my guess is that many students feel like P31, who wrote that "I still feel slightly unsure of how I would actually implement these ideas or what exactly a transition statement entails." Though many students answered that they did intend to "talk with a friend at least once a week about how engineering education and practice can change to support people who are blocked from shaping their world," it is unclear whether they have the requisite knowledge or conversational skills to achieve this. In order to interpret whether intention to act result in action, and also what supports students so that their intentions can result in actions, we would need longitudinal data.

RQ2: Did the Workshops Have an Effect on Students?

As quantitatively measured by our surveys and tested statistically, the workshops produced an immediate increase in Dartmouth engineering students' capability to understand how engineered systems affect politics and to develop systems that inform and empower.

Quantitative data from this study can be described in terms of the sample size, expected value, variance, skew, and outliers. Here we focus on describing the data for the score change between pre- and post-surveys for the control and workshop groups since, in order to answer RQ2, we need to test the difference between the control and workshop group score changes.

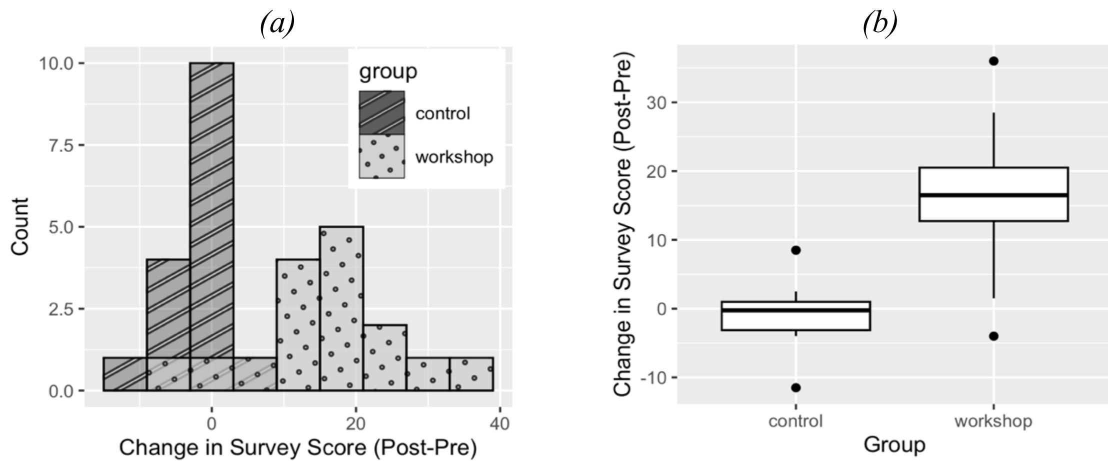

Figure 4. (a) Overlapping histogram of change in survey scores for pre and post groups. The workshop distribution is shown to be centered around a higher change in score as well as to have a larger spread. The distributions appear to be normal, and are not significantly different from the normal distribution as tested by the Shapiro-Wilk test at $\alpha = .05$*. (b) Boxplots of change in survey scores for pre and post groups. Outliers are clearly shown as dots.*

The sample size for the control group is 16, and the sample size for the workshop group is also 16. Figure 4 (a) and (b) show that the expected value (or "center") of the distribution of control scores is about 0, while for workshop scores it is about 16. Also shown in Figure 4 is that the variance of the control group scores is smaller than the variance of the workshop group scores. The boxplot in Figure 4 (b) helps us to see that there are four obvious outlier scores. In Table 2 we summarize these descriptive statistics.

While neither median nor mean have useful interpretations for our data, we show their values in order to demonstrate that there is a difference (regardless of what the specific difference may mean) between workshop and control groups. The range is the most useful measure of variance for our data, especially since the four range values reported for the overall and Likert score changes represent the outliers shown as dots in Figure 4 (b).

Throughout this section we report the Likert-question-only scores and score changes since the grading of the free response questions was a more subjective process that we assume introduced noise into the data. A limitation in this regard is that we did not have time to have multiple team members grade every survey in order to calculate an inter-rater reliability metric that could have made us more confident in the grading of free response questions. Therefore, analyzing results for Likert-questions-only can improve our confidence that there is a difference between the workshop and the control groups, even though the Likert questions were overall less useful for understanding the effect of the workshop beyond the bare existence of the effect. Table 2 shows that there was less variance in both groups when free response questions were excluded and that the larger (positive) change in score for the workshop group holds when free response questions are excluded.

Table 2. Mean score change, median score change, and range of score change for control and workshop groups.

Descriptive Statistic	Control	Workshop
Sample Size	16	16
Mean Change	-0.9	16.2
Median Change	-0.3	16.5
Range of Change	[-11.5, 8.5]	[-4, 36]
Mean Change, Likert Only	0.1	10.6
Median Change, Likert Only	0.0	12.0
Range of Change, Likert Only	[-4, 7]	[-1, 19]

Given that our data is ordinal, Figure 4 and Table 2 can help us determine which statistical test to use for RQ2 (summarized as: do the workshops delivered produce an immediate score change?). Because of 1) the small sample size, 2) the different variances and 3) unknown (but presumably different) underlying distributions, the Brunner Munzel test is the most appropriate test for our hypothesis that score changes among the workshop population are higher than score changes among the control population (Brunner and Munzel, 2000; Karch, 2021). The Brunner Munzel (BM) test is a nonparametric rank test that compares the "stochastic superiority" of one group to that of another, or equivalently the tendency of one group to have larger values than the other. To usefully oversimplify, the BM tests ranks two groups of data in terms of their tendency to have larger values; the calculation requires ranking each data point with respect to every other data point.

In order to use the BM test, we need to modify our hypotheses appropriately since BM does not test a difference between centers, but rather tests whether or not "a tendency to have larger values" exists in one group as compared to the other (Brunner and Munzel, 2000). The BM test has the following hypotheses:

$$H_0: \quad p = .5$$
$$H_1: \quad p > .5$$

The null hypothesis is that there is no stochastic superiority (a tendency to larger values in one group as compared to the other) while the alternative hypothesis is that there is stochastic superiority of one group over the other. The Brunner-Munzel statistic $\hat{p}^*$ is a studentized estimator of the stochastic superiority parameter p that can allow for some degree of inference from the sample to the population (Karch, 2021). Results from the BM test for our data are shown in Table 3.

Table 3. Results of the Brunner-Munzel test on the full score change and the Likert-questions-only score change between the control and workshop groups.

Groups Compared	**BM Statistic ($\hat{p}^*$)**	**Degrees of Freedom (*df*)**	**Sample Estimate of Expected Win-Rate**	**p-value**
Control (n=16) vs Workshop (n=16)	7.47	15.95	0.93	1.37e-06
Control (n=16) vs Workshop (n=16), Likert Only	9.4857	20.04	0.93	7.49e-09

The most general interpretation of the BM statistic for our tests is that the workshop group score change "tends to larger values" than the control group score change. The more specific interpretation using a confidence interval is that we can be 95% confident that at least 80% of the time a given score change from the workshop group will be higher than a given score change from the control group (for Likert scores only, the win-rate increases to 83%). Or in terms of the "contest" interpretation that Karch suggests, we can be 95% confident that workshop score changes will win a contest against control score changes 80% of the time (Karch, 2021). The *expected* rate at which workshop score changes will win is 93% of the time. Using the more common p-value, there is a very low probability, $p<.00001$, that the theoretical workshop population does not have a higher score change than the control population (which is the less theoretical population of Dartmouth engineering students who have not participated in a workshop). We thus reject the null hypothesis that there is not stochastic superiority of score change for the workshop group, and accept the alternative hypothesis that there is superiority of score change for the workshop group. We therefore answer RQ2 in the affirmative that yes, the workshops do produce an immediate increase in Dartmouth engineering students' capability to understand how engineered systems affect politics and to develop systems that inform and empower.

Although we considered a bootstrapping approach that would allow us to estimate the difference between the expected value of each population's score change, we decided that there is no good interpretation for the actual difference (that appears to be about 16 points) between the expected values for the workshop and control groups. That is, we do not have a good sense of how results from our survey translate into outcomes about which we care. What is the meaning of a 16-point difference on our survey? We may be measuring a difference, but is it a meaningful difference? These are important questions for future research. Answering these questions require a longitudinal approach that can track the likelihood of desired outcomes—most generally, continuing to think critically about engineered systems and acting on that thought; more specifically, supporting a transition to local engineered systems. Such a longitudinal study would take many years, perhaps lifetimes. While we assume that workshops similar to the four held for this study do have *some* good effect, such that the difference between the control and workshop score changes is not meaningless, we cannot be certain as to what that good effect is, and we assume that a very long study, likely of interventions with a much stronger signal, would be needed in order to develop an understanding of that good effect. We hope this study lays the foundation for such studies (and in the Conclusion we discuss the specifics of one such possible study), but for now we focus on using our quantitative data to demonstrate that the workshop has *some* presumably meaningful effect.

