

ABSTRACT

PITTS, ELIZABETH ANN. Distributing Biotechnology: (Re)Organizing DNA and Scientific Work. (Under the direction of Jessica Jameson and William Kinsella).

This dissertation introduces a theoretical and methodological framework of *techne*, or persuasive knowledgeable craft, which enables scholars of communication, rhetoric, and science studies to investigate how forms of work can inscribe meaning into objects and relationships. *Technai* are persuasive in that they define what something is and how humans should relate to it. Rather than distinguishing between material work such as laboratory techniques and symbolic work such as language, taking *techne* as an object of analysis enables scholars to document how specific techniques define the relationships that constitute organizations.

This framework is applied to evidence gathered through a 15-month multi-sited ethnography that compared the International Genetically Engineered Machine (iGEM) competition, an organization that structures genetic engineering as distributed manufacturing, with do-it-yourself biology (DIY bio) laboratories, emergent organizations that are modeled on computing hackerspaces. By simplifying the tools and techniques of genetic engineering and reducing institutional barriers to access, organizational actors in both iGEM and DIY bio aim to make the engineering of DNA as pervasive as the coding of software. Yet although they share this ultimate goal, iGEM and DIY bio are organized around different *technai* that enact different models of communication. For example, in attempting to produce standardized DNA sequences that serve the same function in a variety of organisms, synthetic biologists at iGEM apply a transmission model that assumes the biological “meaning” of DNA, like cybernetic information, will remain the same regardless of context. DIY bio enables experimentation with alternative communication models, including

biohacking that aims to decentralize the hierarchical structures of academic and corporate science, laboratory rituals that facilitate identification with the scientific community, and artisanal crafts that engage non-human others in a kind of conversation.

The dissertation demonstrates that these competing approaches to the craft of genetic manipulation serve persuasive ontological functions that organize technical work. Each *techne* encourages a kind of isomorphism, or homogenization of work and governance. In rearranging DNA to constitute novel organisms, the *technai* in these spaces constitute novel organizational forms.

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Distributing Biotechnology: (Re)Organizing DNA and Scientific Work

by
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DEDICATION

For my scientist friends.

BIOGRAPHY

Elizabeth Pitts studies organizational and professional communication in the sciences and engineering. In 2013, she was awarded an IGERT fellowship from the National Science Foundation to conduct collaborative interdisciplinary research on the interactions between genetic technologies and society. Elizabeth's academic research stems from a long-term interest in the accessibility of knowledge. Before enrolling at NC State, she spent more than a decade producing strategic communications for institutions including the White House and the US Department of Education. She has also served as an adjunct faculty member at University of Maryland University College and as a writer for the Pew Charitable Trusts. Elizabeth holds bachelor's and master's degrees in English from Georgetown University.

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CHAPTER 1 : Introduction: Simplifying Biological Work

A: That's what all of this synthetic biology field is about. Making things. Hiding complexity behind abstraction. Setting standards and specifications. And also all of this rests on some new technology that's been developed, where you can have somebody else do the work for you. In terms of synthesizing something, DNA synthesis is coming down in price, and getting less complex to do because people are now doing it in ways where they figure out better ways to do the modules.

B: And that's good for an industrial process. You have to have chunkable—

A: Right. The thing is, people worry about hypothesis-driven science, because a lot of times the answer from somebody who's a devotee of this is, well, I'm not going to try to figure out how something is working. I'm just going to make every possible combination to see which works best.

That's alright. The problem is the only people that could afford to do that right now are people who are in highest institutions that have this massive—

B: Computer.

A: Well, DOD-funded infrastructure. It's funded by the Defense Department mostly, because they are the ones that are really interested in these molecular foundries.

B: That's fascinating because the whole way that people do science is about induction, but hypothesis-driven science is actually a form of deduction.

A: It is, and a lot of that is kind of falling by the wayside. We'll see. Every tool, people lament that it is kind of taking the scientist out of something.

This conversation, which I documented while conducting ethnographic research at a do-it-yourself biology laboratory in the northeastern United States, raises questions about the organization of work in the sciences and engineering. How does technological advancement affect the nature of work? What are the advantages of industrialized science versus science at a smaller scale? At what point might mechanization become counter-productive? Which types of processes should be automated, which are better left to human control, and why?

This dissertation helps to address these questions by providing empirical insights into how emerging genetic engineering techniques enable biological work to become distributed beyond academic and corporate laboratories, while simultaneously changing the nature of this work by approaching biology as a form of applied engineering. Drawing on evidence from a 15-month multi-sited ethnography, I compare the International Genetically Engineered Machine (iGEM) competition, an organization that structures genetic engineering as distributed manufacturing, with do-it-yourself biology (DIY bio) laboratories, emergent organizations that are modeled on computing hackerspaces. By simplifying the tools and techniques of genetic engineering and reducing institutional barriers to access, organizational actors in both iGEM and DIY bio aim to make the engineering of DNA as pervasive as the coding of software.

Although each of the following chapters explores a distinct line of inquiry, the dissertation as a whole is framed by an overarching argument that competing approaches to the *techne*, or knowledgeable craft, of genetic manipulation serve persuasive ontological functions that organize technical work. Compared to the contemporary terms “technique” and “technology,” which often suggest mechanized, objective motion, *techne* in Ancient Greece

referred to “the general ability to devise intelligently means appropriate to certain purposes, whether of necessity or of pleasure” (Bruzina, 1982, p. 166). This definition makes no distinction between material crafts such as laboratory techniques and symbolic crafts such as language, nor does this dissertation. Instead, I draw on the concept of *techne* to develop a theoretical and methodological framework that enables scholars of communication, rhetoric, and science studies to investigate how emerging forms of craft constitute organization by inscribing meaning into objects and relationships.

This approach is particularly beneficial for investigating the work of genetic engineering—work in which the inscription of new meaning can transform living organisms in very tangible ways, from infusing them with a bioluminescent glow to making them capable of bearing only a single sex of offspring. The term “transformation” is in fact a common one in genetic engineering, and it hints at the symbolic nature of this type of material work (Burke, 1966). Through the symbolic work of manipulating DNA, genetic engineers are manipulating the material bodies of living organisms and their own relationships with these organisms—and in so doing, they are manipulating organizational roles and structure.

To introduce the research to follow, this chapter proceeds in three parts. First, I describe the research context of genetic engineering. Second, I situate my work within the socio-material and phenomenological research traditions. Finally, I introduce my research questions and preview how the remaining chapters contribute to answering them.

Research Context: The Distribution of Biotechnology

In recent decades, the biological sciences, like many other fields, have faced increasing pressure to enhance efficiency and generate commercially viable products. Although faculty-industry relations have a long history in the United States, the biological sciences have transformed dramatically over the last 30 years as a result of funding reallocations and policies such as the Bayh-Dole Act that promoted technology transfer (Kleinman, 1998). Today, industry and academia are converging, but in an asymmetrical way (Kleinman & Vallas, 2001). While each regime borrows from the other, ultimately, “it is the logic of profit that is shaping this process” (Kleinman & Vallas, 2006, p. 37).

At the same time, following the standardization and commercialization of tools that has taken place since the 1980s (Kleinman, 1998), biology is now presented with what anthropologist Christopher Kelty calls a “situation of abundance:”

...the proliferation of hundreds, probably thousands, of new tools and technologies for extraction, for synthesis, for analysis, for typing and mapping and sequencing. Centrifuges, thermocyclers, DNA synthesis machines, gene chips of seemingly uncountable variety, specificity, and branding, to say nothing of the proliferation of databases upon databases . . . experimentation isn't yet garage-cheap, but it is indubitably faster and more flexible than ever before. And as it gets cheaper and easier to do, it opens the door to widespread public engagement and participation in the synthesis and engineering of nano-scale structures—including to fields like design and art where definition of what is valuable to do with DNA may differ substantially from those of engineers or biologists. (2010, p. 6)

The research sites featured in this dissertation are products of this abundance that aim to proliferate further abundance and further participation. At iGEM, teams of high school and college students, as well as adults who are not professional biologists, compete to “build, test, and characterize genetically engineered systems and operate them in living cells” (iGEM press kit, 2014). The competition represents a primary vehicle for the organizing and distribution of synthetic biology, a relatively new form of genetic engineering that culminates a century-long effort to transform biological science into a form of applied engineering by constructing novel, useful or “synthetic” life forms (Campos, 2009). In 2014, the year on which my study focuses, iGEM’s Giant Jamboree (a title deliberately borrowed from the world of scouting) became the largest gathering of synthetic biologists that had taken place in the world to date, gathering teams from 245 universities in 32 countries (iGEM press kit, 2014). The more than 2,300 individuals who traveled to Boston’s Hynes Convention Center for the event represented only a fraction of the number who joined an iGEM team but did not attend the Jamboree.

DIY bio laboratories, many of which participate in iGEM and borrow from its library of standardized biological parts, also enable the work of genetic engineering to become more distributed, accessible, and applied. People with little to no expertise in biology can attend workshops or classes in these spaces for less than \$200 and can often attend for free. And by sharing equipment and supplies, those with a sustained interest in biotechnology can maintain access to a functional laboratory for little more than \$100 per month. The individuals working in these spaces have diverse and sometimes conflicting motivations and goals. They include PhD-holding molecular biologists seeking a greater degree of autonomy

than would be available in academic laboratories; designers and architects in search of a new medium to work with; engineers and programmers interested in applying their coding skills to biological systems; artists who explore or critique the contemporary relationships between science and capitalism; and entrepreneurs aiming to develop marketable products.

Both iGEM and DIY bio are twenty-first century phenomena: iGEM was launched as a month-long course at Massachusetts Institute of Technology (MIT) in January 2003, and DIY laboratories began to be organized around 2010 (although, as I discuss in Chapter Four, a network of individuals had been practicing genetic engineering at home well before this time). At the same time, both of these examples recall earlier organizational forms. Although it was deliberately modeled on the 1970s microchip design techniques that enabled the microprocessing revolution of the 1980s (see Streeter, 2010), iGEM is also reminiscent of both Frederick Taylor's (1914) early twentieth century scientific management and, as I discuss in Chapter Three, the cybernetics of the late 1940s and 1950s. For their part, DIY bio practitioners have been compared productively with outlaws in the Wild West, Victorian gentleman scientists, and contemporary software hackers (Kelty, 2010). Yet it remains unclear which precedents will ultimately be applied to govern these organizations, given that both iGEM and DIY bio present significant challenges to existing regulatory structures in both the United States and Europe, which were set up with the much more hierarchical structures of academic and corporate laboratories in mind (Landrain, Meyer, Perez & Sussan, 2013; Schmidt, 2008).

Partially as a result of this uncertainty, the individuals at these research sites are weighing complex questions related to the social, ethical, and regulatory acceptability of

manipulating DNA. They often disagree about what is good, what is just, what is acceptable, and what is technically feasible. Furthermore, some of them are revising their perspectives over time. This dissertation focuses on the deliberations, observations, and practices that various people have shared with me or allowed me to witness or participate in since the spring of 2013. Rather than attempting to present a definitive snapshot of a rapidly evolving field, this dissertation documents and reflects upon on issues that my collaborators and I have identified as worthy of consideration, in the hopes of contributing to broader and more inclusive conversations about the engineering of life. The next section contextualizes this research in the field of organizational communication.

Communication Scholarship and the Materiality of Work

An advantage of investigating the distribution of genetic engineering through the lens of organizational communication, rather than other areas of social scientific or humanistic inquiry, is that communication scholarship highlights negotiations of meaning: “the conditions under which something can count as being something else” (Deetz & Eger, 2014, p. 30). Negotiations of meaning are particularly important to iGEM and DIY bio because neither these organizations, nor the genetically modified organisms that they produce, have become sufficiently well-defined and legitimized to be taken for granted. Over time, organizational meanings typically “become routinized, sedimented, and institutionalized in practices, language, objects, and technologies” so that “what arose as a direct encounter, is reproduced as people are recruited or interpolated into ready-at-hand modes of encounter and construction processes” (Deetz, 2013, p. 223). Thus, studying work and what makes work meaningful “can help to make visible what has so often been taken for granted . . . the actual

work that people do, how they feel about it, how work can be more fully dignified, and how these issues relate to broader social, political, and economic trends” (Cheney, Zorn, Planalp & Lair, 2008, p. 172).

Studying distributed biotechnology as it emerges enables me to help make some of these issues visible well *before* they become routinized (Barben, Fisher, Selin & Guston, 2008; Guston, 2014; Guston & Sarewitz, 2002; Rip & Van Amerom, 2010). Researching social, technical, organizational, and political negotiations as they happen produces scholarship that is relevant not only to academic conversations, but also to practitioners and policymakers. Further, in addressing ethical and practical aspects of the interactions between synthetic biologists, their fellow citizens, and the organisms they engineer, this study answers the call for scholars to actively contribute to “the ongoing reflective critique and reconstruction of communication practices in society” (Craig & Tracy, 1995, p. 269).

Because communication scholarship approaches structures, norms, knowledge, beliefs, and practices as fluid rather than static entities, it is especially helpful in understanding the contestations that accompany emergent organizations in which a common purpose has yet to be established (Barnard, 1938; Deetz, 1992; Taylor & Van Emery, 2000; Ashcraft, Kuhn & Cooren, 2009). Attending to the ramifications of how DNA and work are organized enables me to demonstrate how organizational communication scholarship can engage in meaningful, relevant public and policy dialogue to facilitate more just and productive forms of social relations (Ashcraft, 2011; Cheney, Zorn, Planalp & Lair, 2008; Kuhn, Golden, Jorgenson et al., 2008).

At the same time, studying the production of hybrid life forms presents a challenge to scholars of communication and rhetoric because we have traditionally emphasized human language as a fundamental way of knowing. By focusing almost exclusively on the meanings embedded in language—for example, by analyzing documents, transcripts, or formal talks (Cooren, Kuhn, Cornelissen et al., 2011, p. 1151)—the field has tended to neglect how meaning is inscribed into objects, relationships—and, in the case of iGEM and DIY bio, into living beings. As Jennifer Slack argued in her introduction to a 2005 special issue of *Communication Theory*, “the combination and integration of engineering, biology, communication, and technology. . . is disrupting, rearranging, and reconstituting the everyday as well as the knowledge necessary to study, understand, and intervene in this world of our creation” (2005, p. 5). Making sense of this convergence requires scholarship that cuts across disciplinary distinctions in the field of communication, while also drawing insights from related fields.

Historically, the ontological and epistemological separation of communication and materiality owes much to early modern scientists and philosophers of science, who “aligned science with the material world of things and placed ‘discourse,’ especially discourse as a method, with the immaterial. One could engage in endless argument, or one could do science and control things” (Condit, 2008, p. 401). Drawing on work in organizational communication, rhetorical and communication theory, and science and technology studies (see Figure 1), this dissertation engages in a cross-disciplinary conversation that begins to put language and materiality back together again by illustrating how the discursive is material and how the material is discursive.

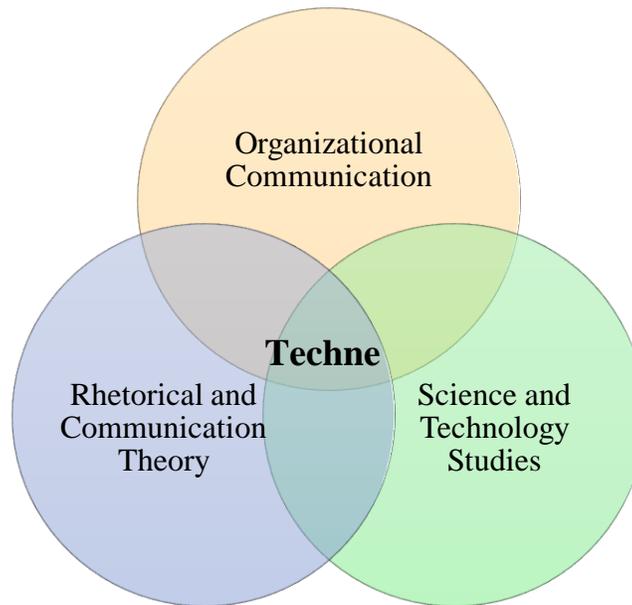


Figure 1: Theoretical Framework

Matter, meaning, and relationality. In this dissertation, I define symbolic-material work as *techne*, or persuasive knowledgeable craft. In advancing this theoretical and methodological framework, which I discuss in more detail in Chapter Two, I build on a growing body of research in organizational communication and science studies that aims to illuminate the interrelatedness of ideas and things by adopting a sociomaterial ontology (Barad, 2003, 2007; Leonardi, 2009, 2013; Mol, 2002; Orlikowski, 2007; Orlikowski & Scott, 2008, 2015; Suchman, 2007). Rather than conceptualizing reality as a collection of atomistic material entities that exist apart from social interaction, sociomateriality begins from the premise that “[m]atter and meaning are not separate elements. They are inextricably fused together, and no event, no matter how energetic, can tear them asunder” (Barad, 2007, p. 3). From this perspective, the meaning of one thing arises only in relation to others: “the

social and the material are constitutively entangled in everyday life” (Orlikowski, 2007, p. 1437). Rather than focusing on “products as constituted,” my analysis highlights the co-constitutive nature of relationships (Deetz & Eger, 2014, p. 33). This perspective is grounded in the assumption that, “Experience, meaning, the very objects of our world arise out of relations and lose sense outside them . . . And these relational formations are deeply political” (Deetz, 2009, p. 40).