With regard to our two other hypotheses—the within participant hypotheses that 1) the workshop post-scores were greater than workshop pre-scores and 2) that control attitude post-scores were greater than control attitude pre-scores—we accept the first and reject the second using the BM test (see R code, Appendix C). As discussed in Chapter 3, the first result is not useful. The second result is useful since it allows us to eliminate the need for a pretest/posttest design (see Discussion). The practical interpretation of this is that the survey itself and three hours do not have a significant effect on attitude scores (nor knowledge nor empowerment scores).

RQ3: What Contributed To or Detracted From Achieving Goals?

As measured by our surveys, interviews, and workshop notes and experiences, certain *structure* and *content* of workshops contributed to or detracted from achieving our goals—which are to improve the capability of Dartmouth students to understand how engineered systems affect politics and to develop systems that inform and empower. These themes of structure and content emerge from and are useful for analyzing our data.

Structure

The structural features of workshops that contributed to our goals were: small group size, long workshop duration, gender balance, recording only via a note-taker who participated in the workshop, gathering over homemade food, facilitation by a knowledgeable and enthusiastic peer, and semi-structured conversation guided by theoretically rich booklets (see Appendix B for booklet). The structural features of workshops that detracted from our goals were: too little structure (too much jumping between topics), too much content for the duration, no reading assigned before the workshop and no substantive follow-up (excepting interviews regarding workshop methods) after the workshop.

Though not many students commented on small group size, gender balance, or non-recording, we assume these facilitated high-quality participation. We assume that small group size allowed for all students to speak and ask questions, as well as for students to develop good rapport, and potentially "bond" to some degree, in a short amount of time. We can't be certain of how large workshops can be before these benefits disappear, but we suggest that future workshops err on the side of smaller sizes (which makes workshops "less efficient" and "more expensive" within a transactional framework, but far more efficient and less expensive given the seminar approach to learning discussed above). Based off anecdotal experience in engineering and seminar contexts, we assume that a group that is no more than 50% men is more welcoming and comfortable for participants who are not men. While ideally people in workshops would be diverse across many identities—to ensure everyone has an equal opportunity to participate, but also for what Landemore calls "cognitive diversity"—given our small sample size gender was the easiest identity about which to ensure the workshops were diverse. We chose not to record workshops to help create an environment of honesty and non-performativity, such that "stupid ideas" or "stupid questions" felt more admissible and students were less inclined to perform their vision of "smart" or "knowledgeable." The only student we asked explicitly about recording using digital electronics was P23, who said:

> I think that would be different from having a notetaker in that I would feel more surveilled and more cautious about what I say. I also would worry that the other people in the room would be worried about the recording. Generally it would feel a bit more restrained.

In our informal cost-benefit analysis, a "more restrained" conversation is a large cost that is not compensated for by the potentially better data from recording. Further, note-takers enjoyed their role, and having this role in a workshop might actually offer some students who are less inclined to participate in conversation the opportunity to engage in workshops in their own ways. As discussed below, if students continue to lead workshops like these, having two leaders—one in the facilitator role, one in the note-taker role—could be very beneficial. So, until we are convinced that it results in a net-beneficial tradeoff, in our future work we will try to avoid recording whenever possible.

Facilitation by a knowledgeable and enthusiastic peer seemed to be very beneficial. P24 wrote that I was “good at steering the conversation with questions and excerpts,” P22 said I “made sure everyone could speak” and many participants found me to be engaging and helpful in answering questions. However one aspect of my facilitation that likely detracted from the success of the workshop was that I was the only one who had the workshop plan in mind; as discussed below, we did not have enough structure. My knowledge and enthusiasm about these topics might be rare, but I am confident that other students can replicate it in time, especially if they are aided by a booklet or other organizational resource that guides content. That is, we found the booklet to be very useful, and I likely should have relied more on the booklet to structure workshops. P18 wrote that the "booklet is a great guide" but P17 “found the workshop a little confusing in terms of structure—[i]t may be useful to have a roadmap of what topics from the booklet we were going to address at any given time.” P19 agreed: “I think the handbook was a good reference, but we didn’t follow its order.” If the booklet is improved and facilitators follow its order, it’s likely that the facilitation task can be approachable to students who have only spent one term (three months) studying the politics and ethics of engineered systems.

Students also found that the homemade food was an important aspect of facilitating workshops. In our interview P21 said that the homemade, mostly locally sourced and mostly finger food—bread, hummus, carrots, apples, panzanella—helped workshop participants bond and be more engaged. P19 wrote "I appreciated the collaborative nature of the exercise (and of sharing the food)! I hope to do more things like this in the future." P17 thought that the "potluck-style" food mirrored the potluck-style conversation that encouraged folks to share something valuable they had brought to the table, and thought that in the future workshops could benefit from truly being potlucks.

We found that workshops were not structured well enough. P19 provides some good insight into the structural limitations of the workshops:

> I would have preferred a little more structure to the workshop I think, though. I value the transparency of an agenda and some sort of guiding reference. I think the handbook was a good reference, but we didn't follow its order, and slides might have showed the order better and saved time in looking up the quotes. I felt by the end that I wanted more time to talk about things, and a little more structure might have allowed us to accomplish more.

The desire for more structure was widespread among workshop participants. P23 wrote that workshops should be "less high level—have an overview, more structured, few abstractions & philosophy words, less referencing of books." As P19 notes, the lack of workshop structure probably resulted in lost time. P29 agreed, writing, "I felt like we had to rush through some things. I wish we had more time." This is likely also a result of too much content for the duration of the workshop. As P27 wrote:

> This workshop could and should be turned into a full class. There is a lot of content that can be expanded upon. For this reason it was also mentally tiring to think through such dense material for so long.

In addition to causing mental fatigue, the workshop structure that tried to pack in too much dense content prevented us from allowing conversations to conclude organically and required me to cut in to introduce new topics in order to “make it through” all the material. In other words, because students were excited to discuss particular topics and “get into the weeds” more than I had anticipated, I had to engage in a real time agenda-modification so that we could cover the most important topics; in most workshops I discarded the booklet’s agenda in favor of the agenda in my head, which seems to have been disorienting for students and a major limitation of workshops. However, it’s worth noting that under-structured workshops may have had the unintended consequence of encouraging more self-study after the workshop since ideas and conversations were left unresolved. As P20 wrote “some of it was dense and I don’t think I 100% grasped 100% of the theory, but I also think that’s okay. I’m leaving more curious than I came in and more excited to explore the literature on my own terms.” In general, it seems that there is need for more structure for conversations on difficult, new and controversial topics like the ones discussed.

Multiple students suggested that more background and more follow-up would be useful. P25 wrote, “I may have benefited from more background information before the session though. It would be useful to have known the terminology to be used.” In interviews students thought that short reading assignments in preparation for workshops could be effective. P17 suggested that in accord with a collaborative, potluck style, students could read different material and share that with peers. This would be more along the lines of a research seminar, but I think a combination of commonly assigned reading and self-selected reading could be very effective, especially in a full course (or workshop series).

Finally, there was room for more interactive content beyond the conversation. P17 summed it up: “I thought there was space for more interactive parts of the lesson: I enjoyed the transition statement exercise though I thought we could have used some warming up to get us moving and ready to think together.” While the theory based content is important, there is likely a need for more interactive aspects of the workshop to meet engineering students in a mode more familiar given their coursework.

Content

In the pithy words of P21, the content of the workshop was “confusing but important.” The theory rich content was necessary, but there could have been more examples and there could have been more focused content, perhaps spread across multiple meetings.

Many students were surprisingly excited about the theory rich content. P27 said the theory presented in the workshop was “necessary for all STEM students to learn,” and P31 wrote “I found it so, so , so, interesting and loved hearing everyone’s thoughts + contributing to discussion + thinking about these things.” However, some students were uncomfortable with the emphasis on theory since it left open all sorts of practical questions about implementation and application. P22 said “I just want a checklist; give me a checklist and I’m happy” and many other students expressed the desire for a more concrete set of action steps. While we think this “convergent thinking” desire for a checklist, to use Haws’ language, should mostly be resisted in favor of cultivating "divergent thinking," we do think there is need for a better balance between theory and practice, between cultivating theoretical confidence and practical confidence (Haws, 2001). The right practical confidence level might be similar to that of P31, who wrote, "I still feel slightly unsure of how I would actually implement these ideas or what exactly a transition statement is." If students are *totally* unsure of "how to actually implement these ideas" then workshops will likely not achieve our goals. Perhaps the practical exercise of creating or critiquing a flawed but useful checklist could help emphasize the need to continue thinking and questioning while engaged in more conventional engineering work.

Workshop content needs to be further simplified and translated from the theory as it is presented in Chapters 1 and 2 of this thesis. P24 wrote, "we need the booklet to be in layman's language because the terminology is difficult." P22 wrote, "at some points it was hard to keep up." Examples that illustrate the theory are a key element of this translation task, providing examples in workshops was made difficult because the theory in Chapters 1 and 2 currently lacks sufficient supporting examples—this is partly because the theory is new enough that its practical implications and resonances have not yet been cognized or analyzed. P31 said, "I could have used some more specific/concrete examples for some of the concepts we were talking about." Interestingly, we found that there was more eye contact between participants and the discussion leader when specific examples were introduced. Insofar as eye contact can be interpreted as engagement, specific examples caused students to be most engaged with the material.

In general, workshop content will develop as the theory in Chapters 1 and 2 develops.

Discussion

Generalizability

Results are not generalizable beyond the Dartmouth population for the reasons discussed in the methods section. Further, we cannot make strong inferences about the Dartmouth population using the results from our sample of that population. That's because of our non-random sampling in the recruitment stage (and partially in the condition assignment stage) that likely biased our sample toward students who were more receptive to the content. As P17 wrote about the workshop, "I think a lot of the success of today came from the awesome group of participants and I wonder if it would translate as well for less justice-oriented designers/engineers."

However, weaker inferences can be made, and these are at least strong enough to inform future work with populations beyond Thayer undergraduates.

Workshop Improvements

The prototype workshops delivered as part of the study point the way towards workshop improvements. Since each part of them could be improved, it's useful to single out the lowest hanging fruit: improving workshops by adding more structure. Since students struggled with the free-flow conversation and lack of clear scheduling and presentation of arguments and evidence, it is likely that a more structured workshop would produce more learning, understanding, and viable seeds of action. Simplifying and translating content is also essential in the quest to reduce communicative barriers. Most engineering students are not familiar with political theory language or argument styles, and while a careful balance needs to be struck between over- and under- reducing, workshop data suggests that future workshops should err on the side of over-reducing the theory. To that end, a more experienced discussion leader would be helpful. Developing interactive components of the workshop that help engineering students "warm-up" to a theoretical seminar style discussion would likely be a major improvement that contributes to the reduction and translation. And, of course, improving the theory on which the workshops are based would contribute to all of these improvements.

Survey Instrument

The survey instrument can be improved. While every question elicited responses that provided useful data, some questions proved to be ambiguous or confusing. For example, there was confusion about the phrase "ethical compromise" in question 11 (the discrete participant's interpretation of "ethical compromise" is discernable for most responses). Many students interpreted "ethical compromise" to mean a compromise that was ethical, in the sense of "a compromise that was morally correct." Probably less than half of the students interpreted it as a trade-off that made the design less morally correct in general, or perhaps at first glance. This second meaning was the intended meaning of the question. As one student wrote, "It could be an ethical compromise if using non-local materials and sources mean that the design would be more economically accessible. This is my understanding of an ethical compromise but I am not sure if this is what the question asks" (P 26). Their interpretation was the intended one, but nonetheless they were uncertain about the intent of the question.

Survey Fatigue: Eliminate PreTest

The care put into responses, as measured by handwriting and length of responses, declined on the second survey. In interviews we found that this survey fatigue was mostly a result of needing to take the same test twice. However, since we found that there was no significant change between the pretest and posttest for the control group scores, we could have obtained the same information without the pretest (but still with the control group). We suspect that eliminating the pretest would improve the quality of the data by reducing survey fatigue; we recommend that future studies take this approach and eliminate the pretest while keeping the control group.

Future Work

Future work should improve on the study design as well as the intervention being studied—in this case, the workshop.

With respect to study design, a longitudinal study would help to understand the effect over time of a particular intervention, and perhaps what the ideal spacing of interventions should be. A larger sample size would improve our ability to make inferences and generalize results, as well as make random sampling more feasible. Future studies could (and probably should) use the control group to compare a newly developed intervention against the state of the art established by this thesis. Honing and further validating the survey instrument should be a focus of future work.

Workshop structure and content should be improved, likely with the ideas mentioned above, and then tested with the new and improved study design. A key recommendation for future work is to hold iterative workshop co-design sessions (at least two or three) in which students are invited to participate in a full-length workshop and then engage in a discussion of how to improve the workshop (and perhaps "workshop" aspects of the workshop on the spot). These sessions would allow for an already honed workshop to be delivered to the first study participants, especially since it seems that the discussion leader becomes more effective over time (and workshops).

Chapter 4: Conclusion

How should we think politically about engineered systems? This thesis provides a preliminary answer to this question by proposing two normative heuristics, one about political knowledge, the other about political empowerment. I argue we should be attuned to the way engineered systems can undermine political knowledge and empowerment, and we should adjust our designs, and design trajectories, accordingly. I hope that this theory contributes to activating much-needed theoretical development and conversation on the politics of engineered systems.

How might we help engineering students to think politically about engineered systems, and act accordingly? The study of engineering and justice workshops presented in this thesis suggests that a small, long-duration, theory focused, peer-led workshop over homemade food improves Dartmouth engineering students' capability to think politically about engineered systems. The study opened many questions about the best way to cultivate engineering students' capability to think politically about engineered systems and act accordingly.

There is little question that engineering schools and engineering educators will be key to providing the space and resources that will help engineering students to develop an understanding of how engineered systems affect politics and to develop systems that inform and empower. Thayer School of Engineering, for example, might support students with a three-level strategy. Level 1 would be to integrate workshop content into the introduction to engineering course (Engs21) and senior capstone course (Engs89/90), building on existing ethics modules. Level 2 would be to develop an Engineering Politics and Ethics Fellowship. This Fellowship might pay 10 students $1,000 per term to study the politics and ethics of engineered systems. Fellows might meet biweekly, as a cohort, with a faculty advisor. Senior fellows could facilitate seminars with junior fellows and take the lead on exemplary engineering projects that support political knowledge and empowerment to the extent possible. Level 3 would be a course on Engineering Politics and Ethics that synthesizes engineering for social justice curricula (from sources including *Engineering Justice*) and engineering ethics curricula with political theory of engineered systems. This course would likely need to be co-taught by engineering and political theory faculty.

Finally, some of the leading engineering and justice scholars cited in Chapter 1 confirmed, via personal correspondence, that research from within an engineering school on the political implications of engineered systems is difficult, rare, and highly valuable (D. Riley, personal communication, April 24, 2023; C. Baillie, personal communication, April 24, 2023; J. Leydens, personal communication, April 24, 2023). Additionally, political theory focused on engineered systems (or "object-oriented" political theory in general) is rare, let alone a fusion of theoretical and empirical work. I hope that this thesis—following most directly Darshan Karwat and Alice Pawley's theses, and Ivan Illich and Arturo Escobar's books—contributes to opening space for critical studies of engineered systems among engineering researchers and political theorists.

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Appendices

Appendix A: Survey Instruments

Engineering & Justice Workshops Study: Pre Survey

For each of the following questions, please answer in the way that best reflects your attitudes, knowledge or intended actions. There are no “right” or “wrong” answers — we want to gather people’s genuine thoughts and intentions about these topics!

This survey has 17 questions: 14 multiple choice (~10 minutes total) and 3 long response (~15 minutes total). The survey should therefore take about 25 minutes.

Name:

1. I think we can change the course of technological development.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

2. I think every problem has a technical solution.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

3. I think engineers have a responsibility to keep politics out of their work.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

4. I think that established ethical approaches are sufficient to guide engineering.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

5. I think it's possible that some types of engineered systems inherently undermine democratic politics.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

6. Imagine you're in the following situation. In a discussion about the ethics of your potential design, a teammate in Engs21 or Engs89/90 says that as long your design is legal there's no need to think about political effects—legislators thought about the political effects of engineered systems when they made the laws! Further, your teammate makes the good argument that thinking about political effects would actually usurp democratic authority; if you thought about political effects, you'd be self-appointing yourselves as legislators without a democratic election.

Do you agree or disagree, and why? Take about five minutes to reason through this situation.

7. I can explain how certain types of engineered systems do or do not produce collective harms.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

8. I can explain why political knowledge is or is not necessary for social justice.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

9. I can explain why political participation is or is not necessary for social justice.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

10. I can explain "the violence of humanitarian design."

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

11. Again imagine that you are in Engs21 or Engs89/90 and that you're at the very early design thinking stages. At this point, you can decide to focus only on designs that have local material and energy sources throughout their entire lifecycle.

1) **What might you utilize to help you think through this situation?**
2) **How might you explain to teammates the ways in which non-local system bounds do or do not affect democracy?**
3) **You eventually decide on a design with non-local system bounds. If you think this is an ethical compromise, how do you explain how your design is part of change towards more ethical systems? If you don't think this is an ethical compromise, why not?**

Take about ten minutes to reason through this situation. If you're finding it difficult to formulate an answer to any of these questions, that's OK - in that case, explain what you find confusing or challenging.