Sociomateriality exemplifies the intersubjectivist problematic in organizational research. Rejecting Cartesian dualism, researchers working within this problematic “construe intersubjectivity as ontology—a way of being in the world—where we are always embedded in an intricate flow of complexly entwined relationally responsive activities” (Cunliffe, 2011, p. 657; also see Merleau-Ponty, 1962). In many ways, this is less a departure from the linguistic turn of the 1930s than a return to linguistic turn’s original purpose of drawing on phenomenology to move beyond subject/object dualism (Deetz, 2003, p. 421-422). Husserl (1962) advanced phenomenology as an alternative to the rationalism of modernity, and particularly to naïve applications of the scientific method that sought “exact, quantifiable categories and objects, which subsequently become rigid and frozen, hiding any contingency they may contain” (Dorfman, 2009, p. 295). Phenomenologists, by contrast, were interested in the “real unity of the world as a whole” (Husserl, 1962, p. 73).

The opposition between these two stances dates to an old ontological debate about whether a whole can be greater than the sum of its parts. Ancient Greek philosophers observed that in general, any given entity can be understood either atomistically or holistically:

as an aggregate of parts, such as barley or wheat in a barrel, or [as] a unity. If the substance is an aggregate, then it cannot possess characteristics apart from those of the parts. If it is a unity, then the substance as a whole must possess attributes of the whole. The attributes of the latter must be more than the sum of the attributes of the parts. For example, water as a substance possesses a qualitative attribute of being wet; the parts of which water is composed—hydrogen and oxygen—are not wet.

(Mickunas and Pilotta, 1998, p. 3-4)

From a phenomenological perspective, the problem with the parts-based approach is that by “operating as if their own language and procedures were ‘transparent,’” its proponents take their objects of investigation for granted (Deetz, 1992, p. 117). Countering this view, Husserl and other phenomenologists argued that “my knowledge of the world, even my scientific knowledge, is gained from my own particular point of view, or from experience of the world without which the symbols of science would be meaningless” (Merleau-Ponty, 1962, p. viii). In other words, a phenomenological analysis draws attention to the way that researchers constitute objects of study through our own subjective understanding. For example, a West Texas accent is recognizable only on relation to alternate ways of speaking; similarly, a child’s Attention Deficit Disorder is identifiable only because of the differences that she displays in comparison with her peers (Slife, 2004, p. 160). Importantly, acknowledging subjectivity and contingency in this way does not diminish the knowledge produced by scientific research: “Nothing is lost from science, or the everyday usefulness of it, in this move, except for the pretense of fixed, independently structured objects of the world” (Deetz, 1992, p. 120).

Rather than advancing a “purely ‘subjective’ analysis” (Ihde, 1990, p. 21), phenomenologists emphasize that actions and objects make sense only in relation to one another: “the meaning of the thing is defined in terms of the use to which the thing is put” (Mickunas & Oastler, 1972, p. 244). Similarly, sociomateriality approaches knowledge more from the standpoint of ontology than epistemology (Orlikowski & Scott, 2015). As Mol (2002) argues, the “driving question no longer is ‘how to find the truth?’ but ‘how are objects handled in practice?’” (p. 5). Indeed, focusing on interactions and relationalities emphasizes not only ontology, but a multiplicity of ontologies: “objects come into being—and disappear—with the practices in which they are manipulated. And since the object of manipulation tends to differ from one practice to another, reality multiplies” (Mol, 2002, p. 5).

I define the practices through which objects come into being as rhetorical because rhetoric is “in the deepest and most fundamental sense the *advocacy of realities*” (Brummett, 1976, p. 31, italics original). Thus, “whatever else it is, rhetoric is inherently organizational” (Cralle, 1990, p. 115). The organizational/ontological function of rhetoric was described decades ago by Kenneth Burke, who used the metaphor of molten liquid to describe how symbolic work facilitates the transformation of reality:

Distinctions, we might say, arise out of a great central moltenness, where all is merged. They have been thrown from a liquid center to the surface, where they have congealed. Let one of these crusted distinctions return to its source, and in this alchemic center it may be remade, again becoming molten liquid, and may enter into

new combinations, whereat it may be again thrown forth as a new crust, a different distinction. (1969a, p. xix)

Burke's vivid language resonates with the phenomenological critique of scientific reductionism. Rather than approaching the world as a compilation of discrete objects of investigation, he is drawing attention to the rhetorical processes through which subjects and objects are continually made and remade. From this perspective, "Discourse, even language itself, [must] be characterized as material rather than merely representational of mental and empirical phenomena" (McGee, 2009, p. 19).

The scientific work of genetic manipulation offers a productive illustration of the materiality of discourse and the discursive qualities of material entities because the gene is a "paradigmatic example of the way in which language constructs an objectified essence where none exists in nature--but where that objectification is useful and is related to real material processes of undeniable significance" (Condit, 1999, p. 334). Scientists describe sequences of DNA as "genes" not because they are obviously or essentially discrete, but because identifying them as discrete entities enables them to accomplish specific goals (Keller, 2000). Rather than diminishing the importance of language in relation to materiality, drawing attention to the discursive/material nature of scientific work in genetics highlights "how it is that meaning arises materially, and hence how meaning matters" (Condit, 1999, p. 335).

Drawing on Austin's Speech Act Theory, Taylor (2001) emphasized the need for scholars of organization and communication to recognize that "At the level of illocution . . . the utterance of the speaker and the 'uptake' (as Austin called it) of the hearer are no longer *about* a world; they *are* a world: that of conversation itself" (p. 275, italics original). Austin

(1961, 1975) himself used the term “performative utterances” to describe language through which speakers are “*doing* something rather than merely *saying* something” (1961, p. 222, italics original). In subsequent chapters of this dissertation, I illustrate how the techne of genetic engineering is precisely this kind of performative utterance.

Genetic manipulation is “discursive” in that it involves the coding of DNA nucleotides adenine, thymine, cytosine, and guanine, which are abbreviated with the letters A, T, C, and G. It is simultaneously “material” in that it rearranges the genetic makeup of living organisms, altering the physical characteristics these organisms exhibit. By seeking to standardize and automate how the materiality of DNA is “written” and “rewritten” across multiple species, emerging forms of genetic engineering complicate taken-for-granted distinctions not only between the discursive and the material, but also between the biological and the technological, the human and the non-human. The techne of genetic engineering exemplifies Burke’s (1966) definition of man as “the symbol-using animal,” as well as his argument:

Paper need not know the meaning of fire in order to burn. But in the “idea” of fire there is a persuasive ingredient. By this route something of the rhetorical motive comes to lurk in every “meaning,” however purely “scientific” its pretensions.

Wherever there is persuasion, there is rhetoric. And wherever there is “meaning,” there is “persuasion.” (1969b, p. 172)

In the context of genetic engineering, these negotiations of meaning have material and ethical consequences for the living organisms being engineered, as well as for the scientific knowledge and technological applications that they help to produce. Accordingly, I

am interested here in contributing to a growing body of work that is accounting for the agency of non-human actors (Ashcraft, Kuhn & Cooren, 2009; Callon, 1986; Brummans, 2006, 2015; 2005; Leonardi & Barley, 2011) and the materiality of structures, contexts, and bodies (Bowen, 2005; Burfoot, 2003; Condit, 1999; Haraway, 2008; McGee, 2009; Packer & Wiley, 2012; Slack, 2005, 2012). Much of this scholarship is indebted to actor network theory (Latour, 1983, 1988; Callon, 1986), a scholarly lens that demonstrates how social life “is enacted through the interactions between various agents (see Latour 2002) – an agent being anything that, or anyone who, ‘makes a difference’ (Cooren 2006: 82) in the ongoing stream of experience” (Brummans, Cooren & Chaput, 2009, p. 54). My research builds on work that Montreal School of organizational communication scholars have done to address two key limitations of actor network theory (ANT). First, in distinguishing only between human and non-human agents, ANT “defines nonhuman agents in the light of human ones and thereby circumvents the question of what it means to be human and what it means to be an agent” (Brummans et al, 2009, p. 55). Second, “while it has offered an intriguing view on social life as a plethora of intersecting actor-networks, ANT analyses have overlooked the role of communication in processes of organizing” (Brummans et al, 2009, p. 55).

Operationalizing *techne* as persuasive knowledgeable craft helps to resolve these issues by drawing attention to the techniques through which the relationships between entities become defined. Rather than proceeding on the assumption that I should investigate the “immaterial” phenomenon of human communication in relation to the “material” biological or technological world, focusing on *techne* enables me to document how the ontological categories of human and non-human, biological and technological, discursive and

material emerge and contribute to the organizing of social relations. For example, as I discuss in Chapter Four, Taylor (2001) uses the term *imbrication* to describe “the way that interagency relationships are interweaved to form . . . infrastructure” (Taylor, Groleau, Heaton & Van Every, 2007, p. 399). In every system of activity, this interweaving brings humans and non-humans together “like the shingles on a roof, the foliage on a tree, or the scales on a fish” by positioning some as agents and others as instruments (Taylor, 2001, p. 280). *Technai* are the processes through which this interweaving takes place. In response to emerging forms of knowledgeable craft, reality becomes malleable in new and different ways. *Techne* “constitutes, within brute reality, that in relation to which nothing can be done, and that in relation to which some kind of making/doing is possible.” (Castoriadis, 1984, p. 240). Focusing my analysis on the persuasive qualities of *techne* enables me to answer calls to “materialize” organizational communication by documenting the realities of day-to-day professional labor (Barley & Kunda, 2001) and the interplay of structures, systems, technologies, identities, and life forms (Ashcraft, et al., 2009). In so doing, I provide empirical evidence to illustrate how organization is “both symbolically made *and* materially real” (Ashcraft et al., 2009, italics original).

This dissertation documents how the tools, techniques, and products of genetic engineering are emerging beyond traditionally gated settings, alongside the individuals who engage in this kind of work. As the fields of engineering, software programming, art, and biology encounter one another in new locations, their ontologies, practices, and norms are colliding, which leads to renegotiations of organizational and institutional form. Defining institutions as “constellations (i.e., relatively fixed arrangements) of formalized rational

beliefs manifested in individuals' organizing behaviors" (Lammers & Barbour, 2006, p. 356) helps to illuminate the constitutive role of technai in organizing scientific work. In the spaces described in this study, multiple sets of formalized rational beliefs—in other words, ontologies materialized as persuasive knowledgeable crafts—are competing to become legitimized. Documenting the coexistence of multiple ways of organizing the work of genetic engineering is valuable because doing it demonstrates that multiple pathways are available to scientists, policymakers, and citizens as we consider the future of biotechnology. Each pathway poses significantly different consequences for both scientific work and the genetically modified organisms that it produces.

The following section introduces my research questions and summarizes my study design, which is described in more detail in Chapter Two. The chapter concludes with an overview of the dissertation as a whole.

A Multi-Sited Ethnographic Approach

To investigate the organizational technai of iGEM and DIY bio, I employed multi-sited ethnographic methods—including participant observation, interviews, and analysis of cultural artifacts (Marcus, 1995; Hine, 2007). As I discuss in Chapter Two, following the craftwork of genetic engineering as it was simplified and distributed took me from New York to Baltimore, Pittsburgh, Boston, Oakland, Silicon Valley, London and Copenhagen. This research was supported by a doctoral dissertation research completion grant¹ and an

¹ NSF Award Number 1456974

Interdisciplinary Graduate Education Research and Training fellowship² from the US National Science Foundation, as well as a travel award from North Carolina State University's (NCSU) Genetic Engineering and Society Center. This support made it possible for my research design to accommodate the fact that “science is about practices carried out between varyingly identified groups and institutions and individuals”; thus, researchers “need to be agile, itinerant and attentive if we are to trace these connections (Hine, 2007, p. 661). Further, multi-sited research enabled me to produce middle-range theory, yielding generalizable insights while attending to the competing claims and accountabilities of various sites (Hine, 2007).

I employed a grounded theory strategy to narrow the focus of the study over time, first seeking data, then describing the events I observed, answering fundamental questions about what was happening, and finally, developing theoretical categories to understand the phenomena and processes that I observed (Charmaz, 2014, p. 38, 43-44). Throughout the inquiry, I moved between data gathering and analysis in an iterative manner, applying the logic of grounded theory, which requires continually “going back to data and forward into analysis”:

Ethnographers can raise their descriptions to abstract categories and theoretical interpretation. Subsequently they can focus further data collection to refine their emerging theoretical framework. This logic aids in overcoming several ethnographic problems: accusations of uncritically adopting research participants' views; lengthy

² NSF Award Number 1068676

unfocused forays into the field setting; superficial, random data collection; and reliance on stock disciplinary categories. (Charmaz, 2014, p. 42)

In keeping with this approach, rather than entering into my research with a predetermined assumption of what “work” means, I took the definition of work as an object of study. As Barley and Kunda (2001) note, “[b]ecause work and organizing are so interdependent, eras of widespread change in the nature of work in society should lead to the emergence and diffusion of new organizational forms and institutions” (p. 76). My final analysis was guided by the following research questions:

- What constitutes work when the tools and techniques of genetic engineering are distributed beyond the gated settings of academic and corporate laboratories?
- What types of beliefs and practices enable this distribution?
- How does the organizing of biological work affect both human and non-human actors?

Dissertation Overview

To answer these questions, this dissertation proceeds as follows: Chapter Two introduces my theoretical and methodological framework. I draw on the history of rhetoric to recuperate an Ancient Greek meaning of the term *techne* and discuss how a scholarly focus on *techne* contributes to contemporary scholarship on discursive/material work and organization. Then, I explain how I operationalized the concept of *techne* in my data collection and analysis.

Chapter Three describes the origins and evolution of a *techne* of genetic information. I explain how Claude Shannon’s transmission model of communication came to be

materialized in some strains of biological work during the late 1940s and 1950s, then contrast this techne of transmission with a more responsive approach that I call an artisanal techne of biological work. Building on these concepts, the second half of the chapter examines how the techne of transmission organizes the symbolic-material work of the iGEM competition by ontologizing sequences of DNA as standardized units of information that retain the same meaning regardless of context. I argue that the materialization of this unidirectional model of communication results in a lack of reflexivity that stifles organizational learning.

Chapter Four introduces and compares three technai of DIY bio: a techne of distribution, a techne of ritual communication, and an artisanal techne that enacts a multidirectional model of communication. Each techne enacts a different definition of what genetic engineering is, and in so doing, it simultaneously defines what genetically modified organisms are, and what kinds of organization DIY laboratories are. More specifically, by advocating for a single definition of what DIY bio is, each techne encourages a kind of isomorphism (DiMaggio & Powell, 1983), or homogenization of work and governance. In rearranging DNA to constitute novel organisms, the technai in these spaces constitute novel organizational forms.

Chapter Five integrates the research findings on iGEM and DIY bio, indicating areas for theoretical development in organizational communication, rhetorical and communication theory, and science and technology studies. I conclude by describing theoretical and practical implications, limitations of the study, and directions for future research.

CHAPTER 2 : Theory and Methods: Techne as Persuasive Knowledgeable Craft

Although the theories and methods of organizational communication offer valuable insights into the forms of scientific work that I discuss in this dissertation, researching genetic engineering also challenges scholars who have traditionally emphasized language as a fundamental way of knowing. As I mentioned previously, genetic manipulation is discursive in that it involves the coding of DNA nucleotides, which are abbreviated with the alphabetic letters A, T, C, and G. It is simultaneously material in that it rearranges the genetic makeup of living organisms. As a result, emerging forms of genetic engineering complicate distinctions between the discursive and the material, the biological and the technological, and the human and the non-human.

This chapter begins to work through these intellectual tangles by approaching genetic engineering as a *techne*, or persuasive knowledgeable craft, which produces organisms both biologically and socially. Although conventional wisdom suggests that we are certainly *doing* something when we communicate, but we aren't *making* something in the way that we make things in the laboratory or at the workbench, I approach communication as a knowledgeable craft in its own right. If we think of communication itself as a way of making things, we can begin to entertain the idea that the material work of scientists and engineers could itself have communicative or persuasive qualities. We might even begin to think about *both* rhetoric and material work as persuasive knowledgeable crafts—in other words, as *technai*.

As I mentioned in the previous chapter, compared to the contemporary terms “technique” and “technology,” which often suggest mechanized, objective motion, *techne* in ancient times referred to “the general ability to devise intelligently means appropriate to

certain purposes, whether of necessity or of pleasure” (Bruzina, 1982: 166). The term originated with the Greeks, who derived it from the Indo-European *tek*, which described the communal work of weaving homes from trunks and twigs (Roochnik, 1996: 19). Over time, its usage broadened to include other productive practices from shipbuilding to the art of politics. It made no distinction between high “art” and lower “craft” as we would today, and it could also mean craftiness in the sense of cunning or ingenuity (Wild, 1941: 255-256). In the writings of Homer and Hesiod, *techne* encompassed both products and processes: it referred to both a “set of rules, system or method of making or doing” that organized productive work and the “artistic products” that such work could yield (Atwill, 1998: 53). The tools or instruments used in various *techne* were called *organa* (Aristotle & Kennedy, 2007: 16), a term that would later form the root of the contemporary word *organization*: “No wonder, therefore, that ideas about tasks, goals, aims, and objectives have become such fundamental organizational concepts, for tools and instruments are mechanical devices invented and developed to aid in performing some kind of goal-oriented activity” (Morgan, 2006: 15).