12. I intend to talk with a friend at least once a week about how engineering education and practice can change to support people who are blocked from shaping their worlds.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

13. I intend to be part of a movement to build engineered systems that use local material and energy sources.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

14. On my next design project I will write a transitions statement about how my design is part of a transition towards social justice.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

15. I would sign a petition to support institutional change—at Thayer, other engineering schools, and in industry—that requires engineers to take 1) time and 2) coursework to think politically about our designs and then to document how our designs changed as a result.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

16. I will stay up to date on literature about collective harms.

☐ Strongly Disagree ☐ Disagree ☐ Neither ☐ Agree ☐ Strongly Agree

17. What challenges can you foresee in ensuring your designs support a transition toward social justice? These challenges will occur in Thayer courses and in your work beyond Thayer. How will you work to overcome them? What assets do you have that will be helpful?

Take about five minutes to identify and strategize.

The following survey statements and questions are classified by the random variable to which they contribute: attitude (A), knowledge (K), or action (E, for empowerment). Surveys were printed on paper and students filled them out with pens or pencils. Likert scales were positioned below likert statements, and students half a page given for free response questions.

Survey Justifications

- **A1: I think we can change the course of technological development.**
    - Likert scale
    - Justification: tests techno-fatalism/determinism, a key barrier to thinking and acting politically on engineered systems
    - Other versions considered: Technological development inevitable. Society's toolset is evolutionarily determined. Technological progress is inevitable; engineered systems are inevitable. We decided on the above formulation since it is a popular expression of techno-fatalism and is more neutral than a question about tech progress (prevents overlap with our question about techno-solutionism).

- **A2: I think every problem has a technical solution.**
    - Likert scale
    - Justification: tests techno-solutionism, a key barrier to thinking and acting politically on engineered systems

    - Other versions considered: problems always have technical solutions.

- **A3: I think engineers have a responsibility to keep politics out of their work.**
    - Likert scale
    - Justification: tests techno-neutrality or "depoliticization" or positivism or facts/values separatism, a key barrier to thinking and acting politically on engineered systems. This question implies that engineers *can* keep politics out of their work.
    - Other versions considered: engineered systems are neither good nor bad—their ethicality depends on how they are used; facts and values can be separated.

- **A4: I think that established ethical approaches are sufficient to guide engineering.**
    - Likert scale
    - Justification: tests willingness to learn about new ethical approaches.
    - Other versions considered: I think the way systems are usually designed and evaluated by engineered is sufficient (this is a slightly different question, but we thought we didn't need to know both and it was more important to understand whether students thought approaches do or do not *exist,* instead of are or are not *being used*).

- **A5: I think it's possible that some types of engineered systems inherently undermine democratic politics.**
  - Likert scale
  - Justification: if it's not possible, no need to learn about a political theory of engineered systems.
- **A6: Imagine you're in the following situation. In a discussion about the ethics of your potential design, a teammate in Engs21 or Engs89/90 says that as long your design is legal there's no need to think about political effects—legislators thought about the political effects of engineered systems when they made the laws! Further, your teammate makes the good argument that thinking about political effects would actually usurp democratic authority; if you thought about political effects, you'd be self-appointing yourselves as legislators without a democratic election. Do you agree or disagree, and why? Take about five minutes to reason through this situation.**
  - Free response, half page of space
  - Justification: while this question is still abstract, it's less abstract then the likert scale questions in that it asks students to reason within the context of the introduction and capstone engineering design course at Thayer with which they are likely familiar. As the grading rubric demonstrates, a "correct" response to this question requires key aspects of the "right" attitude about which we want to establish a baseline understanding and test whether workshops improve. We think this question covers these questions:

- I think that modern engineered systems are not fundamentally new in world history.
    - Justification: it is necessary to see engineered systems as new-to-the-world in order to justify developing an understanding of a new ethical theory; otherwise, established ethical approaches will apply.
- Grading rubric, out of ten points:

Points	Key Word	Details
2.5	fast/new	Engineered systems are new to the world, so there's no legal category for them. This could be a reference to "emerging technology" or the rapid pace of technical change that prevents legislators from predicting/regulating specific harms.
2.5	power	engineers have already disproportionate authority; this is not a good situation, and we should use our power to give back our power; we should nonetheless use our power.
2.5	transition	eventually engineered system design will be subject to democratic regulation, but that's not possible now; we should therefore think politically about engineered systems and make a "transitions statement" on our final report, or otherwise embed a transition toward a more just reality into our design.
2.5	divergent	"divergent thinking" or "political thinking" (not just a reference to professional codes?)

- **K1: I can explain how certain types of engineered systems do or do not produce collective harms.**
    - Likert scale

    - Justification: this question is meant to probe the baseline understanding of the categorical effects of bigfastforever engineered systems. While it is most strongly a prerequisite to understanding the political knowledge heuristic, it is also a prerequisite to understanding the political participation heuristic since collective harms situations also prevent political participation.

K2: I can explain why political knowledge is or is not necessary for social justice.

- **K3: I can explain why political participation is or is not necessary for social justice.**
- **K4: I can explain "the violence of humanitarian design."**
    - Likert scale
    - Justification: our only question that asks for knowledge of the pitfalls of current engineering design practice. Understanding this pitfall is necessary in order to flag when designs are unjust
- **K5: Again imagine that you are in Engs21 or Engs89/90 and that you're at the very early design thinking stages. At this point, you *can* decide to focus only on designs that have local material and energy sources throughout their entire lifecycle.**

1) What might you utilize to help you think through this situation?

2) How might you explain to teammates the ways in which non-local system bounds do or do not affect democracy?

3) You eventually decide on a design with non-local system bounds. If you think this is an ethical compromise, how do you explain how your design is part

of change towards more ethical systems? If you don't think this is an ethical compromise, why not?

Take about ten minutes to reason through this situation. If you're finding it difficult to formulate an answer to any of these questions, that's OK - in that case, explain what you find confusing or challenging.

- Free response, half page of space
- Justification: like attitude free response, this question attempts to provide a more "real" reasoning situation. As the grading rubric demonstrates, a "correct" response to this question requires key aspects of the "right" knowledge about which we want to establish a baseline understanding and test whether workshops improve. We think this question substitutes for the following questions:
    - I can explain how to use a transitions design framework. (which we think is similar to "I can explain the need for using design heuristics within a theory of justice"
    - I can explain how engineered systems with non-local system bounds effect the possibility of political knowledge.
    - I can explain how engineered systems with non-local system bounds effect the possibility of political knowledge.
- Grading rubric, out of fifteen points:

Points	Key Word	Details
1 per	sources	1 point for every non-trivial resource up to 5 resources; non-trivial means no "google" or "internet," and if more than 1 person is listed points are awarded only if their specific

		knowledge is discussed. if less than five, two points for each resource that is discussed (not just listed)
2.5	knowledge	points for discussion of non-local system bounds on political knowledge (collective harms/distributed harms/banality of evil)
2.5	participation	points for discussion of non-local system bounds on political participation (collective harms/distributed harms/banality of evil)
2.5	transitions	transitions design
2.5	divergent	"divergent thinking" or "political thinking" (not just a reference to professional codes?)

- **E1: I intend to talk with a friend at least once a week about how engineering education and practice can change to support people who are blocked from shaping their worlds.**
  - Likert scale
  - Justification: we assume (and some evidence suggests) that sustained, personal conversation is a necessary part of thinking and acting on a political theory of engineered systems. Although this question may seem to focus on the world-forming capability, a lack of political knowledge of course also blocks people from shaping their worlds.
  - Other versions considered: I will join weekly discussion groups about how…
- **E2: I intend to be part of a movement to build engineered systems that use local material and energy sources.**
  - Likert scale

    - Justification: tests an intention to act on a political theory of engineered systems that advocates for the importance of local systems
    - Other versions considered: …and energy sources *unless justice requires.*
- **E3: On my next design project I will write a transitions statement about how my design is part of a transition towards social justice.**
    - Likert scale
    - Justification: tests an intention to act on a particular feature of the workshops, independent of agreement with the substance of the political theory
    - Other versions considered: …and energy sources *unless justice requires.*
- **E4: I would sign a petition to support institutional change—at Thayer, other engineering schools, and in industry—that requires engineers to take 1) time and 2) coursework to think politically about our designs and then to document how our designs changed as a result.**
    - Likert scale
    - Justification: tests an intention to support institutional change suggested by the political theory
- **E5: I will stay up to date on literature about collective harms.**
    - Likert scale
    - Justification: I think that collective harms literature might be the best entry point into thinking about how bigfastforever systems harm democracy. Since I emphasized in workshops how collective harms is a "cutting edge" topic, mostly in philosophy but hopefully soon in engineering/engineering justice literature, this question is catering to students in the workshops—we just

talked a lot about this, will you stay up to date? (in the same way you stay up to date on tiktok?)