An ethnography of *techne* enables researchers of communication, rhetoric, and science studies to draw attention to the discursive qualities of material work and the materiality of discourse. In advancing this theoretical and methodological approach, I contribute to the development of Communication as Constitutive of Organization theory (Cooren, 2004; Putnam & Nicotera, 2009), which positions communication as central to organizational ontology. From this perspective, communication is a way of “forming, making, and composing” organization (Putnam, Nicotera & McPhee, 2009, p. 4). Building on

Giddens' (1984) structuration theory and Weick's (1995b) theory of sensemaking, scholars working in this tradition conceive of organizations not as static objects that contain communication (Smith, 1993), but dynamic processes sustained in and through communication (Putnam & Fairhurst, 2015). Nevertheless, it remains unclear precisely what scholars mean when we say that communication is "constitutive" (Putnam & Nicotera, 2009; Cooren, Kuhn, Cornelissen et al., 2011; Ashcraft, Kuhn & Cooren, 2009; Robichaud & Cooren, 2013). Scholarship has tended to "talk about communicating and organizing as dynamic activities without unpacking the nature of these processes and how they are related to the elements that form an organization" (Putnam, Nicotera & McPhee, 2009, p. 5).

Part of the difficulty stems from the fact that research has focused almost exclusively on the meanings embedded in language—for example, in documents, transcripts, or formal talks (Cooren, Kuhn, Cornelissen et al., 2011, p. 1151)—while neglecting how meaning is inscribed into objects and relationships. Even in "replacing the traditional 'discourse constitutes' question with, 'How do discourse and materiality mutually constitute each other in the routine practices of organizational life?'" (Putnam & Fairhurst, 2015, p. 383), scholars have implicitly defined language and other forms of symbolic work as separate from the physical world. In so doing, they have reified an Enlightenment-era dualism that separates talk from action and language from materiality (Stewart, 1995, 1996), producing scholarship that "leaves an important part of the spectrum of human organizational experience out of sight and presents a limited view on the way an organisation is constituted" (Brummans, Cooren, & Chaput, 2009, p. 54). Perrow's (1967, p. 207) fifty-year-old complaint that "it is surprising that so few studies actually give details regarding the kind of work performed in

organizations that permit technological generalizations” echoes in more recent literature reviews that highlight a dearth of studies of material work (see Ashcraft et al., 2009; Barley, 1996; Barley & Kunda, 2001; Cooren, Kuhn, Cornelissen et al., 2011; Leonardi, 2011; Leonardi & Barley, 2011). In seeking to develop insights that would hold true across diverse professional contexts, organizational scholars have tended to devalue the particularities of different forms of work, employing research methods such as surveys and interviews that neglect the physicality of day-to-day practices (Barley, 1996, p. 405). Even studies that do acknowledge the materiality of work “often fail to actually examine and describe people’s work practices” (Leonardi, 2014, p. 236) or “tend to ‘black box’ the social interactions within which activities are accomplished in order to focus on the materials themselves” (Jarzabkowski & Pinch, 2013, p. 585). Scholars are thus faced with a challenge that is simultaneously theoretical and methodological: how can work practices be studied as communicative forms of organizing?

To address this question, this chapter proceeds in two parts. The first highlights the ontological function of persuasive knowledgeable craft by placing Ancient Greek philosophies of *techne* in conversation with more recent ways of understanding technical work. To illustrate how a scholarly focus on *techne* contributes to contemporary scholarship on discursive/material work and organization, the second part turns from theoretical issues to methodological application, outlining how I operationalized the concept of *techne* in my research and data analysis.

A Brief History of *Techne*

Communication research is distinct from other areas of inquiry in its ability to draw attention to negotiations of meaning (Deetz, 2009). Within this broader field, organizational communication research is distinct in its focus on “those everyday interactive exchanges—typically the object of at least some human design yet invariably unruly in practice—in which discourse, matter, and cognition intertwine to construct work as it is and is becoming” (Okhuysen, Lepak, Ashcraft & colleagues, 2013, p. 500). By approaching forms of social organization as “processes of production” that have political consequences (Deetz, 2009, p. 40), an ethnography of techne answers the call for scholars to make the constitutive function of language both “visible and more democratic” (Deetz, 2009, p. 40) by demonstrating how communication “generates, rather than merely expresses or transmits, work realities” (Okhuysen, Lepak, Ashcraft et al., 2013, p. 499). In so doing, this theoretical framework helps to “materialize” organizational communication by documenting the realities of day-to-day professional labor (Barley & Kunda, 2001) and the interplay of symbols, structures, systems, technologies, identities, and life forms (Ashcraft et al., 2009).

Highlighting the processes through which realities are produced and reproduced over time necessitates “a concern with the relational nature of being and ‘otherness.’ The recovery of conflict and otherness—the difference, outside, and not yet determined—rather than understanding the self, reflection, and empathy become the central driving forces of productive interaction and decision-making” (Deetz, 2009, p. 41). Because human relationships with genetically modified organisms have not yet solidified to the point of being taken for granted, an ethnography that contrasts different technai of genetic manipulation offers an opportunity to draw attention to the communicative crafting of human

relationships with other species in real time. Focusing on *techne* draws attention to the ways in which human relationships with non-human life forms come into being through persuasive forms of work.

Scholars have struggled to balance social constructionism's emphasis on malleability with a recognition that human agency can exert more influence over some material entities than others (Leonardi & Barley, 2008). As the following discussion illustrates, it is evolution of *techne* that "constitutes, within brute reality, that in relation to which nothing can be done, and that in relation to which some kind of making/doing is possible. Technique is creation in that it makes arbitrary use simultaneously of the rational make-up of the world and of its indeterminate interstices" (Castoriadis, 1984, p. 240). *Techne* is thus fundamentally ontological: in response to emerging forms of technical work, reality becomes malleable in new and different ways. Rather than asking what is or is not malleable, an ethnography of *techne* poses more nuanced questions such as: What qualities characterize particular *technai*? What types of ethics and politics does each *techne* encourage, and what considerations does it minimize? Moreover, what types of relationships does each *techne* produce between humans and the entities that surround us? The Ancient Greeks posed these questions of rhetoric alongside other forms of knowledgeable craft, and their answers offer insights into how the political and ethical relationalities of various discursive/material *technai* can be investigated and weighed.

Techne in Ancient Greece. Even in its earliest appearances, the concept of *techne* consistently linked rhetoric, productive work, organizing, and the ongoing distribution of power. As Johnson (2010) notes, as both a process of forming knowledge and a form of

knowledge in itself, *techne* “begins within the maker” and is squarely “in the human domain. For the ancients, this was of supreme importance as it called forth the beginning of human control over and intervention in making. No longer were the gods the sole source of production” (p. 677). *Techne* shaped and amplified human control over the natural world. *Mechanical Problems* (*Mechanica*), a classical treatise on applied mathematics, begins with the following ode to *techne*, which is translated here as “skill:”

Remarkable things occur in accordance with nature, the cause of which is unknown, and others occur contrary to nature, which are produced by skill for the benefit of mankind. For in many cases nature produces effects against our advantage; for nature always acts consistently and simply, but our advantage changes in many ways. When, then, we have to produce an effect contrary to nature, we are at a loss, because of the difficulty, and require skill. Therefore we call that part of skill which assists such difficulties, a device. For as the poet Antiphon wrote, this is true: “We by skill gain mastery over things in which we are conquered by nature.” Of this kind are those in which the less master the greater, and things possessing little weight move heavy weights, and all similar devices which we term mechanical problems. (Anonymous, 1936, p. 331)

Like the anonymous author of this passage, Aristotle and others aptly described *techne* as “the dividing line” between nature and culture (Atwill, 1998, p. 83). *Technai* from politics to medicine to seafaring played a fundamental role in “authorizing specific models of social, political, and economic order,” serving as “powerful catalysts in the redistribution of wealth and political power and in the construction of new modes of social identification and

economic exchange” (Atwill 1998, p. 103). The tools or instruments used in various *techne* were called *organa* (Aristotle & Kennedy, 2007, p. 16), a term that would later form the root of the contemporary word organization: “No wonder, therefore, that ideas about tasks, goals, aims, and objectives have become such fundamental organizational concepts, for tools and instruments are mechanical devices invented and developed to aid in performing some kind of goal-oriented activity” (Morgan, 2006, p. 15).

Rhetoric as techne. By the fifth century BCE, as the co-development of democracy and literacy made it possible for the earliest theories of rhetoric to emerge, a group of traveling lecturers calling themselves sophists, meaning “wisdom bearers” (Murphy, Katula & Hoppman, 2014, p. 28), began to advertise themselves as teachers of the “techniques of civic life,” including rhetoric (Kennedy, 1963, p. 26). The sophists trained their students in rhetoric, the *techne* of persuading effectively in the courts, in legislative assemblies, or at ceremonial gatherings. Focused on these pragmatic forums, in which truth is socially negotiated, they tended to be skeptical of absolutes (Kennedy, 1963, p. 13), holding that “all knowledge is subjective, and thus probable, relative, contingent, and uncertain, and could only be created in and through style” (Katz, 1996, p. 84). Indeed, Carter (1988) argues that the sophists laid a social constructionist foundation for classical rhetoric by defining knowledge production as a communal enterprise. Like phenomenologists, sociomaterialists, and some leading twentieth century physicists, the sophists viewed reality “as a synthetic unity in which all elements are interrelated and in flux (as opposed to autonomous, fixed, and stable)” (Katz, 1996, p. 251). For many of them, language served as the only way defining the relationships that simultaneously distinguish and connect one thing to another.

Language, here, is not only an epistemology or way of knowing, it is also fundamentally ontological: it defines our understanding of what exists in the first place. For example, a popular sophistic method of intellectual exploration, the *dissoi logoi* or opposing arguments, involved arguing an issue from both sides to encourage speakers to grapple with the co-existence of multiple realities. Similarly, for the sophists, “analogical thought in general, and metaphor in particular, [was] not realized through a rational process but, if effective, [was] apprehended immediately” (Enos, 1986, p. 10). In their view, the *techne* of rhetoric was a material intervention: the means by which social, political, and ethical relationships are continually made and re-made, not only through the intellectual act of producing thought in language, but also through the physical performance of oral communication (Katz, 1996, p. 92-93). One sophist, Gorgias, argued that rhetoric is an intrinsic component of knowledge production because knowledge can only be produced in and through the sensory perception of language (Katz, 1996, p. 89). Another, Protagoras, taught that “man is the measure of all things, of things that are as to how they are, and of things that are not as to how they are not” (Murphy et. al, 2014, p. 31). From this perspective, “each individual’s perceptions are immediately true for him at any given moment, and . . . there is no means of deciding which of several opinions about the same thing is the true one; there is no such thing as ‘truer’ though there is such a thing as ‘better’” (Freeman, 1966, p. 348, cited in Lauer, 2004, p. 15). Reality is socially negotiated through rhetoric, a *techne* that “has more to do with the polis than the individual soul” and is “far more likely to disrupt standards of value than to secure them” (Atwill, 1998, p. 21).

Techné and knowledge production. Plato took a different view, arguing for most of his career that sophistic rhetoric could not be a true art because sophistic orators lacked *episteme*, or absolute knowledge, of the subjects on which they spoke. Roochnik (1996) observes that “Plato’s preoccupation with rhetoric is manifest” because “rhetoric is the first discipline to claim technical mastery over the field to which Socrates himself is devoted” (p. 181) —namely philosophy, the contemplation of how the good life can be lived. For Plato, the universal truths of *episteme* could be uncovered only via the philosophical method of dialectical questioning and answering, as opposed to the “cheap, basic, specialized instruction” of the sophists, many of whom emphasized rigid formulas and reductionist thinking (Walker, 2000, p. 32).

The vehemence of Plato’s criticism of sophistic rhetoric speaks implicitly to the respect that he accorded to the notion of *techné*. In Chapter Three of *The Republic*, he ascribes the genesis of community to the distribution of labor via technical specialization (369a-371e). Later in the same work, he likens the *techné* of statecraft to the *techné* of sailing to illustrate the dangers of allowing the ship of state to be steered by those who know nothing of the art of navigation (*The Republic*, 488c-d). While this comparison was clearly intended to discourage the involvement of “mere amateurs” in political life, it also shows that Plato “thought the art of politics could be useful in the same way as any other *techné*, that is it could produce finished works of lasting value” (Winner, 1983, p. 97).

Plato’s teachings illustrated how specific forms of technical work embodied distinct forms of knowledge and how some types of knowledge were more ethically reflexive than others. In the *Gorgias*, he suggests that rhetoric as taught by the sophists is a cheap imitation

of the *techne* of politics, much as pastry baking is nothing more than a simulation of the *techne* of medicine (*Gorgias*, 501). In other words, sophists could only flatter or please their audiences, much as a chef might deliver a tasty morsel that claimed, but failed to deliver, the health benefits of a doctor's prescription. The difference is that the *techne* of medicine, unlike pastry baking, "has investigated both the nature of the object it serves and the cause of the things it does, and is able to give an account of each of these," whereas baking is purely "concerned with pleasure, to which the whole of its service is entirely devoted" (*Gorgias*, 502). Not surprisingly, Plato accused sophistic rhetoric of contributing to moral decline—for example, by enabling the guilty to go free, or allowing corrupt politicians to deceive the masses.

In a later work, *The Phaedrus*, Plato revised this view to suggest that rhetoric could be a genuine *techne* if it treated the soul much as a *techne* of medicine would treat the body by cultivating wisdom in its audiences, rather than merely pleasure. He argued that practitioners of both arts must "analyze a nature, in the one that of the body . . . to apply medicine and diet to create health and strength in the one case—while in the other to apply proper words and rules of conduct to communicate such convictions and virtues as you may desire" (1956, p. 61). More specifically, to employ a true rhetorical *techne*, a speaker must first learn philosophy to "know the truth about each point he makes" (1956, p. 50). Thus, for Plato, the study of ontology—of what is—is required for effective rhetoric but also takes place apart from and prior to the practice of rhetoric (Enos, 1981). Speakers must master the subject matter of their remarks before turning to the art of persuasion (Bryant, 1981, p. 10). Where the sophists saw rhetoric as a source of invention and intervention (Atwill, 1998), for

Plato, rhetoric—even once elevated to the status of *techne*—could explain reality only “after the fact to those unable to engage in philosophical method” (Katz, 1996, p. 254). For him, knowledge or *logos* was the subject matter that dialectic uncovered; *techne* was merely the social function of knowledge gained elsewhere (Atwill, 1998, p. 127).

In severing the application of knowledge from the origination of knowledge, Plato simultaneously severed intellectual life from political life, suggesting that, “The true champion of justice, if he intends to survive even for a short time, must necessarily confine himself to private life and leave politics alone” (*Apology* 32a, cited in Atwill, 1998, p. 121). In his view, the *techne* of rhetoric could prepare speakers to refine their natural talent through study and practice, identify points of agreement and disagreement among audiences, and index arguments according to the types of audiences being addressed (Grube, 1980, p. 214-5). In a passage that has particular relevance to contemporary considerations of the discursive qualities of biotechnical practices, he also advised that rhetors should approach discourse “like a living creature,” ensuring that it is “put together that it has its own body and lacks neither head nor feet, middle nor extremities, all composed in such a way that they suit both each other and the whole” (1956, p. 53) and “divide into species according to natural articulations, avoiding the attempt to shatter the unity of a natural part, as a clumsy butcher might do” (1956, p. 55). Yet none of this involves determinations of what kind of speech to make in first place, as the determination of subject matter is, again, solely the domain of philosophy. In *The Phaedrus*, he draws on an analogy of a charioteer being led by two winged horses: “one of them is noble and handsome and of good breeding, while the other is the very opposite, so that the charioteer necessarily has a difficult and troublesome task”

(1956, p. 28). Ramsey (1999) suggests that while the noble horse represents philosophy, the “base horse represents rhetoric because it is strong enough to run wild and to drag the noble horse behind it” (p. 259). Thus the charioteer’s task is to keep the two in stride, and in so doing, to cultivate the “hybrid techne of the soul” (Ramsey, 1999, p. 258).

Cicero (1942) was among the first to observe that in positioning rhetoric as dependent on philosophy, Plato proves himself to be the consummate persuasive orator. Yet as Plato’s strict division of rhetoric from the invention of knowledge was advanced by his student Aristotle, among others, it became increasingly natural to think of persuasion as simply a vehicle for knowledge gained elsewhere, rather than a materially oriented art in its own right. Unlike Plato, Aristotle acknowledged rhetoric, along with dialectic, as a techne. For Aristotle, both rhetoric and dialectic were arts that dealt with uncertain knowledge, and rhetoric, specifically, dealt with uncertain matters in civic life: “things that seem capable of admitting two possibilities” (*Rhetoric*, I, 1357a, 4-5). Nevertheless, he also held that there was a separate realm of scientific knowledge that was certain and therefore separate from the argumentative craftwork of rhetoric and dialectic (Warnick, 1989, p. 303). As Aristotle puts it,

But the more we try to make either dialectic or rhetoric not, what they really are, practical faculties, but sciences, the more we shall inadvertently be destroying their true nature; for we shall be re-fashioning them and shall be passing into the region of sciences dealing with definite subjects rather than simply with words and forms of reasoning. (*Rhetoric*, I, 1359b, 11-14).

In this passage and in his larger body of work, Aristotle separates knowledge from language and scientific subject matter from words (Katz, 1996, p. 82). As Atwill (1998) notes, “What is lost . . . is the sense of the art of rhetoric as a valued mode of intervention into existing conditions and a means for the invention of new possibilities” (p. 189).