- **E6: What challenges can you foresee in ensuring your designs support a transition toward social justice? These challenges will occur in Thayer courses and in your work beyond Thayer. How will you work to overcome them? What assets do you have that will be helpful? Take about five minutes to identify and strategize.**
    - Free response, half page of space
    - Justification: like attitude and knowledge free response, this question attempts to provide a more "real" reasoning situation. As the grading rubric demonstrates, a "correct" response to this question requires key aspects of the "right" action about which we want to establish a baseline understanding and test whether workshops improve. We think this question substitutes for the following questions:
        - I will seek out work post Thayer that supports democracy
    - Grading rubric, out of 10 points:

Points	Key Word	Details
2	ignorance	the impossibility of an individual developing political knowledge of bigfastforever engineered systems
2	culture	cultural barriers/pressures
2	education	need for continuing education, "I know that I don't know much"
2	institution	

2	divergent	"divergent thinking" or "political thinking" (not just a reference to professional codes?)

Extra Post-Workshop Questions

18. Please take about five minutes to provide your thoughts on the workshop. Any and all thoughts are useful. The next page asks focused questions, but before you answer those we'd like to know your unprompted thoughts.

If you didn't already speak to these questions on the following page, we'd like to have your thoughts on the following. Please be specific and provide details in your answers.

19. What are your thoughts on the content?

20. What are your thoughts on the instructor?

21. Would you want a version of this workshop integrated into engs21 or 89/90?

Interview Questions

The goal of interviews was to understand what was good and bad about the workshops to inform future convenings around engineering and justice, such as curricular or extracurricular courses, one-off workshops, series of workshops, booklets, visualizations, etc.

Short Questions (10 mins):

- What did you expect? (What do you expect when you hear "justice"?)
- What did you think of sharing homemade food together?
- Was the workshop too long, too short, just right?
- Would you have preferred reading beforehand? (So we're all on the same page? And we have time to digest the arguments?)
- Would you have preferred more structure/lecture at the beginning, followed by more discussion later on?
- More examples? Visualizations? What kinds?
- Do you/will you remember what you learned?
- Survey fatigue: Do you feel like the quality of you answers deteriorated? If there had just been a post survey would you have been more motivated to spend more time on your answers?

Long Questions (15 mins):

- What would a course/long term solution be like? (propose idea… 1/3 course, offered every term. Distrib, looks good on resume… Thayer req? Maybe workshops to supplement or in near term)
- If workshops like this were the short term solution, what would they be like? Would you do reading in preparation for a workshop? Look at something beforehand?
- Engineering politics and ethics fellowship?

Appendix B: Workshop Booklet

The workshop booklet is designed to be printed and then cut along the horizontal midline of each page so that four leaves can be folded together to make a 16 page booklet. We used cardstock paper for most booklets (in the first workshop not all participants got a well-made booklet with cardstock; there was a prototyping process!). We bound them by sewing the content pages shown below onto a slightly larger cover leaf that participants could decorate themselves.

Though theoretically dense, this mnemonic device was one of the most effective components of the workshops, according to participants. The most recent iteration of the workbook is presented here; we will continue to iterate.

Goals 2

Abstract goal: optimize any engineered system with respect to social justice

Workshop goals:
1. Develop an understanding of the types of engineered systems that are inherently unjust
2. Understand how we can be part of a movement to transition away from such systems

Assumptions:
- Everyone's knowledge and participation is important! Share! Think, listen, speak!
- No blaming; let's focus on how to do better!
- Things convene systems! (cars are more than cars)
- Politics (just systems) not ethics (just actions); as with racism, we need to think systemically.
- Focus on categorical effects of engineered systems.
- All is not a nice clean puzzle; think divergently!
- Politics is always already in our work; engineers have disproportionate power, and this is unjust. We must acknowledge that *and* work to give it back to the people (us!) even though it's not clear how.

BigFastForever System Examples 15

The **big** and **forever** system of **oil/gas extraction and combustion** distributes causes of harm, from oil spills to climate change to inhumane working conditions. These harms occur *even though we have good intentions*—this system is (currently) vital to almost everybody. The system is immensely difficult to change (it prevents political participation now and in the future), and the people who cause the system are so distributed that we are not motivated to develop the political knowledge necessary to make it good (without eliminating it).

The **big** system of **global shipping** allows causes of harm (Americans buying clothing) to be distributed. Even if its technically possible to regulate this system (which is unlikely), it's politically impossible since people who cause the system to exist ("consumers") are not motivated to develop the necessary knowledge. The system is immensely difficult to change and therefore disempowers people from shaping their world.

Perhaps the ultimate **big, fast** and **forever** system is **The Stack**—the accidental megastructure of planetary scale computation, the internet system (*see* Bratton).

Harms Diagram 4

	Collective Harms Distributed Causes (strangers and I cause)	**Conventional Harms** Non-Distrib. Causes (friends and I cause)
Distributed Effects (harm to me and strangers)	• Climate change • some tragedy of the commons	
Non-Distrib. Near Effects (harm to me and friends)	• Industrial accidents • Chernobyl	
Non-Distrib. Far Effects (harm to strangers)	• Sweatshops • CAFOS • Rare earth mining	• Conventional war • Murder • Colonialism

"Cases of 'collective harm' are ubiquitous. In these cases, when enough people act in a certain sort of way serious harm results, and yet no individual act of the relevant sort seems to itself make a difference" (Nefsky 2019).

Assumptions: Harms with distributed causes are new to the world. Unlike conventional harms, we can (and do) cause such harms with good intentions.

Definitions 13

Note: these are preliminary definitions. True definitions would be determined through democratic deliberation; but because engineers have disproportionate power but no access to democratic deliberation, we need to provide our own (reductive, flawed) definitions with the hope and plan that we can help recover democratic publics and give back our political power.

politics: the sum of deliberation, decisions, and actions to reform and form the artificial systems that shape our worlds

democracy: a way of life in which politics is done by every citizen in a community

engineered systems: systems built using methods needed to build bigfastforever (non-local) systems; these systems are new-to-the-world (since 1784?)

local: belongs to our time and our place

justice: "the first virtue of social institutions"; a useful political ideal; a theory of which is presented in Nussbaum's *Creating Capabilities*

Local Eng. System Examples 16

It's very hard to give examples of "local" engineered systems since almost all now depend on bigfastforever systems for materials and energy. (This is not the case for non-engineered systems, such as a local farm). Aligned with the cosmolocalism scenario, the best "local" systems are open and connected, similar to what we might think of as a "regional" system. Here are some hypothetical cosmolocal engineered systems:

- Local drinking water systems
- Local manufacturing systems
- Local tractor systems
- Local human waste systems
- Local housing systems
- Local HVAC systems
- Local electric power systems
- Local computing systems
- Local road systems
- Local bike systems

Let's build/support these! An interesting (failed?) attempt is Open Source Ecology. Other examples?

Table Of Contents 1

Definitions (cont.) 14

political knowledge: knowledge of, by, and for the people of how a system's effects contribute to or detract from justice. It is active, holistic, local.

political participation: use of the capability to shape one's world. It is fundamental to the good life and any theory of justice or just community.

big system: spatially distributed causes and/or spatially distributed or distant effects; interacts with many people and places

fast system: state changes rapidly; a description one year is out of date the next

forever system: temporally distributed or distant effects; lasts a long time

cosmolocalism: a balance between being rooted in a place and being open to global flows of ideas, information, people, things, money (Manzini)

The Argument 3

1) A political definition of the category "engineered systems" is necessary to build just systems. It should focus on their spatial and temporal system bounds.

2) Big, fast, and forever (nonlocal) systems are historically new, have yet to be theorized, and have significant political effects.

3) Nonlocal engineered systems: allow collective actions that can't be regulated, change too fast for deliberative decision making, and disempower current and future people from shaping their worlds.

4) Because highly nonlocal engineered systems can cause fundamental, existential political harms, they are only just if they deliver fundamental, existential benefits. This tradeoff should be made conspicuous for all nonlocal engineered systems.

5) Transitioning towards more local engineered systems that better balance the tradeoff between political harms and benefits will be a difficult, likely long term task. We need to develop habits, cultures, and institutions that support this transition. Making transition statements can help spark those supports.

Political Knowledge 6

The knowledge needed to progress toward justice is inhibited when: 1) the object of knowledge changes faster than deliberation can occur; 2) the object of knowledge occurs far in the future with uncertain effects; and 3) changing the object of knowledge appears impossible. In other words, political knowledge is inhibited by high speed, long duration, and large scale system bounds.

The problem in 3), collective harms situations, is the most difficult to understand. It boils down to the fact that people are not motivated to develop political knowledge of a system for which the causes are distributed! This does not mean we are "bad"—it's just a political reality that is a design constraint. This constraint is why "collective action" to remedy "collective harms" is impossible (*see* Scheffler, etc.). Motivated experts are not a solution since people have local knowledge about what's best for them and their communities (*see* Dewey, Pamuk, Hayek).

Since political knowledge is needed to progress toward justice, this means bigfastforever designs inhibit justice.

Transitions Statement 11

This [design/tool/system] has nonlocal system bounds because it depends on [big/fast/forever system]. It is therefore part of a collective action—"conventional engineering"—that has both usurped democratic power *and* has provided the methods for progress towards justice. I intend for this design to be part of a transition toward minimizing the former and maximizing the latter. However, political knowledge of this design is impossible insofar as not all effected by it can contribute their knowledge. I can only detail my best effort to make this design support a transition to just, local systems. Here's what I did/plan to do:

• political participation… transitions toward repair & ownership by a community or one of its subsets

• cradle to cradle… trans. local materials and energy

• capabilities approach… trans. support capabilities

• violence of humanitarian design… are my good intentions potentially harmful?

• collaborative… involved people affected by design?

• ??

The Task 8

To engineer local systems in order to eliminate nonlocal systems! To work together with others to make this nonviolent transition—be part of a community working for systemic change. This means we must:

- Use local materials and energy sources in our design projects!
  - Cradle to Cradle
  - Cosmolocalism
- don't "take a job" that supports bigfastforever systems (most status quo engineering jobs); instead, do the hard work with your community to make work that supports a transition to local systems
- support institutional and cultural change that encourages engineers to think and act politically
- and insofar as we can't do all this immediately, talk, write, share, and commit to **transitions statements.** These statements should articulate how we are participating in developing more just engineered systems

Pitfalls and Barriers 9

- Adaptive preferences
  - *See* Nussbaum 2011, 81-84
- Violence of humanitarian design
  - *See* Keshavarz 2020, 2016
- Not thinking systemically & holistically
  - Ethics vs Politics
  - *See* Nussbaum's Capabilities Approach
  - *See* Winner 1990
- Assuming political knowledge by experts or of bigfastforever systems is possible
  - *See* Pamuk 2020
- Forgetting others' need for world-forming
  - *See* Escobar 2018, Illich 1973, Case & Deaton 2020, Graeber 2018
- Lack of institutional support
  - *See* Riley 2008
- Lack of cultural support
  - Resistance to divergent thinking
  - *See* Haws 2001, Riley 2008
- Lack of ready-made work
- Difficulty of transitions mindset/statements

Text Resource 12

- General Reference, Dom's Thayer Thesis:
  - whatisthis.technology/erl/thayer_thesis.pdf
  - references all below sources
- Collective Harms
  - *Distant Strangers*, Judith Licthenberg
  - *CHs and the Inefficacy Prob.,* Julia Nefsky
- Political Knowledge
  - *The Public and Its Problems*, John Dewey
- Political Participation (& Just Design in general)
  - *Tools for Conviviality,* Ivan Ilich
  - *Designs for the Pluriverse,* Arturo Escobar
- Degrowth, Cosmolocalism
  - *The Future is Degrowth,* Schmelzer et. al.
  - *Dstrib. Sys. And Cosmo. Localism,* Manzini
- Critique of Engineering Ethics
  - *Eng. Eth. and Political Imagination,* Winner
- Engineering Justice
  - *Engineering Justice*, Leydens and Lucena
  - *Engineering and Social Justice,* Riley
- Transition Design
  - Transition Design Seminar at CMU

Engineered Systems Tree Diagram 5

Engineered Systems

Local	**Nonlocal**
• small, slow, short term	• big, fast, and/or forever
• don't necess. inhibit just	• necessarily inhibit justice
• if supports cosmolocal community, likely just	• blocks political knowledge and participation
• unlikely to be achieved in the short term	• likely to persist as we transition toward justice

This heuristic, political categorization of engineered systems should be a good entry point to thinking politically about engineered systems!

Design Questions 10

- Are materials and energy for this system sourced non-locally?
- Are there any system effects that are distributed among a large number of people and places outside of my political community?
- Are there very long term system effects? if so, are any not politically necessary?
- Does the system state change so rapidly that a description during one year will always be outdated in the next year?
- If I am designing the elimination of a system, will my design cause (unnecessary) suffering?
- Does my system rely on systems that have "yes" answers for any of the above? (this is a "complicity" and systems thinking question).
- Have I consulted relevant literature that can help me think politically about my design?
- Have I drafted a transition statement that can help me think politically about my design?
- ??

Political Participation 7

Thought experiment: Imagine you live in the perfect Crystal Palace, which through ingenious engineered systems fulfills absolutely *all* your possible needs and desires *except* for your desire to shape your world in an important way, since to do so would mess up the perfection. Is it worth living in the Crystal Palace?

To a very imperfect degree in all sorts of ways, we are already performing this experiment. Seems the results include deaths of despair and "bullshit jobs".

"The principal source of injustice in our epoch is political approval for the existence of tools that by their very nature restrict to a very few the liberty to use them in an autonomous way."
—Ivan Illich, *Tools for Conviviality* (1973), 43

The capability to make, tend, and repair our communal worlds—the capability to participate politically—is a capability everyone must have in a just society (*see* Nussbaum 2011).

Our "impact" as engineers needs to support others' capability to have an impact in their worlds!