Techne and ethics. Aristotle attempted to reconcile the best of both sophistic and Platonic teachings by contextualizing *techne* alongside other kinds of knowledge taxonomically, much as he categorized species. Aristotle distinguished *episteme*, theoretical knowledge of eternal truths, from knowledge that originated with humans. He then divided the latter into the productive knowledge of *techne*, “a state concerned with making, involving a true course of reasoning,” and the practical knowledge of *phronesis*, “to be able to deliberate well about what is good and expedient for himself, not in some particular respect, e.g. about what sorts of thing conduce to health or to strength, but about what sorts of thing conduce to the good life in general” (*Nicomachean Ethics*, 1140a, 19-26, in Aristotle, 2001).

Technai, in this formulation, are constitutive: they are “concerned with coming into being, i.e. with contriving and considering how something may come into being which is capable of either being or not being, and whose origin is in the maker and not in the thing made” (*Nicomachean Ethics*, 1140a11, in Aristotle, 2001). They are arts and crafts such as medicine and building that involve “both particular and general knowledge, both knowing-how and knowing-that; *techne* is both applicable and conceptualized” (Miller, 1989, p. 22). Rhetoric, from the Aristotelian perspective, is a *techne* that helps to determine things that “belong to no definite science” (*Rhetoric*, I, 1354a1)—in other words, subjective questions such as what action to take, what to celebrate or blame, or whom to hold responsible in a

court of law, as opposed to the certainties of science. On one hand, this suggests that *technai* are sophisticated and reflexive processes that embody forms of rationality. For example, in *Metaphysics*, echoing Plato's comparison of medicine and pastry baking, Aristotle distinguishes a true art or *techne* from a mere knack according to the degrees of knowledge and understanding possessed by its practitioners (Dubinsky, 2002, p. 132), anticipating contemporary discussions of work and professional identity. "[M]en of experience," he argues—in other words, men who possess a knack for something—"know that the thing is so, but do not know why" (*Metaphysics*, 981a, 29-30). The artists or "master-workers in each craft" are, for him, "more honourable" and "wiser than the manual workers, because they know the causes of the things that are done," while the manual laborers merely "act without knowing what they do, as fire burns" (*Metaphysics*, 981b, 1-4).

On the other hand, although Aristotle suggests that practitioners of *techne* do have a sophisticated understanding of the reasoning behind their work, he also says that the rationality of *techne* considers only means of production, rather than the ends towards which production is aimed (Self, 1979, p. 132). From this perspective, *techne*—and particularly the *techne* of persuasion—is concerned solely with the useful and does not encompass considerations of the good. For example, Miller (1989) demonstrates that if rhetoric is an Aristotelian *techne*, it is concerned with means, rather than ends, and thus capable of only the most stilted of ethical reflections. If it involves practical knowledge, *phronesis*, it is not a *techne* but a *praxis*, a form of action that must concern itself with *both* means and ends—with questions of what is right and just (Miller, 1989). Thus, *technai* as defined by Aristotle are not concerned with virtue—that is the realm of *phronesis*. "This distinction is important,"

as Sullivan (1990) notes, “for a skill can be used for good or bad ends, but a virtue automatically embodies good ends” (p. 378; also see Garver, 1985, p. 69). Yet because Aristotle’s definition of *phronesis*, unlike Plato’s, is socially determined (Sullivan, 1990), even the reasoning of ends that he describes will be guided by the ideology of the society (Katz, 1992). In this formulation, the *techne* of rhetoric is elevated as a way of addressing political and ethical arguments, but as with Plato, it cannot serve as a source of knowledge in its own right (Katz, 1996, p. 82). As Aristotle himself puts it, “The general Lines of Argument have no special subject-matter, and therefore will not increase our understanding of any particular class of things” (*Rhetoric*, I, 1358a22).

The relative flatness of Aristotle’s conception of *techne* may stem in part from the way that he conducted his inquiry into the world. Dunne (1993) notes that “His preferred procedure was to analyze already-constituted beings and only through retrospective inferences from within this discourse of *being* to shed light on the process of *becoming*” (p. 326, italics original). For example, in *The Metaphysics*, Aristotle argues that “Of the productions or processes one part is called thinking and the other making—that which proceeds from the starting-point and the form is thinking, and that which proceeds from the final step of the thinking is making” (2001, 1032b, 14-15). As an example, he suggests that in practicing the *techne* of medicine, doctors begin to heal their patients by first following a train of thought about what it means to be healthy: “since *this* is health, if the subject is to be healthy *this* must first be present” (2001, 1132b, 5, italics original). The physician proceeds in this manner, according to Aristotle, “until he reduces the matter to a final something which

he himself can produce. Then the process from this point onward, i.e. the process towards health, is called a ‘making’” (2001, 1132b, 9-10).

This approach is reminiscent of Plato in that it assumes that form or *eidos* precedes production. In making this assumption, Aristotle neglects the ontological function of *techne*, such as the determination of what a patient’s condition is in the first place, as well as the fact that physicians may redefine their understandings of both health and medicine as they practice their craft over time. Rather than recognizing that thinking and practice can be mutually informative, Aristotle suggests that thinking can inform *techne*, but *techne* cannot inform thinking. The same issue arises in his similarly flattened conception of the rhetorical *techne* of deliberation. He argues that “We deliberate not about ends but about means. For a doctor does not deliberate whether he shall heal, nor an orator whether he shall persuade, nor a statesman whether he shall produce law and order, nor does any one else deliberate about his end” (*Nicomachean Ethics*, 1112b, 13-15). This assumes that the ends people want to pursue are always self-evident. Yet as Dunne observes, ends do not necessarily precede deliberation; instead, deliberation often involves the ontological production of ends:

To say that a general’s end is victory and that his deliberation therefore is only about the means to achieve it is to gloss over the fact that much of his most difficult pondering may be about just what would count as victory here or—where ‘victory’ may be impossible—what would be an acceptable compromise, or—failing even that—a not dishonorable defeat. (1993, p. 352)

Recognizing the complex intertwining of thinking and doing, arguing and making, Dunne suggests, might result in a “‘phronetic’ *techne*, i.e., one whose responsiveness to the situation

is not fully specifiable in advance and which is experiential, charged with perceptiveness, and rooted in the sensory and emotional life” (1993, p. 355).

Techne and relationality. In making this argument, Dunne echoes Isocrates, an elder contemporary of Plato’s, who understood wisdom and the *techne* of rhetoric as fundamentally intertwined. Isocrates offered an education or *paideia* that aimed to cultivate ethical responsibility in his students as it cultivated the art of speech. This training defined the *techne* of rhetoric as self-consciously relational: the cultivation of responsibility in the speaker necessarily involves the ongoing consideration of an audience’s needs and values. Isocrates’ *paideia* was closely associated with “the construction of a certain type of subjectivity,” and referred not “so much to knowledge that one ‘has’ as . . . to knowledge that one ‘is’” (Atwill, 1998, p. 128). From this standpoint, it is impossible to separate knowledge from the knower: anticipating phenomenologists, he suggested that any such separation results not from objective reality, but from reductionist methods (Katz, 1996, p. 102). Instead of separating *logos* and *techne* as Plato and Aristotle did, he defined rhetoric as a *logon techne*—a term that, like the contemporary word *technology*, unites *techne* or craftsmanship with *logos*, the “framework of principles derived from the application of reason” (Ingold, 2011, p. 294). Isocrates argued that eloquent speech could serve as “the surest index of a sound understanding, and discourse which is true and lawful and just [as] the outward image of a good and faithful soul” (*Antidosis*, cited in Bizzell & Herzberg, 2001, p. 75). This communicative understanding of the self anticipated the linguistic subjectivity described by Althusser, Lacan, and other late twentieth century theorists, who argued that it is only through language that an individual becomes a subject (see Deetz, 1992, p. 134-9).

Isocrates rejected the notion that the practice of his art could mold students into entirely different people, but he believed that it could play a significant role in helping them to develop the faculty of doing good. As he put it,

the kind of art which can implant honesty and justice in depraved natures has never existed and does not now exist . . . But I do hold that people can become better and worthier if they conceive an ambition to speak well, if they become possessed of the desire to be able to persuade their hearers, and, finally, if they set their hearts on seizing their advantage. (*Antidosis*, cited in Bizzell & Herzberg, 2001, p. 77)

By “advantage,” he goes on to say, he means more than the pursuit of power over others. Instead, by his logic, “the stronger a man’s desire to persuade his hearers, the more zealously will he strive to be honorable and to have the esteem of his fellow citizens” (ibid.). Isocrates critiqued Plato and Aristotle as well as the sophists for reducing rhetoric to rigid formulas (Papillion, 1995, p. 150) or, as he put it, “applying the analogy of an art with hard and fast rules to a creative process” (*Against the Sophists*, cited in Bizzell & Herzberg, 2001, p. 73). Effective rhetoric, for him, involved a pragmatic ethics that required speakers to “carry a flexible attitude into any given rhetorical situation” (Sipiora, 2012, p. 9). Instead of applying a technical rhetoric of predetermined rules, he encouraged speakers to remain constantly attuned to *kairos*, or opportune timing, adapting their craft on the fly as they gained greater understanding of the individuals they addressed and the circumstances in which they found themselves. *Phronesis*, here, is conjoined with “pragmatic ethics within the ‘situation’ and ‘time’ of discourse” (Sipiora, 2012, p. 8)—and specifically, an attentiveness to situation and time as perceived by a particular audience. This accommodating attitude required a

responsiveness to others. For Isocrates, the “highest kind of oratory” was “that which deals with the greatest affairs and, while best displaying the ability of those who speak, brings most profit to those who hear” (*Panegyricus*, 4.4). As Haskins (2004) notes, “In contrast with Aristotle’s rigid conception of citizenly virtue as a procedural function within a well-ordered state, Isocrates aestheticize[d] and thereby mad[e] desirable the identity of a citizen” (p. 128)—an identity that was fundamentally rooted in advancing the collective good.

Isocrates saw the *techne* of rhetoric as constitutive not only of a speaker’s identity, but of civilization itself. In the *Antidosis*, he argues that,

Because there has been implanted in us the power to persuade each other and to make clear to each other whatever we desire, not only have we escaped the life of wild beasts, but we have come together and founded cities and made laws and invented arts; and, generally speaking, there is no institution devised by man which the power of speech has not helped us to establish.. (Bizzell & Herzberg, 2001, p. 75)

Thus, the *logon techne* of persuasion is the means through which we “secure, disrupt, and create social and political order” (Atwill, 1998, p. 127). The composing of language is quite literally the making of the world; in fact, the contemporary understanding of writing as a way of “making meaning” likely originated with Isocrates (Katz, 1996, p. 98). For him, written composition was:

a kind of making itself, in that the written word preserved an image of the word in the mind, in the living intelligence of the maker. Isocrates herein took the Archaic conception of the written word as a form of preservation and molded this preservation

into an art that captured the shape and form of the thought of man. (Lentz, 1989, p. 125)

This represented “a remarkable rupture with earlier rhetorical schools and traditions, many of which limited their ‘art’ to a concern for mechanical functions of speech” (Sipiora, 2012, p. 8). Compared to these mechanistic approaches, Isocrates’ *logon techne* was a vastly more complex and sophisticated enterprise.

However, partially because of the force with which Plato and Aristotle successfully separated rhetoric from philosophy, the term “rhetoric” began to stand for a much narrower understanding of the knowledgeable craft of persuasion. Rather than an Isocratean *logon techne* that produced an attentive, ethically conscious eloquence, rhetoric became known as “little more than a few genres of pragmatic speechmaking” (Walker, 2000, p. 34). To illustrate the significance of this shift, Walker (2000) likens Isocrates’ rhetoric to the discipline we now know as English:

It is as if the entire enterprise of the discipline “English” were [thanks to Plato and Aristotle] to become identified almost exclusively with the teaching of business and technical writing. . . . To continue this analogy, imagine that people were to begin thinking of “English” not as “English” but as (perhaps) “business writing,” or “practical writing,” or simply as “writing” or, to use the most common (though wildly inadequate) cover term now in use, as “composition.” And then imagine that this term shift were to be appropriated by an extremely influential philosopher—or a university president—and that, in the long run, it were to stick. (p. 33-34)

Specialization and the diminishment of techne. As techne was translated over time into the English “art” or “craft,” understandings of knowledgeable production became increasingly mechanistic and decreasingly associated with persuasion and ethics. The earliest English usage of the term “art” occurred in approximately the thirteenth century in *St. Margarete*, a work in which Saint Margaret calls on the devil to “telle me of youre art” (“art, n.1”), recalling the ancient meaning of techne as craftiness and skill. Until the seventeenth century, “art” referred broadly to “matters as various as mathematics, medicine and angling.” for example, “[i]n the medieval university curriculum the arts (‘the seven arts’ and later ‘the liberal (q.v.) arts’) were grammar, logic, rhetoric, arithmetic, geometry, music and astronomy” (Williams, 1985, p. 41). In this context, the “artist” and the “artisan” were synonymous descriptions of those who practiced the arts—essentially, “any skilled person” (ibid.)

Yet by the Renaissance, the techne of rhetoric, in particular, was diminished as scholars not only codified the Platonic/Aristotelian division of rhetoric and subject matter, but also defined persuasion itself in increasingly narrow terms. In the sixteenth century, Peter Ramus, an influential scholar at the University of Paris, successfully advocated for a curriculum that defined the orator as “simply a person skilled in speaking, with good style and delivery,” rather than an active contributor to civic life (Bizzell & Herzberg, 2001, p. 676). In the late sixteenth and early seventeenth century, Francis Bacon adapted Plato’s idea/matter binary into a new binary of matter vs. discourse (Condit, 2008, p. 401). As he put it,

. . .the end which this science of mine proposes is the invention not of arguments but of arts; not of things in accordance with principles, but of principles themselves; not of probable reasons, but of designations and directions for works. And as the intention is different, so accordingly, is the effect; the effect of the one being to overcome an opponent in argument, of the other to command nature in action.

(Bacon, 2017, p. 21)

Although he approached rhetoric as a more sophisticated enterprise than Ramus did, Bacon nevertheless defined persuasion in opposition to the tangible production of *techne*, placing science “on the side of the materially real (arts, work, things) and opposed to the realm of the immaterial (arguments and opinions)” (Condit, 2001, p. 401).

This redefinition of human technique went hand-in-hand with the ontological reformulation of reality by figures such as Galileo, Newton, and Descartes, who described the universe as a machine whose structure and motion could be determined “through exclusive use of mathematics both in describing the phenomenon in question and in asserting the relationships that define it” (Bruzina, 1982, p. 178). Where medieval *techne* was governed by “an accumulated *experience* of what works and what does not, derived in part from his own personal work and in part from a long tradition in the craft,” this modern ontology of the physical sciences defined reality as “a system of mass and force relationships, that is, a system whose basic nature is exclusively indicated through the methods by which it is known, by methods of quantitative measure” (Bruzina, 1982, p. 179-80, italics original).

Before the mechanized conception of the universe emerged, *techne* has been, in the Ancient Greek poet Antiphon's words, the means of "gain[ing] mastery over things in which we are conquered in nature" (Anonymous, p. 331). But once nature itself was seen as mechanical, the nature of making also changed. As Ingold (2011) puts it,

The image of the artisan, immersed with the whole of his being in a sensuous engagement with the material, was gradually supplanted by that of the operative whose job it is to set in motion an exterior system of productive forces, according to principles of mechanical functioning that are entirely indifferent to particular human aptitudes and sensibilities. . . The artisan, of course, knows what he is making, and works to clear standards of perfection. He may be less than clear, however, about the methods by which his results are achieved, and is often quite unable to specify these methods with any precision. The operative, on the other hand, is guided in his activity by formal and explicit rules of procedure whose validity is independent of the specific ends to which they are applied. (p. 295)

For the operative, as for Plato, form precedes production. Thus, the creativity of making is purely abstract: it is associated with the conceptualization of a novel form, rather than the form's materialization. As the operative supplanted the artisan, the prestige that was once accorded to knowledgeable craft became more associated with the architect who designed a house than the builder who constructed it, and with the theoretical scientist who proposed a hypothesis, rather than the technician who tested it in the laboratory (Ingold, 2011, p. 295). In both examples, the application of technical craft becomes understood as merely the operationalization of predetermined ends. Barley (1996) provides empirical evidence to

support this division of intellectual and material labor in contrasting scientists' "principled understanding" of materials, technologies, and techniques with the more "contextual" understanding of laboratory technicians, who "have a feel" for tactile procedures and are often better able to perform such work than their more senior colleagues.

Thus, over time, other *technai* have followed rhetoric's lead in becoming understood as a means of execution rather than invention. As specialization increased in the seventeenth century, art was elevated and distinguished from craft, which became associated with the work of the lower classes (Ingold, 2011, p. 350). In the eighteenth century, the distinction between the upper-class artist and the lower-class artisan was institutionalized as the newly formed Royal Academy in England excluded engravers from its membership by dismissing them as "'skilled manual worker[s]' without 'intellectual' or imaginative' or 'creative' purposes" (Williams, 1985, p. 41). Michel de Certeau (1984) summarizes how this technical optimization drained knowledgeable craft of its knowledge:

From this know-how, what could be detached from human performance was gradually cut out and "perfected" with machines that use regulatable combinations of forms, materials, and forces. These "technical organs" are withdrawn from manual competence . . . Henceforth know-how (*savoir faire*) finds itself slowly deprived of what objectively articulated it with respect to a "how-to-do" (*un faire*). As its techniques are gradually taken away from it in order to transform them into machines, it seems to withdraw into a subjective knowledge (*savoir*) separated from the language of its procedures . . . (p. 69)

In this account, just as procedural language is taken as merely the transmission of creative ideas, so too is technical work taken as merely the putting of ideas into practice. Marx (1964) drew attention to the alienation brought about by this reformulation of labor. Taylor (1914) used it to his advantage to automate labor in pursuit of efficiency.