Appendix C: Data and R Code

Quantitative data and R code can be found at

github.com/dominiccarrese/thayer_thesis.

```
# Authored by Dominic Carrese, 2023
#
#****************************
# Begin license text.
#
# Copyright 2023, Dominic Carrese
#
# Permission is hereby granted, free of charge, to any person obtaining
 a copy
# of this software and associated documentation files (the “Software”),
 to deal
# in the Software without restriction, including without limitation the
 rights
# to use, copy, modify, merge, publish, distribute, sublicense, and/or
sell
# copies of the Software, and to permit persons to whom the Software is
# furnished to do so, subject to the following conditions:
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# copies or substantial portions of the Software.
#
# THE SOFTWARE IS PROVIDED “AS IS”, WITHOUT WARRANTY OF ANY KIND, EXPRE
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# AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHE
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# LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISI
NG FROM,
# OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALING
S IN THE
# SOFTWARE.
#
# End license text.
#  ****************************


#install.packages("stringr")
# install.packages("ggplot2")
# install.packages("ggpattern")
```

```r
# install.packages("brunnermunzel")

library(stringr)
library(ggplot2)
library(ggpattern)
library(brunnermunzel)
library(boot)

#************************************#
#        read data                   #
#************************************#

data<- read.csv("~/Downloads/wdat8.csv")
# data$Name<-NULL
# write.csv(data, file="anon_data")

#loop through columns
for (i in 1:ncol(data)) {

  #loop through rows
  for (j in 1:nrow(data)) {
      col<-data[,i]
      num<-0
      #skip NAs
      if (is.na(col[j])){}

      #these if statements map likert scale words to numbers
      else if( stringr::str_detect(col[j],"^sa$") ){
        data[j,i]<-as.integer(5)
        num<-1
      }
      else if( stringr::str_detect(col[j],"^a$") ){
        data[j,i]<-as.integer(4)
        num<-1
      }
      else if( stringr::str_detect(col[j], "^n$") ){
        data[j,i]<-as.integer(3)
        num<-1
      }
      else if( stringr::str_detect(col[j], "^d$") ){
        data[j,i]<-as.integer(2)
        num<-1
      }
      else if( stringr::str_detect(col[j], "^sd$") ){
        data[j,i]<-as.integer(1)
        num<-1
      }
      else if( stringr::str_detect(col[j], "^a/n$") ){
        data[j,i]<-as.integer(3.5)
        num<-1
```

```r
      }

  }

  if (num==1){
    data[i]<-lapply(data[i], as.numeric)
  }

  #if the column should map "sa" to 5 and "sd" to 1, flip mapping
  if( stringr::str_detect(names(data)[i], "A2$|A3$|A4$") ){
    data[,i]<-data[,i]*-1+6
    }
}


#***********************************#
#        process data               #
#***********************************#



#select workshop group and construct pre and post scores
workshop<-data[data$Workshop>0,]
prework<-rowSums(workshop[,4:31])
postwork<-rowSums(workshop[,32:59])
deltawork<-postwork-prework

#select control group and construct pre and post scores
control<-data[data$Workshop==0,]
precontrol<-rowSums(control[,4:31])
postcontrol<-rowSums(control[,32:59])
deltacontrol<-postcontrol-precontrol

#alternative wdata, just from likert scores
likert_questions<-stringr::str_detect(names(data), "1$|2$|3$|4$|5$")
likert_control<-control[,likert_questions]
likert_precontrol<-rowSums(likert_control[1:14])
likert_postcontrol<-rowSums(likert_control[15:28])
likert_deltacontrol<-likert_postcontrol-likert_precontrol

likert_work<-workshop[,likert_questions]
likert_prework<-rowSums(likert_work[1:14])
likert_postwork<-rowSums(likert_work[15:28])
likert_deltawork<-likert_postwork-likert_prework


#isolate random variables A, K, E
A_control<-control[,stringr::str_detect(names(data), "PrA|PoA")]
A_precontrol<-rowSums(A_control[,1:9])
A_postcontrol<-rowSums(A_control[,10:ncol(A_control)])
```

```
A_work<-workshop[,stringr::str_detect(names(data), "PrA|PoA")]
A_prework<-rowSums(A_work[,1:9])
A_postwork<-rowSums(A_work[,10:ncol(A_work)])

K_control<-control[,stringr::str_detect(names(data), "PrK|PoK")]
K_precontrol<-rowSums(K_control[,1:9])
K_postcontrol<-rowSums(K_control[,10:ncol(K_control)])

K_work<-workshop[,stringr::str_detect(names(data), "PrK|PoK")]
K_prework<-rowSums(K_work[,1:9])
K_postwork<-rowSums(K_work[,10:ncol(K_work)])

E_control<-control[,stringr::str_detect(names(data), "PrE|PoE")]
E_precontrol<-rowSums(E_control[,1:10])
E_postcontrol<-rowSums(E_control[,11:ncol(E_control)])

E_work<-workshop[,stringr::str_detect(names(data), "PrE|PoE")]
E_prework<-rowSums(E_work[,1:10])
E_postwork<-rowSums(E_work[,11:ncol(E_work)])

summary_data<-data.frame(row.names = c(control$Name, workshop$Name),
                         Participant = c(1:32),
                         Workshop=c(control$Workshop, workshop$Workshop
),
                         Delta=c(deltacontrol,deltawork),
                         Delta_Likert=c(likert_postcontrol-likert_preco
ntrol, likert_postwork-likert_prework),
                         A_pre=c(A_precontrol, A_prework),
                         A_post=c(A_postcontrol, A_postwork),
                         K_pre=c(K_precontrol, K_prework),
                         K_post=c(K_postcontrol, K_postwork),
                         E_pre=c(E_precontrol, E_prework),
                         E_post=c(E_postcontrol, E_postwork),
                         Likert_pre=c(likert_precontrol,likert_prework)
,
                         Likert_post=c(likert_postcontrol,likert_postwo
rk))
summary_data$Pre_total<-summary_data$A_pre+summary_data$K_pre+summary_d
ata$E_pre
summary_data$Post_total<-summary_data$A_post+summary_data$K_post+summar
y_data$E_post
summary_data$A_delta<-summary_data$A_post-summary_data$A_pre
summary_data$K_delta<-summary_data$K_post-summary_data$K_pre
summary_data$E_delta<-summary_data$E_post-summary_data$E_pre


short_summary_data<-data.frame(row.names = c("control", "workshop"),
                               Mean_Delta=c(mean(summary_data$Delta[sum
mary_data$Workshop==0]), mean(summary_data$Delta[summary_data$Workshop>
0])),
```

```
                                Median_Delta=c(median(summary_data$Delta
[summary_data$Workshop==0]), median(summary_data$Delta[summary_data$Wor
kshop>0])),
                                Mean_Likert_Delta=c(mean(summary_data$De
lta_Likert[summary_data$Workshop==0]),mean(summary_data$Delta_Likert[su
mmary_data$Workshop>0])),
                                Median_Likert_Delta=c(median(summary_dat
a$Delta_Likert[summary_data$Workshop==0]),median(summary_data$Delta_Lik
ert[summary_data$Workshop>0])),
                                Mean_A_Pre=c(mean(summary_data$A_pre[sum
mary_data$Workshop==0]),mean(summary_data$A_pre[summary_data$Workshop>0
])),
                                Mean_A_Post=c(mean(summary_data$A_post[s
ummary_data$Workshop==0]),mean(summary_data$A_post[summary_data$Worksho
p>0])),
                                Mean_K_Pre=c(mean(summary_data$K_pre[sum
mary_data$Workshop==0]),mean(summary_data$K_pre[summary_data$Workshop>0
])),
                                Mean_K_Post=c(mean(summary_data$K_post[s
ummary_data$Workshop==0]),mean(summary_data$K_post[summary_data$Worksho
p>0])),
                                Mean_E_Pre=c(mean(summary_data$A_pre[sum
mary_data$Workshop==0]),mean(summary_data$E_pre[summary_data$Workshop>0
])),
                                Mean_E_Post=c(mean(summary_data$A_post[s
ummary_data$Workshop==0]),mean(summary_data$E_post[summary_data$Worksho
p>0]))
                                )

init_highperformers<-summary_data[summary_data$A_pre>22,]

outliers_data<-data.frame(row.names = c("control high outlier", "contro
l low outlier", "workshop high outlier", "workshop low outlier"),
                          Delta=c(summary_data$Delta[summary_data$Parti
cipant==1], summary_data$Delta[summary_data$Participant==11],
                                  summary_data$Delta[summary_data$Parti
cipant==18], summary_data$Delta[summary_data$Participant==21]),
                          Likert_Delta=c(summary_data$Delta_Likert[summ
ary_data$Participant==1], summary_data$Delta_Likert[summary_data$Partic
ipant==11],
                                         summary_data$Delta_Likert[summ
ary_data$Participant==18], summary_data$Delta_Likert[summary_data$Parti
cipant==21]),
                          A_Pre=c(summary_data$A_pre[summary_data$Parti
cipant==1], summary_data$A_pre[summary_data$Participant==11],
                                     summary_data$A_pre[summary_data$
Participant==18], summary_data$A_pre[summary_data$Participant==21]),
                          A_Post=c(summary_data$A_post[summary_data$Par
ticipant==1], summary_data$A_post[summary_data$Participant==11],
                                   summary_data$A_post[summary_data$Par
```

```
ticipant==18], summary_data$A_post[summary_data$Participant==21]),
                          K_Pre=c(summary_data$K_pre[summary_data$Parti
cipant==1], summary_data$K_pre[summary_data$Participant==11],
                                       summary_data$K_pre[summary_data$
Participant==18], summary_data$K_pre[summary_data$Participant==21]),
                          K_Post=c(summary_data$K_post[summary_data$Par
ticipant==1], summary_data$K_post[summary_data$Participant==11],
                                   summary_data$K_post[summary_data$Par
ticipant==18], summary_data$K_post[summary_data$Participant==21]),
                          E_Pre=c(summary_data$E_pre[summary_data$Parti
cipant==1], summary_data$E_pre[summary_data$Participant==11],