Twentieth century philosophers have suggested that the separation of *savoir*, to know, from *faire*, meaning to do or to make, has come to plague not only the application of knowledgeable techniques in science and engineering, but also the forms of reasoning that characterize the broader society in which such techniques proliferate. Heidegger (1977) contrasts the reasoning of modern technology—which enframes the natural world as “standing reserve:” material defined, in its “whole structure and in every one of its constituent parts,” by the utility it provides for humans (p. 8)—with the Ancient Greeks understanding of *techne* as “the bringing-forth of the true into the beautiful” (p. 18). Horkheimer (1947) uses the term “subjective reason” to describe the stilted reasoning of means without considerations of ends, which focuses on “the adequacy of procedures for purposes more or less taken for granted and supposedly self-explanatory” and “attaches little importance to the question whether the purposes as such are reasonable” (p. 3). Ellul (1964) describes “technical automatism” as a state in which the autonomy of techniques replaces what was formerly the autonomy of humans: “Technique itself,” he argues, “ipso facto and without indulgence or possible discussion, selects among the means to be employed. The human being is no longer in any sense the agent of choice” (p. 80). Weber (1978) makes a similar argument, contrasting what he calls “purposive-rational action,” the instrumental reasoning of efficiency calculations, with the practical reasoning of intersubjective human

experience. Habermas (1984) contrasted purposive-rational action with communicative action that aims for a more genuine kind of conversation.

Levi-Strauss (1962) offers a reminder that the automation of work has not eliminated older forms of *techne*. Recalling the ancient association of *techne* with cunning, he uses the term “bricoleur” to describe “someone who works with his hands and uses devious means compared to those of a craftsman” (p. 11). Compared with the engineer, whose tasks are dictated by “the availability of raw materials and tools conceived and procured for the purpose of the project,” the bricoleur is adept at making do with whatever materials are available (*ibid.*). Levi-Strauss describes this approach as explicitly communicative, hinting at how material work can be understood as a kind of dialogue. In his words, the bricoleur turns “to an already existent set made up of tools and materials, to consider or reconsider what it contains and, finally and above all, *to engage in a sort of dialogue with it* and, before choosing between them, to index the possible answers which the whole set can offer to his problem” (Levi-Strauss, 1962, p. 12, italics added).

The forms of reasoning embodied in this and other forms of work have defined a central problematic in organizational communication research (Mumby & Stohl, 1996, 2007), where contemporary discussions of technological labor and rationality echo ancient Greek considerations of *techne*, ethics, and relationality. Drawing on Weber, Mumby and Stohl (1996) suggest that:

our field is characterized by pluralist understandings of what counts as rational, which in turn shape the various ways in which we can make knowledge claims.

Furthermore, we suggest that problematizing rationality leads to the undermining of

any unitary, singular notion of a particularly central organizational principle—that of effectiveness. Not only does organizational communication scholarship expand and challenge notions of whose interest should provide measures of effectiveness, but we problematize the very ground on which effectiveness is based. (p. 59)

An ethnography of *techne* contributes to this problematic by building on organizational research that contrasts the rationalities of various forms of work. More than half a century ago, Trist and Bamforth (1951) documented the coal industry's transition from "hand-got" techniques to the mechanized "longwall" method of mining. Stinchcombe (1959) contrasted artisanal and bureaucratic forms of production in the construction industry. Drawing on Woodward (1965), Perrow (1967) defined organizations as systems of coordinated *techne*—or as he put it, "systems for getting work done, for applying techniques to the problem of altering raw materials"—whether the "raw material" was "a living being, human or otherwise, a symbol or an inanimate object" (p. 195). More recently, Weick (1995a) drew on Levi-Strauss' (1962) characterization of the "bricoleur" to outline an improvisational approach to organizational design in which order is achieved not through "intention, planning, and implementation" but "from improvisation based on intimate knowledge of resources" (p. 353).

The parallel argument that language is an inventive, knowledgeable craft has also been investigated in a variety of professional settings. Indeed, in Tompkins' (1997) account, the field of organizational communication originated with Yeager's (1929) work on business and professional speaking, which approached rhetoric as an instrumentally rationalized technical craft:

In the beginning was business and professional speaking. This era can be characterized as rational, mechanistic and aimed to influence the decision-making process in organizations. It stressed the rhetoric initiative of the individual but tried to align that with the interests of the organization. (Tompkins, 1997, p. 367)

Since then, a body of work too broad to summarize here has taken a more critical stance toward workplace activities and demonstrated how the *techne* of communication sustains work and organization, often—for example, by enacting knowledge production (Canary, 2010; Canary & McPhee; 2008; Iverson & McPhee, 2008), structuring policies (Kirby & Krone, 2002), or shaping the form of routine work (Barley, 2015). Of particular relevance to the analytical framework of *techne* are Knorr-Cetina's (1981) definition of scientific organizations as communication systems and Kinsella's (1997) argument that scientific knowledge is “both a product of rhetorical construction and a set of rhetorical resources” (p. iii), although these analyses focused more on language than the persuasive qualities of symbolic/material work.

By contrast, the analytical framework of *techne* illustrates how persuasive knowledgeable crafts constitute discursive/material relationalities. Rather than investigating the “immaterial” phenomenon of human communication in relation to the “material” biological or technological world, understanding *techne* as rhetorical highlights the materially constitutive function of rhetoric (Stewart, 1995, 1996). From this perspective, it is a knowledgeable craft, a way of making things by carving ontologies. Whether employing a Foucauldian lens (Hardy & Thomas, 2015) or positioning discourse and materiality as imbricated systems of agency-instrumentality (Taylor, 2001; Leonardi, 2011), a plenum of

agencies (Taylor & Van Every, 2000; Cooren, 2004), or a mangle of practice (Pickering, 1995), organizational research on discourse and materiality tends to operationalize the two phenomena as empirically distinct (Introna, 2013; Putnam, 2015). Scholars of the rhetoric of science have assumed a similar dualism. For example, Wickman (2012) has shown how Aristotle’s explanation of *techne* enables rhetoricians to expand their field of study beyond texts to include practices and modes of representation in the sciences. Graves (1995) has argued that “crucial aspects of the *process* of scientific inquiry (not the data) are rhetorical,” and suggested that accordingly, scholars of rhetoric should “focus on practice (how language is used) in the *process* of inquiry” (p. 107, italics original). Happe (2013) crystallizes the discursive/material binary by suggesting that discourse is “where habits of mind are reproduced, far removed from the intent or consciousness of its authors or from the material practices of the laboratory” (p. 15). As the following section demonstrates, operationalizing *techne* as persuasive knowledgeable craft more adequately recognizes how the ontological function of discourse is materialized in persuasive laboratory work.

Operationalizing *Techne* as Persuasive Knowledgeable Craft

If we adopt a sociomaterial ontology and accept that rhetoric functions as the “*advocacy of realities*” (Brummett, 1976, p. 31, italics original) and is therefore “inherently organizational” (Crabbe, 1990, p. 115), then not only can rhetoric be a *techne*, but a *techne* can also be a rhetoric—a persuasive knowledgeable craft. As Latour (1993) observes,

We do not need to attach our explanations to the two pure forms known as the Object or Subject/Society, because these are, on the contrary, partial and purified results of the central practice that is our sole concern. The explanations we seek will indeed

obtain Nature and Society, but only as a final outcome, not as a beginning. Nature does revolve, but not around the Subject/Society. It revolves around the collective that produces things and people. The Subject does revolve, but not around Nature. It revolves around the collective out of which people and things are generated. (p. 79)

Techne are the means through which Object and Subject/Society, to use Latour's terms, are produced. Following Introna's (2013) suggestion that "when this duality is actually abandoned, this heterogeneous entanglement need not be explained, it simply needs to be described in its actuality" (p. 330), an ethnography of techne documents the sociomaterial nature of techniques, the objects they produce, and the organizational forms that accompany knowledgeable production. Scholars working in the sociomaterialist tradition have been critiqued for offering an ambiguous definition of what it means for discourse and materiality to be "constitutively entangled" (Mutch, 2013). An ethnography of techne helps to address this critique by focusing attention on *how* meaning comes to matter through persuasive knowledgeable craft. This approach enables scholars of the communicative organizing of work to demonstrate how rhetoric constitutes practices such as scientific techniques, and how differences in these practices, in turn, constitute conflicts in organizational systems. For example, rather than dividing discourse from materiality as Bacon did, or separating persuasion from truth-seeking as Plato and Aristotle did, we might draw on Isocrates' logon techne to draw productive connections between the crafting of language, the crafting of subjectivity, the crafting of social and political order, and the crafting of ethical relationships.

Defining techne as persuasive knowledgeable craft also enables us to draw attention to the comparative ethics of specific ways of making—for instance, by contrasting Aristotle's

relatively formulaic approach to Isocrates' adaptation to audience and context. We might recognize a *techne* that involves reasoning of means but not the reasoning of ends as Aristotelian, a *techne* that involves the tangible apprehension of metaphor as sophistic, or a *techne* that focuses on the unity of wholes rather than the accumulation of parts as Isocratean. In relation to genetic engineering, we might consider whether the practitioners of persuasive knowledgeable craft know how "to divide into species according to natural articulations, avoiding the attempt to shatter the unity of a natural part, as a clumsy butcher might do" (1956, p. 55) as Plato recommended. Plato's view of persuasive speech sets a similarly high standard, suggesting that "every discourse, like a living creature, should be so put together that it has its own body and lacks neither head nor feet, middle nor extremities, all composed in such a way that they suit both each other and the whole" (1956, p. 53).

Carving relationalities. These examples raise the issue of how to carry out an ethnography of *technai* that engineer living beings by re-engineering their DNA. Theories of communication are only beginning to address the vital labor of non-human organisms such as those that "participate" in the work of genetic engineering. As Broadfoot and Munshi (2015) note, scholars need to address the question, "How can we represent all agents without relegating one or more of them to the position of patient or object?" (p. 5). Similarly, Cooren, Brummans and Charrieras (2008) have argued,

the challenge for organization scholars is to remain on the *terra firma* of social interactions and practices, and to show how social collectivities such as organizations act without reducing them to what *people* do . . . In this view, an organization is a hybrid, protean and polymorphous entity composed of human and nonhuman agents

(documents, computers, spokespersons, employees) that *do things in the organization's name or on its behalf* . . . Hence, agency is considered to reside ‘neither in subjects nor objects, but in a joint mediation between the built-in properties of objects and the intentions and purpose of human subjects’ (p. 1342, italics original).

In relation to the technai of genetic engineering, the challenge is how to remain open to the agency of life forms that do not “speak” in human language, and that furthermore are practically invisible to the unaided human eye. Latour provides one instructive example in *The Pasteurization of France* (1988), his account of Louis Pasteur’s successful enlisting of microbes as a kind of ally in his work—for example, by learning the kinds of media in which they preferred to multiply, so that the overall population eventually became large enough to be observed by the human eye and then experimented upon. In other words, it was only by understanding the agency of the bacterium that carries anthrax that Pasteur was able to bring that bacterium under his control. Callon’s (1999) study of St. Brieuc Bay draws attention to the fact that human attempts to forge interspecies alliances can also fail. In his analysis, scallops became “dissidents” by refusing to comply with the plans of their human “collaborators” (1999, p. 79).

Like these non-human entities, the genetically modified organisms that I encountered in my fieldwork sometimes pursued their own agendas. The laboratories that comprise my primary research sites are therefore vital material examples of how organizing is “fueled by [the] push and pull of imbuing agency and taking it away” (Brummans, 2015, p. 2). Because the scholarly lens of actor network theory (ANT) illustrates how social life “is enacted

through the interactions between various agents (see Latour 2002) – an agent being anything that, or anyone who, ‘makes a difference’ (Cooren 2006: 82) in the ongoing stream of experience” (Brummans, Cooren & Chaput, 2009, p. 54), conceptualizing my field site as a heterogeneous actor network (Latour, 1983) enabled me to acknowledge the agency of both human and non-human research participants.

In carrying out this research, I tried to avoid making assumptions in advance about who the most relevant actors in the study would be, instead remaining open and curious about the potential influence that non-human actors might exert. Following the example of Latour and Callon, I entered into my fieldwork with heightened attention to the interactions of human and other species, paying close attention to evolving power differentials as well as the ways in which “storytellers attribute causes, date events, endow entities with qualities, [and] classify actors” (Latour, 1988, p. 10). But in addition to thinking of my human research collaborators as storytellers, over time I began to conceptualize them as practitioners of *techne* to investigate the ontological function of their persuasive work.

Documenting how the agency of non-human organisms was defined by various *technai* involved investigating not only how people attempted to enlist non-human organisms as allies in their laboratory work, but also how people defined the reality of what the organisms were and how the organisms responded to various relational techniques. By tracing these negotiations, my research illustrates the role of communication in processes of organizing, a feature that many ANT analyses have overlooked (Brummans et al., 2009, p. 55).

For instance, Bateson (1987) notes that the terms we use to describe objects or behaviors “are really not strictly applicable to the individual;” instead, they “describe *transactions* between the individual and his material and human environment. No man is ‘resourceful’ or ‘dependent’ or ‘fatalistic’ in a vacuum. His characteristic, whatever it be, is not his but is rather a characteristic of what goes on between him and something (or somebody) else” (p. 303, italics original). Similarly, my research demonstrates that non-human laboratory organisms are “compliant” or “productive” or “difficult” only in relation to the interactions they have with humans. Bateson refers to this process of definition as “punctuation,” which he describes as the cultivation of particular ways of relating to “the infinitely complex stream of events (including [our] own behavior) so that this stream appears to be made up of one type of short sequences rather than an-other [*sic*]” (p. 170). Different persuasive crafts of genetic manipulation materialize punctuate “short sequences” of DNA quite differently, and in so doing, they punctuate different relationships between humans and non-human species.

Indeed, in the context of genetic engineering, punctuating is akin to cutting and pasting. Drawing on Derrida’s (1992) use of cutting as a metaphor to describe how one phenomenon can interrupt the flow of others, Strathern (1996) argues that although Latour suggests that networks can extend indefinitely, they can also be “cut” by external forces—for instance, the patenting of an invention can make it difficult for a previous collaboration to continue. Similarly, Barad (2007, p. 140) uses the term agential cuts to describe the ontological distinctions that divide subjects from objects, and Brummans and colleagues (2009) argue that “what and how an organisation *is* is a matter of ‘cutting’ the chain of

agencies in a particular way, which has very particular consequences for the constitution of the world” (p. 63, italics original). In my research, this statement is as true of organisms as organizations—and moreover, the cutting of the former structures how the latter is cut. In documenting how various technai approached the cutting and pasting of DNA sequences, I documented the carving of relational ontologies that shaped not only organisms, but organizations. Rather than approaching human and nonhuman actors symmetrically, as ANT analyses tend to do (Pickering, 1995, p. 12), focusing on techne enabled me to emphasize the power differentials that accompany these negotiations.

By tracing how competing technai shape emergent forms and sites of scientific work, operationalizing techne as persuasive knowledgeable craft contributes methodologically to a growing body of scholarship that considers how discursive practices achieve the social form of an organization (Putnam & Nicotera, 2009). In addition to recognizing the interconnectedness of discourse, practice, and materiality, this approach explores communication itself as a socially shaped material phenomenon—for example, by “focusing on discourse as inscription in the material strata of sound, optical media, the built environment, and the brain” (Packer and Wiley, 2012, p. 3), and, I would add, as inscription in the material strata of DNA. As ethnographer Philip Vannini (2009) notes,

to study material culture is to study the technological underpinnings of culture, and to study technology is to study the material character of everyday life and its processes of objectification. What is central to such a view is an understanding of sociality and culture as a form of *making*, *doing*, and *acting* and an understanding of the world as a material presence apprehended by humans through pragmatic, sensuous

intentionality. In comprehending culture as deeply shaped by *techne*—that is, craft, skill, creativity—and in viewing social interaction as a process rich with material properties we do not intend to either reintroduce antiquated notions of instrumentalism or essentialism. Rather, we simply intend to remark on the importance of treating everyday life as an active form of negotiation—a form of work as it were—that engages the colors, the textures, the tastes, the fragrances, the sounds, the temperature, the kinesthetic movement, and the practical and symbolic value of the stuff that makes up life. (p. 3, italics original)

Vannini's emphasis on making, doing, and acting resonates with communication as constitutive of organizing (CCO) theory, which views organizing an ongoing accomplishment that is achieved through communication (Putnam & Nicotera, 2009). Because various actors hold divergent motivations and goals, organizational structure is "in process and in contention" (Ashcraft et al., 2009, p. 18)—in other words, it is continually being made and re-made, or perhaps more accurately in this case, engineered and re-engineered. As Leonardi and Barley (2011) argue, "a perspective that treats materiality as organizational communication opens up new avenues of research for communication scholars" (p. 104). An ethnography of *techne* draws attention to the process through which the relationships between entities become defined. Rather than investigating the "immaterial" phenomenon of human communication in relation to the "material" biological or technological world, focusing on *techne* enabled me to document how the ontological categories of human and non-human, biological and technological, discursive and material emerged at particular research sites.

Research design and data collection. My research on the technai of genetic engineering was launched in spring in 2013, when I learned of an art exhibit in Brooklyn, New York, that featured genetically modified organisms. Motivated by an interest in the political and ethical implications of approaching genetic engineering as art, as well as curiosity about the logistics and infrastructure required to accomplish this work outside of academic or corporate laboratories, I applied multi-sited ethnographic methods, including participant observation, interviews, and analysis of cultural artifacts (Hine, 2007; Marcus, 1995), to investigate the emergence of biotechnical practices in nontraditional settings.