                                  summary_data$E_pre[summary_data$Parti
cipant==18], summary_data$E_pre[summary_data$Participant==21]),
                          E_Post=c(summary_data$E_post[summary_data$Par
ticipant==1], summary_data$E_post[summary_data$Participant==11],
                                   summary_data$E_post[summary_data$Par
ticipant==18], summary_data$E_post[summary_data$Participant==21])
                          )

sum_table <- data.frame(t(short_summary_data))
outlier_table <- data.frame(t(outliers_data))

write.csv2(sum_table, file="summary_table")
write.csv2(outlier_table, file="outlier_table")

#************************************#
#       figures                      #
#************************************#


# overlapping histograms
dc<-data.frame(deltacontrol)
dc$group<-"control"
dw<-data.frame(deltawork)
dw$group<-"workshop"
colnames(dc)[1]<-"delta"
colnames(dw)[1]<-"delta"

png("summ_histogram.png", units="in", width=3.5, height=3, res=300)
ggplot( rbind(dc, dw), aes(x=delta, fill=group, pattern=group) ) +
  geom_histogram_pattern(data = dc, alpha = 0.4, binwidth = 6,
                        colour = 'black',
                        ) +
  geom_histogram_pattern(data = dw, alpha = 0.7, binwidth = 6,
                        colour = 'black',
                       ) +
  scale_fill_grey()+
  guides(colour = guide_legend(override.aes = c(alpha = .1, alpha=.2)))
+
```

```r
  theme(legend.position=c(.8,.8), legend.key.size = unit(.3,"inch"))+
  labs(x="Change in Survey Score (Post-Pre)", y = "Count")

## Warning: Duplicated aesthetics after name standardisation: alpha

dev.off()

## quartz_off_screen
##                 2

# boxplot
png("summ_boxplot.png", units="in", width=3.5, height=3, res=300)
ggplot( rbind(dc, dw), aes(x=group, y=delta, color=group), fill=group,
color=group) +
  geom_boxplot(data = dc) +
  geom_boxplot(data = dw) +
  scale_color_manual(values=c("black", "black")) +
  labs(y = "Change in Survey Score (Post-Pre)", x="Group") +
  theme(legend.position = "none")
dev.off()

## quartz_off_screen
##                 2

#histograms, boxplots, and variance
hist(deltacontrol)

hist(deltawork)

boxplot(deltacontrol)

boxplot(deltawork)

hist(prework)

hist(postwork)

range(deltacontrol)

## [1] -11.5   8.5

range(deltawork)

## [1] -4 36

#***********************************#
#        test normality             #
#***********************************#

shapiro.test(deltacontrol)

##
##  Shapiro-Wilk normality test
##
```

```
## data:  deltacontrol
## W = 0.9062, p-value = 0.1011

qqnorm(deltacontrol)
qqline(deltacontrol)

shapiro.test(deltawork)

##
##  Shapiro-Wilk normality test
##
## data:  deltawork
## W = 0.98244, p-value = 0.9799

qqnorm(deltawork)
qqline(deltawork)

hist(likert_deltacontrol)

hist(likert_deltawork)

range(likert_deltacontrol)

## [1] -4  7

range(likert_deltawork)

## [1] -1 19

##HYPOTHESIS TESTING
# for Brunner Munzel test, adding the argument est="difference" produce
s a
# different sample estimate, confidence interval, and way to interpret
the test.
# we go with the "original" P(X<Y)+.5*P(X=Y) estimate

#hypothesis 1. Are postworkshop scores higher than preworkshop scores?
brunnermunzel.test(prework, postwork)

##
##  Brunner-Munzel Test
##
## data:  prework and postwork
## Brunner-Munzel Test Statistic = 6.767, df = 19.308, p-value = 1.682e
-06
## 95 percent confidence interval:
##  0.7753343 1.0215407
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.8984375

brunnermunzel.test(A_prework, A_postwork)
```

```
##
##  Brunner-Munzel Test
##
## data:  A_prework and A_postwork
## Brunner-Munzel Test Statistic = 3.175, df = 27.43, p-value = 0.00368
2
## 95 percent confidence interval:
##  0.5961665 0.9468023
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.7714844
```

```
brunnermunzel.test(K_prework, K_postwork)
```

```
##
##  Brunner-Munzel Test
##
## data:  K_prework and K_postwork
## Brunner-Munzel Test Statistic = 10.137, df = 18.82, p-value = 4.65e-
09
## 95 percent confidence interval:
##  0.8486579 1.0302483
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.9394531
```

```
brunnermunzel.test(E_prework, E_postwork)
```

```
##
##  Brunner-Munzel Test
##
## data:  E_prework and E_postwork
## Brunner-Munzel Test Statistic = 4.1935, df = 26.722, p-value =
## 0.0002693
## 95 percent confidence interval:
##  0.6605201 0.9683861
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.8144531
```

```
#simulation of situation where A_prework and A_postwork are not signifi
cantly
# different, but (A_postwork-A_prework) is significantly different from

# (A_postcontrol-A_precontrol)

# sim_wpre<-round(runif(n=16, min=20, max=32), 0)
# sim_wpost<-round(runif(n=16, min=22, max=34), 0)
# sim_cpre<-round(runif(n=16, min=20, max=30), 0)
# sim_cpost<-round(runif(n=16, min=18, max=29), 0)
```

```
sim_wpre<-c(31, 22, 25, 23, 31, 20, 26, 25, 25, 22, 28, 27, 26, 31, 25,
 21)
sim_wpost<-c(31, 28, 28, 25, 29, 26, 26, 25, 30, 23, 22, 26, 26, 28, 25
, 30)
sim_cpre<-c(30, 29, 29, 26, 26, 22, 26, 23, 23, 22, 24, 28, 20, 28, 27,
 21)
sim_cpost<-c(26, 28, 24, 28, 24, 27, 26, 20, 23, 21, 20, 23, 25, 18, 21
, 25)
sim_wdelta<-sim_wpost-sim_wpre
sim_cdelta<-sim_cpost-sim_cpre

brunnermunzel.test(sim_wpre, sim_wpost) #insig

##
##  Brunner-Munzel Test
##
## data:  sim_wpre and sim_wpost
## Brunner-Munzel Test Statistic = 1.1945, df = 24.541, p-value = 0.243
7
## 95 percent confidence interval:
##  0.4106882 0.8354055
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.6230469

brunnermunzel.test(sim_cpre, sim_cpost) #insig

##
##  Brunner-Munzel Test
##
## data:  sim_cpre and sim_cpost
## Brunner-Munzel Test Statistic = -1.3883, df = 28.857, p-value = 0.17
57
## 95 percent confidence interval:
##  0.1569995 0.5656568
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.3613281

brunnermunzel.test(sim_wpre, sim_cpost) #insig

##
##  Brunner-Munzel Test
##
## data:  sim_wpre and sim_cpost
## Brunner-Munzel Test Statistic = -1.3517, df = 29.941, p-value = 0.18
66
## 95 percent confidence interval:
##  0.1616032 0.5688656
## sample estimates:
```

```
## P(X<Y)+.5*P(X=Y)
##        0.3652344

brunnermunzel.test(sim_wdelta,sim_cdelta) #sig

##
##  Brunner-Munzel Test
##
## data:  sim_wdelta and sim_cdelta
## Brunner-Munzel Test Statistic = -2.144, df = 28.979, p-value = 0.040
56
## 95 percent confidence interval:
##  0.1030978 0.4906522
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##         0.296875

brunnermunzel.test(sim_wpost, sim_cpost) #sig

##
##  Brunner-Munzel Test
##
## data:  sim_wpost and sim_cpost
## Brunner-Munzel Test Statistic = -3.3391, df = 29.713, p-value =
## 0.002274
## 95 percent confidence interval:
##  0.05925605 0.39386895
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.2265625

#hypothesis 2. Are control group attitude scores higher
# on the second survey as compared to the first?
brunnermunzel.test(A_precontrol, A_postcontrol)

##
##  Brunner-Munzel Test
##
## data:  A_precontrol and A_postcontrol
## Brunner-Munzel Test Statistic = -0.11043, df = 29.544, p-value = 0.9
128
## 95 percent confidence interval:
##  0.2714193 0.7051432
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.4882812

#hypothesis 3. Are score changes higher for workshop group than control
 group?
brunnermunzel.test(deltacontrol, deltawork)
```

```
##
##  Brunner-Munzel Test
##
## data:  deltacontrol and deltawork
## Brunner-Munzel Test Statistic = 7.4661, df = 15.95, p-value = 1.369e
-06
## 95 percent confidence interval:
##  0.8076525 1.0517225
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.9296875

brunnermunzel.test(likert_deltacontrol, likert_deltawork)

##
##  Brunner-Munzel Test
##
## data:  likert_deltacontrol and likert_deltawork
## Brunner-Munzel Test Statistic = 9.4857, df = 20.04, p-value = 7.489e
-09
## 95 percent confidence interval:
##  0.8382559 1.0289316
## sample estimates:
## P(X<Y)+.5*P(X=Y)
##        0.9335938

#bootstrapping, from https://data.library.virginia.edu/the-wilcoxon-ran
k-sum-test/
# med.diff <- function(d, i) {
#   tmp <- d[i,]
#   median(tmp$Delta[tmp$Workshop==0]) -
#     median(tmp$Delta[tmp$Workshop>0])
# }
#
# boot.out <- boot(data = summary_data, statistic = med.diff, R = 1000)
# median(boot.out$t)
# boot.ci(boot.out, type = "perc")




### Supplementary/Exploratory Code

likdeltbyq<-likert_control[15:28]-likert_control[1:14]
colSums(likdeltbyq)

## PoA1 PoA2 PoA3 PoA4 PoA5 PoK1 PoK2 PoK3 PoK4 PoE1 PoE2 PoE3 PoE4 PoE
5
##   -2    2    1    4    0    2   -2    0   -3    0    0   -1    1    -
1
```

```
n<-c(1:100)
political_empowerment<-1/n
png("pe.png", units="in", width=4, height=4, res=300)
plot(n,political_empowerment,
     xlab = "n (number of sytem causes)",
     ylab = "PE (political empowerment)")
text(50, .5, substitute(paste(italic(PE(n)==frac(1,n)))))
dev.off()

## quartz_off_screen
##                  2

find_mode <- function(x) {
  u <- unique(x)
  tab <- tabulate(match(x, u))
  u[tab == max(tab)]
}

find_mode(data$PrA1)

## [1] 4

min(data$PrA1)

## [1] 2

x<-c(1:1000)
y<-x+(sample(10000,1000)-5000)/100
uncertainty<-data.frame(x,y)

png("uncertainty.png", units="in", width=3, height=2.4, res=300)
ggplot(data=uncertainty, aes(x=x, y=y)) + geom_line(aes(x)) + theme_cla
ssic() +
  theme(axis.text.x=element_blank(),
        axis.text.y=element_blank(),
        axis.ticks.y=element_blank(),
        axis.ticks.x=element_blank())+
  geom_ribbon(data=uncertainty, aes( ymin=y^1.2*-2+3*x, ymax=y^1.2*2+x)
, linetype=2, alpha=0.1)+
  geom_ribbon(data=uncertainty, aes( ymin=y^1.1*-2+3*x, ymax=y^1.1*2+x)
, linetype=2, alpha=0.1)+
  labs(y = "a system effect", x="time")
dev.off()
```