Unlike traditional participant observation, which originated as a way of learning about small, relatively stationary societies (Gusterson, 1997, p. 115), multi-sited ethnography aims to investigate shifting circulations of objects, identities, and meanings (Marcus, 1995, 2011). As Hine (2007) observes,

science is about practices carried out between varyingly identified groups and institutions and individuals . . . we need to be agile, itinerant and attentive if we are to trace these connections. Also, too much focus on laboratory ethnographies ties us into a representation of science that may have little purchase for the policy makers and practitioners we might want to influence. (p. 661)

Multi-sited ethnographers determine their research sites by following “chains, paths, threads, conjunctions, or juxtapositions . . . with an explicit, posited logic of association or connection among sites that in fact defines the argument of the ethnography” (Marcus, 1995, p. 105).

They draw attention to the interconnections among social practices, and in so doing, construct an argument about how their research sites are related. The emergence of this

approach was in part a response to work of scholars such as Latour and Haraway, who have expanded science studies methodology beyond human-centered approaches to recognize both the agency of non-human actors and the movement of social practices across space and time (see Marcus, 1995, p. 103-4).

My logic of association was to follow the work of genetic engineering as it emerged beyond the gated settings of academic and corporate laboratories. I emphasized what Gusterson (1997) calls polymorphous engagement: “interacting with informants across a number of dispersed sites, not just in local communities, and sometimes in virtual form. . . collecting data eclectically from a disparate array of sources in many different ways” including formal interviews, informal socializing, extensive reading of documents, and attention to representations in popular culture (p. 116). This approach encourages the researcher to adapt data collection strategies as needed to gain access to dispersed, well-educated, and relatively powerful groups of individuals such as scientists and practitioners of scientific techniques who work in places “where loitering strangers with notebooks are rarely welcome, and where potential informants are too busy to chat” (Gusterson, 1997, p. 116). In total, data collection comprised approximately 400 hours of ethnographic research, including interviews, participant observation, apprenticeship, and conversation across research sites. A simplified timeline of this research is presented in Figure 2 below.

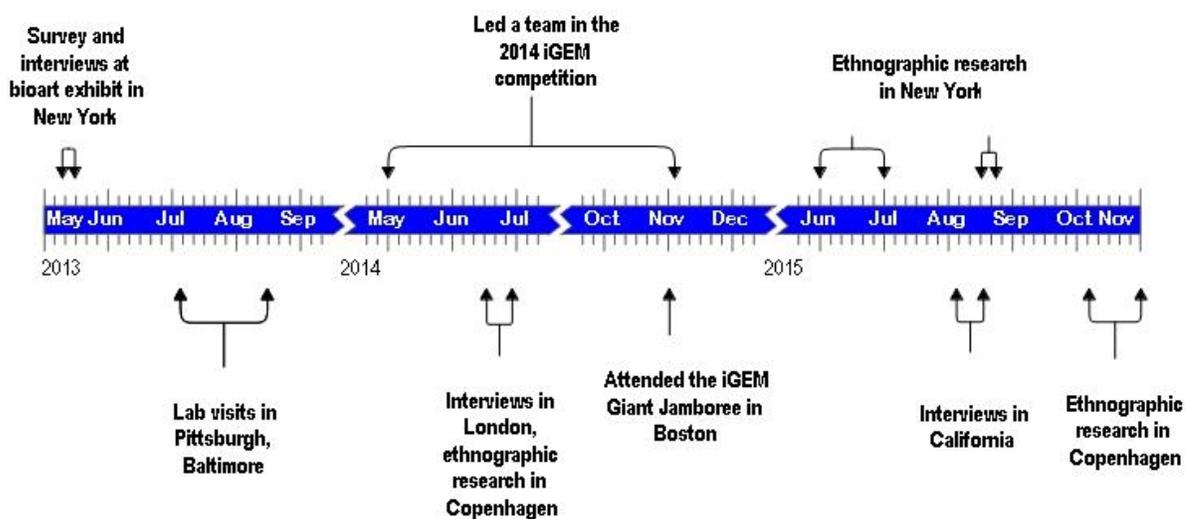


Figure 2: Research Timeline

In spring 2013, I conducted surveys and interviews with the attendees and curators associated with the previously mentioned art exhibit in Brooklyn, New York and attended bioartist talks at the community laboratory affiliated with this exhibit. These initial encounters introduced me to the DIY bio movement, which makes relatively simple genetic engineering practices accessible to individuals who are unaffiliated with academic or corporate laboratories. Early interviews also helped me to identify subsequent research sites. For example, one research collaborator mentioned that the (iGEM) competition, which is the focus of Chapter Three, inspired him to take up genetic engineering. Another mentioned having recently spoken with individuals affiliated with another community laboratory in Baltimore, as well as others interested in starting DIY laboratories in other locations. So, while visiting friends and family in summer 2013, I took a course at the Baltimore laboratory and spent time with a Pittsburgh bioartist who documents human alterations of plant and

animal species ranging from selective breeding to genetic engineering. In fall 2013, I organized a discussion at NCSU, featuring two of this artist's students, an artist and filmmaker, who were producing an online documentary that focuses on the DIY bio community. As a fellow in NCSU's Integrative Graduate Education and Research Traineeship (IGERT) program, I also took a graduate-level course in genetic engineering in fall 2013 that provided me with a deeper understanding of the science and some of its applications.

In summer and fall 2014, I served as captain of a multidisciplinary team of doctoral students who represented NCSU in the iGEM competition. Participating in iGEM was of interest for two reasons. First, as I mentioned above, a research collaborator in New York had described iGEM as a key motivator for his interest in DIY bio. Second, leading a team in the 2014 iGEM competition offered an opportunity for me to collaborate with the CEO of the Glowing Plant project, the world's first crowd-funded genetically modified organism, which originated at a Silicon Valley DIY bio lab in 2013. The plant's developers had attracted media attention after soliciting support via the crowdfunding website Kickstarter to engineer and distribute genetically modified mustard plants that would glow in the dark after being modified with the DNA of a bioluminescent jellyfish. Although their campaign generated more than ten times their original \$40,000 goal, it also resulted in significant backlash, including negative media coverage in national news outlets and calls for the federal government to halt the project. After allowing the campaign to collect all donated funds, Kickstarter quietly changed its regulations to prohibit future affiliates from distributing genetically modified organisms in exchange for their donations. Following the controversy,

BioCurious, the DIY laboratory where the plant had originated, asked the plant's developers to continue the project elsewhere, as their organizational guidelines prohibited the environmental release of genetically modified organisms. I took the iGEM project as an opportunity to interview individuals who had been affiliated with the DIY laboratory that launched the plant to ask for their perspectives on the controversy and the broader question of distributing genetically modified organisms beyond the laboratory. In addition, with the help of faculty advisors, the iGEM team worked with the Glowing Plant project's CEO to develop a concept-mapping tool that visualizes different understandings of what it means for an innovation to be responsible, ultimately winning the competition's prize for "Best Policy and Practices Advance."

As my research progressed, the iGEM project also prompted conversations with DIY bio practitioners in other locations, many of whom were preparing to participate in iGEM at the same time that I was, as the competition's rules had been changed in 2014 to welcome their participation for the first time (previously, the competition had been limited to undergraduates enrolled at colleges and universities). So, in summer 2014, as I interviewed practitioners in London's Biohackspace and collaborated with Biologigaragen, a DIY bio laboratory in Copenhagen, Denmark, to organize the 10-day Kopenlab citizen science festival, I was learning about the convergence of DIY bio and iGEM, as well as the ways in which DIY practitioners around the world were reacting to the news coverage that the Glowing Plant had generated, much of which also discussed DIY bio itself. While helping to organize the festival—a process that ranged from helping to build tables for exhibits to assisting with a strawberry DNA extraction (described in Chapter Four) to leading a

discussion on my iGEM teams' research on the Glowing Plant—I had informal conversations with DIY bio practitioners from Denmark, Switzerland, Finland, and Singapore. With the permission of research collaborators, I also began taking photographs of some of the spaces in which our work was taking place, a practice that I continued throughout my research in DIY laboratories. (To protect the anonymity of my research collaborators, very few photos included people's faces or other identifying information, and no personally identifiable images are featured in the following pages.) The ethnographic research that I conducted at the Kopenlab festival also introduced me to the ways in which DIY practitioners collaborate with academic and corporate laboratories, prompting me to adjust the scope of my research to account for how DIY bio intersected with these other scientific actor networks.

In October and early November 2014, while attending the five-day “iGEM Giant Jamboree” in Boston, Massachusetts, I took ethnographic field notes, observed several teams' project presentations, and interviewed participants about their experiences. The next stage of data collection focused on the websites of every annual iGEM gathering that had taken place since the competition was launched in 2004. To trace how the work of genetic engineering was conceptualized at iGEM over time, I focused on content that a) discussed this work, b) described the competition itself, or c) provided guidance for teams, either by issuing formal rules and requirements or highlighting examples for teams to emulate. Using Evernote data collection software, I also worked with a research assistant to catalog text and images from d) the websites of all teams that were awarded the Best Human Practices Advance prize (which was re-named Best Policy and Practices Advance in 2014), beginning

in 2008 when the prize was first awarded, and e) the websites of teams that were recognized as best in the overall competition. A total of 186 web pages were saved into PDF format and incorporated into NVivo qualitative data analysis software, where they were coded using the constant comparative method (Charmaz, 2014; Corbin & Strauss, 2008; Glaser, 1978).

In fall 2014, after the iGEM competition concluded, I attended a workshop on research agendas in the societal aspects of synthetic biology at Arizona State University. The executive director of the Brooklyn community lab also attended this event, and mentioned in a group discussion that she was experiencing a kind of social science fatigue—in other words, she felt that a significant number of researchers were getting a lot more out of their visits to the lab than the lab was getting in return. She suggested that a more reciprocal arrangement might involve hosting someone who would help her develop metrics to evaluate the benefits her lab provides. I took her up on the offer, and with support from a US National Science Foundation dissertation research grant, I spent about five weeks at this lab in summer 2015. I also visited the San Francisco Bay area and Silicon Valley for 12 days in August 2015 in order to talk in person with individuals who have been involved with the Glowing Plant project and the iGEM competition.

In October 2015, I completed the final phase of my fieldwork by returning to Copenhagen to conduct ethnographic research the DIY bio laboratory there. This allowed me to revisit several individuals who participated in my summer 2014 research, while also assisting and spending time with individuals who had become affiliated with the laboratory in the intervening time. In addition, I interviewed academic and corporate affiliates of this lab, as well as people associated with formal governing bodies such as the Danish Board of

Technology and more informal governing bodies such as the university laboratories that help define institutional norms of practice. Research participants at this site included PhD-holding scientists working in academic, corporate, and DIY laboratories; artists and designers; scholars of governance; entrepreneurs; engineers; and individuals who were new to the space and to the practice of DIY bio. Some of our conversations continued via Skype and email into late 2015 early 2016.

Data analysis. In keeping with grounded theory methodology (Charmaz, 2014; Corbin & Strauss, 2008; Glaser, 1978), I initiated this research with a series of “sensitizing concepts” (Blumer, 1969) in mind. Sensitizing concepts serve as points of departure for analysis, offering tentative ways of developing ideas without locking researchers into a particular way of thinking or knowing (Charmaz, 2014, p. 30). *Techne* was among the sensitizing concepts that I brought with me into this research, but it achieved prominence in the study only over time, and my definition of *techne* as persuasive knowledgeable craft emerged through the process of gathering and analyzing data. So, although this chapter reviewed the relevant literature prior to discussing my results for clarity of presentation, in actuality I identified and developed this analytical framework as the research progressed.

In accordance with the constant comparative method (Charmaz, 2014; Corbin & Strauss, 2008; Glaser, 1978), successive memos were written throughout the research process to identify provisional lines of analysis and refine methodological strategies. Because the research occurred over an extended period of time at multiple sites, I was able to return to key collaborators to discuss and refine emerging theoretical ideas (see Charmaz, 2014, p. 108). The evolution of the *techne* of genetic engineering was already on the minds of many

of my participant collaborators, in part because of the increasing popularization of synthetic biology that I discussed in Chapter One and revisit in Chapter Three. Thus, as I conducted interviews, assisted with laboratory work, and participated in classes, workshops, and other activities at DIY laboratories, research participants reflected on the strengths and weaknesses of using various metaphors to describe biological processes as they explained their work to me and other novice practitioners, often with little or no prompting. Further, because several DIY laboratories in both the United States and Europe were competing in iGEM while I was visiting them or had competed the competition in recent years, my ethnographic research in these laboratories afforded frequent opportunities to investigate their perspectives on the competition, and to compare the everyday work of DIY bio with the ways in which iGEM teams described their efforts online and in the interviews that I had conducted there.

Interviews and ethnographic field notes were transcribed by the author and a professional transcription service, and all data was coded iteratively by the author. As described in Chapter One, I applied a grounded theory strategy to narrow the focus of the study over time, moving back and forth between data gathering, memo writing, and coding in an iterative manner to narrow the scope of analysis and achieve theoretical saturation (Charmaz, 2014). In the later stages of analysis, I created a series of diagrams to identify the relationships between analytical categories, integrate related categories, and map out the following arguments (Charmaz, 2014; Glaser, 1978; Glaser, 1978).

CHAPTER 3 : Communication Models in Bioengineering: Cybernetics and the Techne of Genetically Engineered “Machines”

In defining techne as persuasive knowledgeable craft, the previous chapter highlighted how techniques constitute relationships—for example, the relationship between nature and culture, between one organism and another, between individuals and organizations. Technai are persuasive in that they define what something is and how humans should relate to it. In crafting relational ontologies through symbolic action, technai craft social organization. Thus, the theoretical framework of techne suggests questions such as, what forms of reasoning underlie a particular technique? What types of relationships does it organize, and what purposes does it serve?

To consider these questions in relation to the technai of the life sciences, this chapter begins by discussing the origins and evolution of a techne of genetic information, explaining how Claude Shannon’s transmission model of communication came to be materialized in some strains of biological work during the late 1940s and 1950s. This techne of transmission, which laid part of the groundwork for cybernetics and ultimately for contemporary synthetic biology, approaches DNA as a carrier for standardized messages that can function in the same manner regardless of context. Over time, cybernetics evolved to place significantly more emphasis on interaction and relationality, developing a reflexive stance that emphasized the observer’s role in constructing human-machine systems. Similarly, genetics evolved to acknowledge the many ways in which the manifestation of “biological meaning”—a term that Keller (2000, p. 8) uses to emphasize the ways in which genetic material varies in its interaction with specific material environments—is a far more complex process than mere

transmission (also see Kay, 2000, p. 14-37). I argue that this reflexive understanding of biological meaning is materialized in an alternate, more artisanal craft of biological work. An artisanal *techne*, as I define it, is a persuasive craft that is not standardized or mechanized, but responsive to the interactions of biological material with specific contexts—in other words, a persuasive craft that embodies a multidirectional model of communication.

Building on these concepts, the second half of the chapter examines how the *techne* of transmission organizes the iGEM competition. iGEM describes itself as the world's premier competition for synthetic biology, an emerging field that aims to simplify the process of genetic engineering in order to make this process more efficient. I demonstrate how the *techne* of synthetic biology as practiced at iGEM enacts a cybernetic transmission model of communication, which structures iGEM as a cybernetic organization (Morgan, 2006). The collective work of the competition enables genetic engineering to be reorganized as distributed manufacturing. Participating teams produce standardized sequences of DNA called BioBricks that can be detached from their original context and commodified like LEGO parts for the production of novel life forms (Carlson, 2010; Calvert, 2012; Latour, 1987; Maddalena, 2014).

By manufacturing BioBricks, iGEM teams contribute to synthetic biology's goal of making biology easier to engineer, enabling the competition to serve as proof of concept for a highly lucrative effort to standardize genetic engineering in the manner of other engineering fields. Yet iGEM's *techne* of simplification and standardization simultaneously constrains the competition's ability to function as a cybernetic learning organization by discouraging reflexivity—a core principle of second-order cybernetics. On one hand, ontologizing

organisms as machines focuses teams' labors on the fabrication of DNA sequences that will function the same way in practically any organism, much as a standardized screw functions the same way in practically any machine. On the other hand, by enacting this simplified ontology, the techne of synthetic biology discourages participants from engaging with biological complexity: conceptualizing biological material as mechanical denies its ability to adapt and vary in relation to different contexts. This simplified ontology serves as what scholars of cybernetic organization call an "inhibiting loop" (Argyris, 1977) that impedes teams' ability to draw on past mistakes to refine future action. By positioning the engineering of biology as an end in itself, the competition de-incentivizes deliberation about the appropriate applications of synthetic biology and the social and ethical aspects of biotechnical work. In this formulation, living organisms and the processes that keep them alive are enframed as what Heidegger (1977) called "standing reserve": material defined, in both its "whole structure *and in every one of its constituent parts,*" by the utility it provides for humans (p. 17, italics added).

Put more simply, rather than training them to understand how biology functions, the techne of iGEM trains students to simplify biology in order to make genetic engineering faster and more efficient. In so doing, this techne of standardization enacts a particular kind of ethic—what Katz (1992), drawing on Habermas (1970) and others, has called the ethic of expediency. The competition organizes the work of synthetic biology as what Habermas (1970, 1984) calls "purposive-rational action": a form of rationality in which technical calculation replaces social values as the basis for action and decision-making. In systems of purposive-rational action, validity is determined not by "the intersubjectivity of the mutual

understanding of intentions” or “the general recognition of obligations,” but by what is seen to be empirically true or analytically correct (Habermas, 1970, p. 92). Action and choice therefore aim not toward “the realization of practical goals but toward the solution of technical problems” (Habermas, 1970, p. 103). Discussions of safety and risk, along with the discussions of what are now called “Policy and Practices” issues, created possibilities for discursive opening (Thackaberry, 2004)—the opportunity to approach norms and habits from new perspectives, which can facilitate learning how to learn (Bateson, 1987). Yet these opportunities are largely precluded by the *techne* of transmission, simplification, and control.

Meaning vs. Information: Communication Models in Bioscientific Work

To understand how a cybernetic model of communication organizes symbolic-material work at iGEM, it helps to understand how the cybernetic model of communication began to organize some strains of biological research. To aid the Allied effort in World War II, Norbert Wiener, known as the father of cybernetics, drew on the Greek term *kubernetes*, meaning steersman, to envision cybernetics as a kind of *techne*: in his words, an effort “to develop *a language and techniques* that will enable us indeed to attack the problem of control and communication in general, but also to find the proper repertory of ideas and techniques to classify their particular manifestations under certain concepts” (1954, p. 16, italics added). As the effort progressed in the years following the war, Claude Shannon’s transmission model of communication provided a theory of information to unite the highly interdisciplinary field of cybernetics:

Shannon needed to provide a precise definition of information that transformed it into a physical parameter capable of quantification. He accomplished this transformation

by distinguishing information from meaning. He reserved “meaning” for the content actually included in a particular message. He used “information” to refer to the number of different possible messages that could be carried along a channel, depending on the message’s length and on the number of choices of symbols for transmission at each point in the message. (Aspray, 1985, p. 119-120)

Whereas meaning is dependent upon the embodied experience and material and linguistic (i.e., semantic and syntactic) context of the person interpreting a message, information as defined by Shannon retains a standard value as it moves from one context to another (Shannon, 1948; Shannon & Weaver, 1949). As Shannon himself (1948) acknowledged, “Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities” (p. 379). However, for his purposes, the “semantic aspects of communication [were] irrelevant to the engineering problem” (Shannon, 1948, p. 379). Rather than minimizing the influence that information can wield on social systems, in this statement, Shannon is recognizing that “a computational understanding of digits can never speak to such matters” (Peters, 2016, p. 100)—in other words, to matters of contextual and material meaning. By abstracting and standardizing meaning to transform it into information, Shannon helped to position information theory as a meta-discipline to coordinate academic work from mathematics and the natural sciences to the social sciences (Bowker, 1993). The notion of information as discrete, quantifiable bits that could be transported immaterially from one location to another brought together researchers working on sociotechnical systems as diverse as the “telegraph, telephone, radio, television, and computing machines—in fact, to any system, physical or biological, in which

information is being transferred or manipulated through time or space” (Aspray, 1985, p. 122). Because cybernetic information remained the same regardless of context, it could (at least in theory) be neatly exported from engineering to biology to other fields and back again, with machines and living organisms serving as heuristics for one another.

Thanks to Shannon’s model of communication, in the cybernetic tradition, both living and nonliving entities are ontologized as disembodied systems of information—what Hayles (1999) calls “a pattern, not a presence”—in other words, “a probability function with no dimensions, no materiality, and no necessary connection with meaning” (p. 18). For example, one cybernetician, Gordon Pask, anticipated the contemporary field of synthetic biology by envisioning what he called an “animal computer, which could be valuable for slow speed, essentially parallel data processing” and began to experiment with positioning single-celled organisms “as basic computing elements which are automatically reproducing and available in quantity” (Bowker, 1993, p. 120). Similarly, in a 1943 publication called “A Logical Calculus Immanent in Nervous Activity,” cyberneticians Warren McCulloch and Walter Pitts had applied a transmission model of communication to the activity of neurons in the brain. In this publication, they suggested that “Because of the ‘all-or-none’ character of nervous activity, neural events and the relations among them can be treated by means of propositional logic” (McCulloch & Pitts, 1943/1990, p. 99). The “all-or-none” character to which they referred was a digital character—an ontology of neurons as a series of discrete, quantifiable bits that could be modeled using simple binary propositions such as yes or no, true or false (Gefter, 2015; Maddalena, 2014). The result was “a mechanistic model of the mind, the first

application of computation to the brain, and the first argument that the brain, at bottom, is an information processor” (Gefter, 2015).

Yet despite their triumph in “extrapolat[ing] from amorphous pink tissue on the laboratory table to the clean abstractions of the model” (Hayles, 1999, p. 57), McCulloch and Pitts found that “their work had barely made a ripple among brain scientists—in part because the symbolic logic they’d employed was hard to decipher, but also because their stark and oversimplified model didn’t capture the full messiness of the biological brain” (Gefter, 2015), which involved infinitely more interaction and complexity than the transmission model of communication allowed. By the late 1950s, McCulloch and Pitts had participated in a series of experiments that disproved their own model. Together with Jerry Lettvin and Humberto Maturana, they demonstrated that a frog’s brain could not, in fact, be characterized as having a purely “all-or-none” character: “Instead of the brain computing information digital neuron by digital neuron using the exacting implement of mathematical logic, messy, analog processes in the eye were doing at least part of the interpretive work” (Gefter, 2015).

Cyberneticians acknowledged the material differences between biological and mechanical systems, suggesting that “We all know that we ought to study the organism, and not the computer, if we wish to understand the organism. Differences in levels of organization maybe [*sic*] more than quantitative” (von Foerster, Mead & Teuber, 1952, cited in Hayles, 1999, p. 64). Yet analogizing the two was nevertheless a useful learning aid; in their words, “the computing robot provides us with analogs that are helpful as far as they seem to hold, and no less helpful whenever they break down” (von Foerster, Mead & Teuber,

1952, cited in Hayles, 1999, p. 64). Thus, the organism/machine analogy shapes the trajectory of biological inquiry by determining what types of research questions to pursue:

Even when the experiment fails, the basic terms of the comparison operate to constitute the signifying difference. If I say a chicken is not like a tractor, I have characterized the chicken in terms of the tractor, no less than when I assert that the two are alike . . . Although some characteristics of the analogy may be explicitly denied, the basic linkages it embodies cannot be denied, for they are intrinsic to being able to think the model. (Hayles, 1999, p. 64)

To Wiener, the differences between organisms and machines were irksome. He had abandoned the pursuit of a doctorate in biology earlier in his career out of frustration with the painstaking exactitude of laboratory protocols. In his view, the problem with biology experiments was that they progressed more slowly and less consistently than the rapidly evolving abstractions he envisioned. As he put it:

This impatience was largely the result of my mental quickness and physical slowness. I could see the end to be accomplished long before I could labor through the manipulative stages that were to bring me there. When scientific work consists in meticulously careful and precise manipulation which is always to be accompanied by a neat record of progress, both written and graphical, impatience is a real handicap. How much of a handicap this syndrome of clumsiness was I could not know until I had tried. I had moved into biology, not because it corresponded with what I could do, but because it corresponded with what I wanted to do. It was inevitable that those

about me discouraged me from further work in zoology and all other sciences of experiment and observation. (as cited in Rosenblith & Wiesner, 1965, p. 4)

In this passage, Wiener references the artisanal nature of work in biology laboratories, where impatience is a “handicap” because the techniques are slow and meticulous and require great dexterity. The tiniest wrong movement, or the right movement at the wrong point in time, can spoil weeks of preparation, producing the feeling of clumsiness that Wiener described. For him, focusing on abstract information rather than contextual meaning was a way to pull away from this messy and unpredictable work, much as Plato took the clean mathematics of geometry as his model of the natural world (Toulmin & Goodfield, 1982, p. 74). As an alternative, Wiener proposed that in cybernetics, “To describe an organism, we do not try to specify each molecule in it, and catalogue it bit by bit, but rather to answer certain questions about it which reveal the pattern” (Wiener, 1954, p. 95).

The digitization of DNA. For scholars in the biological sciences and many other fields, the appeal of cybernetic abstraction was not only academic, but also financial. “Anyone tapping into the network of words used by cybernetics would be tapping into the network of problems that cyberneticians were aiming to solve” (Bowker, 1993, p. 117): primarily, the problem of controlling systems of humans and machines in the face of a wartime enemy that was seen as mechanized, calculating, and ruthless (Galison, 1994). Because cybernetics research was considered “the cutting edge of military and industrial research,” adopting a cybernetic ontology and terminology was a reasonable strategy to earn increasingly available government research grants while also doing a good turn for one’s country (Bowker, 1993, p. 117).

For geneticists, cybernetics was particularly appealing because the notion of information as a quantifiable variable provided a way of simplifying complexity. Specifically, information theory advanced what historian Evelyn Fox Keller (1995) has called the “theory of gene action”—an earlier conceptualization of the gene as a discrete, quantifiable entity that carried biological “messages” much as Shannon’s discrete, quantifiable units of information were envisioned to carry messages across communication systems.

Before they began to ontologize genetic material as information, biologists had generally thought about heredity as a combination of the transfer of lineage from parent to offspring and the longer-term process through which an embryo grows over time (Keller, 1995, p. 4). Essentially, this perspective suggests that the development of organisms is a combination of *both* nature and nurture. For example, individuals with the same genetic material can grow to exhibit significantly different characteristics depending on their environments. Foreshadowing contemporary epigenetics, this older research paradigm materialized a multidirectional model of communication by highlighting how biological meaning required the interaction of materials and contexts. It simultaneously defined laboratory work as an artisanal *techne* that acknowledged the give and take of biological and ecological relationality. To work with biology, from this perspective, is to apply a craft that adapts to this give and take, much as a gardener cares differently for the same plant in a hot, dry summer versus a rainy season.

By contrast, the theory of gene action materializes a mechanical *techne*, approaching genetic material as information that remains standardized across a variety of contexts. This

transmission model of genetic information essentially “exists outside of time and space,” positioning material contexts as “but a way station for the timeless bit of immanence that resides in an organism’s genes” (Doyle, 1997, p. 60). American geneticists had become increasingly attracted to this model in the 1930s, in part because it helped them carve a niche for themselves amidst the older fields of embryology and physiology, and in part because it simplified the complexity of biological work (Keller, 1995). In the late 1940s, they began use the atom as a model on which to base the gene, encouraged by the popular book *What is Life?* by physicist and Nobel laureate Erwin Schrödinger. In the book, Schrödinger discusses genes in atomic terms, describing genetics as the study of the organism as a “four dimensional pattern” that he defined as “not only the structure and functioning of the organism in the adult, or in any other particular stage, but the whole of its ontogenetic development” (1945, p. 19-20). “Pattern” in this account “refers to the ongoing growth and development of an organism, a thick description of the birth, growth and life of an organism, a cradle-to-grave biography” (Doyle, 1997, p. 27). Moreover, for Schrödinger, the pattern of an organism was located inside the “coded and scripted chromosome” (Doyle, 1997, p. 28). Although Schrödinger took care to qualify his proposals as those of a mere amateur rather than a professional biologist, his simplification of biological complexity helped to launch the field of molecular biology by “appeal[ing] to a wide variety of readers, convincing each group that a move in the direction of ‘the physical study of the living cell’ would be in their best interest” (Ceccarelli, 2001, p. 108).

One of the physicists that Schrödinger inspired to go into biology was Francis Crick, who would go on to share a Nobel prize with his collaborator James Watson. A month after

publishing their landmark article identifying the double helical structure of DNA in April 1953, Crick and Watson published a second article in May 1953 called “Genetical Implications of the Structure of Deoxyribonucleic Acid,” which reformulated Schrödinger’s pattern into cybernetic code (see Doyle, 1997, p. 35). In this second publication, they applied Shannon’s transmission model to DNA, suggesting, “in a long molecule many different permutations are possible, and it therefore seems likely that the precise sequence of the bases is the code which carries the genetical information” (Watson & Crick, 1953, p. 965). Thus, coupled with Shannon’s subsequent theory of information, Schrödinger’s discussion of genes as atoms solidified a model of organisms as compilations of discrete, quantifiable parts. Rather than investigating how a fertilized egg could develop into a complex differentiated organism, geneticists narrowed their focus to study how genes produced their effects (Keller, 1995, p. 14). In doing so, they attributed “agency, autonomy, and causal responsibility” primarily to genes rather than a combination of developmental factors (Keller, 1995, p. 14). Table 1 below presents a simplified comparison of the transmission model of genetic information and its older, more artisanal predecessor.

Table 1: Comparing Technai of Biological Work

Artisanal Techné	Techné of genetic information
Biological meaning = variable, contextual	Genes = standardized units
Communication = multidirectional	Communication = one-way transmission
Biological work = adaptable, responsive	Biological work = mechanical

T.H. Morgan, a prominent geneticist, had acknowledged as early as 1934 that assuming genes transmitted messages unidirectionally had disadvantages. As he put it, “The implication in most genetic interpretation is that all the genes are acting all the time in the

same way. This would leave unexplained why some cells of the embryo develop in one way, some in another, if the genes are the only agents in the results” (Keller, 1995, p. 14). In 1937, the president of the American Association of the Advancement of Science, Ross Harrison, similarly warned that “The prestige of success enjoyed by the gene theory might easily become a hindrance to the understanding of development by directing our attention solely to the genome” (Keller, 1995, p. 15).

The cybernetic vision of information bolstered a transmission model of genetic communication despite these warnings. For instance, after reading Wiener’s *Cybernetics*, the biologist John Haldane reported in 1948 that he was “gradually learning to think in terms of messages and noise” and suggested that “A mutation seems to be a bit of noise which gets incorporated into a message” (Kay, 2000, p. 87). In 1950, Haldane’s colleague Hans Kalmus published an article in the *Journal of Heredity* called “A Cybernetic Aspect of Genetics” in which he argued that “A gene, we might say, is a message, which can survive the death of the individual and can thus be received repeatedly by several organisms of different generations” (p. 19). Wiener actively cultivated this cross-pollination of cybernetics and genetics in both the highly technical *Cybernetics* and *The Human Use of Human Beings*, a book he published in 1950 for popular audiences. In the latter work, he discusses genetics as information transfer and devotes an entire chapter to comparing organisms to messages, proposing that an “[o]rganism is opposed to chaos, to disintegration, to death, as message is to noise” (Wiener, 1954, p. 95). Over time, what began as a heuristic metaphor became solidified as factual ontology: thanks in large part to cybernetics, “biological specificity became informational,

and information, message, and code eventually became biological concepts” (Kay, 2000, p. 22).

Transmission as techne. Although these statements were made decades before the current field of synthetic biology emerged, they prefigured the persuasive techniques that iGEM participants would apply in genetic manipulation. The competition ontologizes DNA sequences as standardized LEGO-like bricks, much like the digital ones and zeroes that computer scientists rearrange in coding software (Maddalena, 2014). The techne of iGEM enacts a cybernetic transmission model of communication by approaching DNA as a form of information that will retain the same meaning regardless of context. The transmission model of communication, with its associations of “transfer, exchange, and action at a distance” suggests a model of society in which “conceptions of language seem . . . intent on controlling the environment and mankind and for transmitting facts rather than generating insight” (Deetz, 1973, p. 51). Similarly, the transmission model of gene action suggests that content is conveyed with as little corruption from the “medium” of biology as possible. The media of cells and bodies, like the medium of language, are assumed to be problematic “noise.”

As contemporary biologists will readily emphasize, what’s missing in these accounts are the bodies and environments that contribute to the manifestation of biological meaning. Transmission models position DNA as a kind of language, but a peculiar language in which letters, words, and sentences always mean the same thing. While it has facilitated groundbreaking advancements in both research and applied medicine, the notion of genetic transmission also had drawbacks (Boudry & Pigliucci, 2013; Doyle, 1997; Kay, 2000; Keller, 1995, 2000; Nicholson, 2013). The problem with equating biological systems and mechanical

ones is that doing so requires one “to erase from view the very real differences in embodied materiality” (Hayles, 1999, p. 99)—such as the propensity of DNA sequences, cells, and entire organisms to adapt and vary in relation to particular contexts (Boudry & Pigliucci, 2013; Nicholson, 2013). As Keller (2000) notes, “genetic stability is not absolute, and fortunately not. If genes were truly immortal, and if their replication proceeded with perfect fidelity, the evolution of new genetic structures would never have been possible” (p. 31-2).

Through the 1950s and 1960s, some strands of research in genetics continued to draw attention to the flaws associated with conceptualizing genetic communication as one-way transmission rather than acknowledging the multidirectional interactions of biological materials and systems (Keller, 2000, p. 27). In 1960, Rollin Hotchkiss of the Rockefeller Institute described the contrast between these approaches in precisely these terms, arguing that:

We are turning away from the DNA of a decade just over, a relatively unchanging, stable reservoir of linear information. It has had its convincing tellings and smugly one-dimensional retellings and become ‘well known’ (which is to say, often mentioned). But it has become necessary to face the fact that DNA grows, issues directives, opens up, closes, twists, and untwists. *We are coming to realize how marvelously communicative it is*, and that it is not aloof, metabolically inert material, but instead one maintained and exquisitely balanced in an actively supported status quo. (as cited in Keller, 2000, p. 27-28, italics added)

In describing DNA as communicative, Hotchkiss references the interrelationship of ontology, epistemology, and technique. What is knowable about DNA depends in part on

determining what DNA is in the first place, and understanding what DNA is depends in part on the techniques of knowledge production that we apply. Seeing biological meaning as multidirectional requires one to accept the argument that this material varies in relation to context. Similarly, seeing biological meaning as standardized requires one to accept the argument that bodies are accumulations of standardized units called genes. Adopting one stance or the other is the result of a rhetorical process—a process of persuasion that is materialized in two different techniques. As the following section illustrates, each *techne* also materializes a form of rationality, a logic of means and ends that influences what it is possible to learn.

A *techne* of adaptive learning. Learning, from a cybernetic perspective, is applying feedback to modify future behavior based on past mistakes. Feedback, as Wiener defined it, is:

a method of controlling a system by reinserting into it the results of its past performance. If these results are merely used as numerical data for the criticism of the system and its regulation, we have the simple feedback of control engineers. If, however, the information which proceeds backward from the performance is able to change the general method and pattern of performance, we have a process which may well be called learning. (1954, p. 61)

Although it depends on Shannon's reduction of meaning to information, the cybernetic notion of feedback focuses more on complexity than simplification, emphasizing the need not only for messages to be sent out unidirectionally, but also for messages to be received and contemplated in pursuit of greater control over human-machine systems. For example,

Wiener argued that “administrative officials. . . should take part in a two-way stream of communication, and not merely in one descending from the top. Otherwise, the top officials may find that they have based their policy on a complete misconception of the facts that their underlings possess” (1954, p. 49). This is a functionalist argument: in stressing that managers should listen to their employees, Wiener is suggesting not that they should go so far as revising organizational goals in response to employee feedback, but that organizational goals are more likely to be achieved expediently when managers’ remain attuned to the messages that employees are sending. This orientation reflects the wartime context in which cybernetics originated.

Nevertheless, early cyberneticians did reflexively acknowledge the observer’s role in constructing human-machine systems (Heylighen & Joslyn, 2001, p. 157). For example, taking issue with a colleague who claimed to have an objective view of human-machine systems, one participant, Frank Fremont-Smith, argued that “You cannot possibly, Dr. Stroud, eliminate the human being”; in other words, “You are studying and changing his relation to the machines by virtue of the fact that you are studying him” (as cited in Hayles, 2009, p. 68).

Other cyberneticians including Margaret Mead and Gregory Bateson went on to develop the concept of reflexivity more fully. In addition to acknowledging the observer’s role in human-machine systems, they developed Wiener’s notion of learning into a *techne* capable not only of adapting various means to serve a predetermined end, but of rethinking the end itself. They began by highlighting the ethical and practical consequences of the unreflexive pursuit of control. For example, Bateson challenged the functionalist assumptions

of first-order cybernetics in a series of questions that drew attention to the relational nature of cybernetic techne, and the ways in which these persuasive techniques served simultaneously as means and as ends in themselves:

Are we to reserve the techniques and the right to manipulate people as the privilege of a few planning, goal-oriented, and power-hungry individuals, to whom the instrumentality of science makes a natural appeal? Now that we have the techniques, are we, in cold blood, going to treat people as things? Or what are we going to do with these techniques? (Bateson, 1972/1987, p. 169)

Bateson's alternative to the unreflexive application of techne emphasized the importance of what he called deuterio-learning, or learning to learn. He argued that when we learn, we acquire not only content but also habits of mind that shape our ways of relating to one another and to the world around us. In his typology of learning, the most basic level, zero-learning, involved "the receipt of a signal" (1987, p. 253) that was "not subject to correction by trial-and-error" (1987, p. 291). Zero learning is followed by successive levels of using past mistakes as corrective guides for future action:

Zero learning will then be the label for the immediate base of all those acts (simple and complex) which are not subject to correction by trial and error. Learning I will be an appropriate label for the revision of choice within an unchanged set of alternatives; Learning II will be the label for the revision of the set from which the choice is to be made; and so on. (Bateson, 1987, p. 291)

In Bateson's terminology, each higher level is "meta" to or about the messages being exchanged at the lower level. For example, in a Pavlovian experiment, a dog exhibits zero

learning when it equates the sound of a buzzer with the reward of meat powder and begins to salivate (1987, p. 208). At the next level, the dog would recognize that “messages may be about (or ‘meta’ to) the relationship between messages of different levels”—for instance, by recognizing that if its harness smells of meat powder, it can expect that the buzzer will also result in a meat powder reward (1987, p. 253). In this second step, the dog is learning not to associate the buzzer with a reward, but how to approach a Pavlovian experiment successfully. At the next level, the dog learns how to learn to approach different kinds of experiments—what Bateson calls “learning to learn to receive signals” (1987, p. 254). At this “trito-learning” level, the dog is learning to acquire new habits of mind—new ways of relating to unique contexts.

At the highest levels of Bateson’s pyramid, deutero-learning trains cybernetic systems thinkers to be able to reconsider and sometimes reformulate the goals they initially set out to achieve, manifesting in an adaptive techne that aims less to control than to engage the world in conversation. He viewed the world as “made up of a very complex net-work [sic] (rather than a chain) of entities which have this sort of relationship to each other, but with this difference, that many of the entities have their own supplies of energy and perhaps even their own ideas of where they would like to go” (Bateson, 1987, p. 273). Based on this relational ontology, he advocated for a cybernetic techne that was artisanal rather than standardized, and that emphasized responsiveness more than transmission, arguing that “the problems of control become more akin to art than to science, not merely because we tend to think of the difficult and unpredictable as contexts for art but also because the results of error are likely to be ugliness” (Bateson, 1987, p. 273).

As his daughter, anthropologist Mary Catherine Bateson, noted after his death, Bateson's key insight was to highlight the relational nature of knowing and communicating. She used the example of genetics to describe this relationality:

The extraordinary and detailed work of mapping the human genome, for instance, makes it easy to forget that the individual phenotype is formed by the interaction of multiple genetic factors, not by any one of them in isolation; and all of them are expressed in a complex dance with the surrounding environment, air and earth and other organisms. Even with current progress in chaos and complexity theory, we remain less skilled at thinking about interactions than we are at thinking about entities, things.” (2000, p. vii)

The second-order cybernetics of Bateson and Mead complemented abstraction and digitization with a strong emphasis on relationality, responsiveness, and reflexivity. This is the sophisticated cybernetics that organizational communication scholars have developed into a body of theory that:

challenges simplistic notions of linear cause and effect by appealing to our commonsense understanding that communication processes can be enormously complex and subtle. Although rooted in technological functionalist thought, it emphasizes the problems of technological control, the perverse complexity and unpredictability of feedback processes, and the perverse likelihood that communicative acts will have unintended consequences despite our best intentions. A great practical lesson of cybernetics is that the whole is greater than the sum of its parts, so it is important for us as communicators to transcend our individual

perspectives, to look at the communication process from a broader, systemic viewpoint . . . (Craig, 1999, p. 142)

For the purposes of this chapter, attending to the “perverse complexity and unpredictability of feedback processes” is particularly important, because these concepts highlight how organizational learning is dependent upon the ability to “metacommunicate.” Metacommunication is communication about the patterning of interaction through communication (Watzlawick, Beavin & Jackson, 1968, p. 39-43). The lack of metacommunication underlies “inhibiting loops”: circumstances in which feedback is stifled because people are unable or highly reluctant to discuss organizational problems (Argyris, 1977). Similarly, the lack of metacommunication underlies a variety of other pathologies, including the classic example of a marital problem in which one spouse attributes their withdrawal to the other’s nagging, and the other attributes their nagging to the spouse’s withdrawal (Watzlawick, Beavin & Jackson, 1968, p. 56-58). In this example, each spouse is “punctuating” the same series of events in different ways—in other words, cultivating a specific manner of relating to “the infinitely complex stream of events (including [his or her] own behavior) so that this stream appears to be made up of one type of short sequences rather than an-other [*sic*]” (Bateson, 1987, p. 170).

Although working in a different research tradition, Deetz (1992), drawing on Habermas (1970), has proposed a line of thinking that resonates with Bateson’s concept of punctuation. Specifically, Deetz argues that organizational communication becomes “systematically distorted” when stakeholders are prevented from questioning organizational means or ends as a result of “latent prejudice, predefined personal identity, or object

production” (p. 173-4). In the following section, I argue that the inability to metacommunicate stems from a distorted “object production,” to use Deetz’s term, of genetically modified organisms. The international synthetic biology competition that I discuss is systematically distorted by a techne that draws on cybernetic information theory to “punctuate” sequences of DNA as standardized LEGO bricks. Because the organization’s fundamental goal is to simplify genetic engineering by building these standardized biological units, metacommunication that considers the weaknesses of this techne is discouraged to the point of becoming silenced.

How to Make Biology Easier to Engineer: The Techne of Synthetic Biology

At the International Genetically Engineered Machine (iGEM) competition, cybernetic abstraction—the transformation of context-driven biological meaning into context-less information—what Hayles calls “a pattern, not a presence”—serves as an ontological foundation for the organizing of bioscientific work. The techne of iGEM enacts a transmission model of communication to standardize and simplify genetic engineering, organizing scientific work as the distributed manufacturing of biological systems. The entire effort is rooted in a cybernetic model of communication, as the competition’s architect, bioengineer Drew Endy, has explained:

There’s a way to think about this that maps directly into communications theory, where you think about a sender and a receiver and a message being transmitted along a channel. In evolution I think you can make a mapping where you have a parent generation, which is the sender, the transmitter, and you have the progeny, the children, which are the receiver. The message that’s being transmitted is the design of

the living organism, and the channel that the signal's being propagated along is the process of replication of the machine. (Endy, 2008)

Endy and Tom Knight, another of iGEM's creators, are leading figures in the field of synthetic biology, an emerging field that aims, in Endy's words, "to make biology easier to engineer" (Endy, 2008). Echoing Norbert Wiener's impatience with the tedium of work in biology laboratories, synthetic biologists dismiss artisanal technai of genetic engineering as cumbersome and unnecessarily time-consuming. Knight, for instance, observed that his "initial tremendous frustration" with biology stemmed from the fact that "every experiment turned into two experiments": first, the desired experiment, and second, "the experiment that you had to do in order to do the experiment that you wanted to do," such as "will this enzyme work with this DNA, or, is it not methylated, or something else . . . Basically, there are too many things to worry about" ("Notes on Tom Knight's Talk," iGEM, 2006).

To increase the speed and efficiency of laboratory work, synthetic biologists draw on electrical and mechanical engineering as models to reduce the number of things to worry about. Specifically, Endy, Knight, and their MIT colleague Randy Rettberg sought advice from Lynn Conway, a computer scientist/electrical engineer/systems architect who had studied cybernetics at MIT in the late 1950s (personal communication with Drew Endy, August 12, 2015). In the 1970s and 1980s at Xerox PARC, Conway worked with Cal Tech professor Carver Mead to facilitate major advancements in the design of digital systems by standardizing and simplifying the process of microchip design through a process they called Very Large Scale Integration, or VLSI (Casal Moore, n.d.). Prior to this collaboration, microchip design had been restricted to large semiconductor firms. Rather than designing

chips from scratch, computer engineers were required to order components that were “like Lego sets,” according to Conway (Casal Moore, n.d.).

VLSI simplified, standardized, and distributed the process of designing LEGOs; iGEM aims to do the same for DNA sequences. For example, in a 2005 Nature article that proposed core principles to define the field of synthetic biology, Endy noted that although “any competent electrical engineering student” could produce several working circuits in less than an hour, the development of a biological equivalent to such a circuit had required two leading biophysicists to conduct an entire year of research, and that furthermore, the same level of effort would be required for the feat to be repeated (p. 449).

From this perspective, the problem with artisanal genetic engineering is that unlike true engineers, its practitioners are forever reinventing the wheel: in Endy’s words, “Stated plainly, the engineering of biology remains complex because we have never made it simple” (2005, p. 449). He and other synthetic biologists simplify bioengineering by approaching biology like any other form of technology, as evidenced by the title of Rob Carlson’s (2010) popular book on the field, *Biology is Technology: The Promise, Peril, and New Business of Engineering Life*. In Carlson’s words,

Successful aeronautical engineers do not attempt to build aircraft with the complexity of a hawk, a hummingbird, or even a moth; they succeed by first reducing complexity to eliminate all the mechanisms they are unable to understand and reproduce. In comparison, even the simplest cell contains far more knobs, bells, and whistles than we can presently understand. No biological engineer will succeed in building a

system de novo until most of that complexity is stripped away, leaving only the barest essentials. (2010, p. 6)

At iGEM, this “stripping away” begins with ontologizing DNA as disembodied information—a Platonic move that is enacted in the persuasive techniques of participating teams. This deliberate simplification is consistent with the cybernetic construction of simplified models that “necessarily ignore those aspects of the system which are irrelevant to the purposes for which the model is constructed” (Heylighen & Joslyn, 2001, p. 156), as well as Luhmann’s contention that “the gist of technology is simplification” (1990, p. 224). The techne of iGEM approaches sequences of DNA as if they were digital bits of cybernetic information that, instead of interacting with bodily and ecological systems, serve identical functions in any context. This reduction of biological “meaning” to genetic transmission structures the work of the competition as a form of distributed manufacturing.

Specifically, participating teams work to develop “Standardized Biological Parts” or “BioBricks”: DNA sequences that can be mixed and matched like LEGO bricks to create novel organisms (Balmer & Bulpin, 2013; Campos, 2012; Maddalena, 2014). As this terminology suggests, iGEM’s vision of biological material is highly modularized: it fetishizes discrete, quantifiable parts rather than biological wholes. As early as 1998, two of the competition’s organizers, Tom Knight and Randy Rettberg, began to explore the possibility of “treat[ing] cells as living circuit boards, letting genes stand in for electrical components like resistors and capacitors” and “redesign[ing] living cells by assembling biological ‘circuits’ from a set of standardized ‘parts’ (genes), just as an engineer can build circuits to control electronic devices by combining the right components” (Trafton, 2011).

Success would mean that it was possible to “treat biology as a manufacturing technology, programming cells to produce things they wouldn’t normally make—for example, drugs, fuels, or plastics” (Trafton, 2011). As Knight put it, “Biology just happens to be in the business of making more copies . . . But we can subvert that. We can use it to make just about anything” (Trafton, 2011).

Idempotent Vector Design for Standard Assembly of Biobricks

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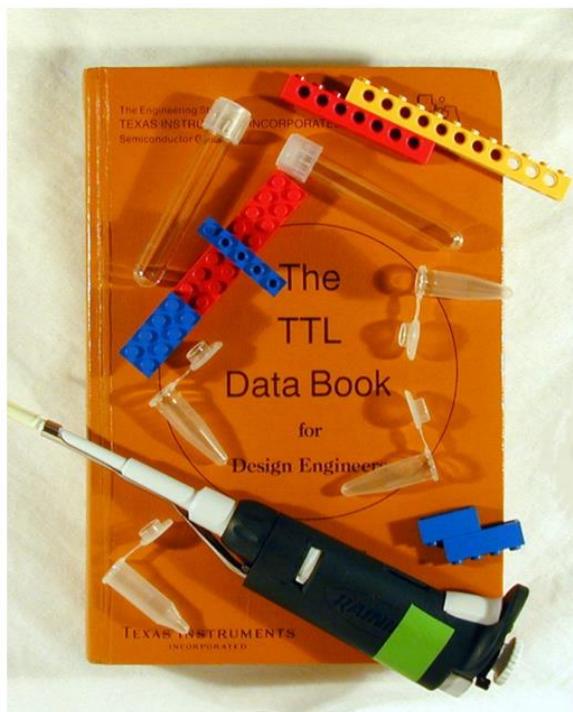


Figure 3: The Cover of Tom Knight’s 2003 Working Paper, “Idempotent Vector Design for Standard Assembly of BioBricks”

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iGEM grew out of a month-long course taught at MIT in 2003 by Drew Endy, Tom Knight, Randy Rettberg, Pamela Silver, and Gerry Sussman that was funded by an \$80,000 grant from the Defense Advanced Research Projects Agency, or DARPA, a research arm of the US Department of Defense (Smolke, 2009, p. 1099; personal communication with Drew Endy, August 12, 2015). The course invited undergraduate students to design simple biological systems—specifically, single-celled organisms that would blink on and off like an oscillating electronic circuit (“Board of Directors;” “iGEM/Learn About”; Pollock, 2005). Although students in this initial course were unable to finish building their biological “machines” in the time allowed for the course (Trafton, 2011), their efforts set an example for others to follow. In 2004, four additional schools—Boston University, Caltech, Princeton, and the University of Texas at Austin—competed over a six-month period to “design and build genetically encoded finite state machines using standard, interchangeable biological parts,” an effort that culminated in the first Jamboree, a term deliberately borrowed from the world of scouting (personal communication with Drew Endy, August 12, 2015). Since then, iGEM has expanded into an annual event that united high school, undergraduate, and graduate-level researchers from 245 universities in 32 countries in 2014 (iGEM Press Kit, 2014), the year on which this chapter focuses. Over the years, teams’ achievements have included a bacterial biosensor to detect arsenic contamination in water, a vaccine to combat ulcer-causing bacteria, and bacteria that smell like mint or glow in the dark (Trafton, 2011).

In 2003, the same year that the initial MIT course was offered, Knight introduced the concept of BioBricks in a working paper that called for “remov[ing] much of the tedium and surprise during assembly of genetic components into larger systems” (p. 2). As demonstrated

by Figure 3, the cover of this working paper shows biology laboratory tools—a pipette, test tubes, and microcentrifuge tubes—overlaid alongside LEGO bricks on the *TTL Data Book for Design Engineers*, an early 1980s Texas Instruments catalog that grouped circuits into classes that share similar functions, thereby simplifying the process of determining what circuits to employ in various circumstances. Circuits, even the most complex microprocessors, are built on the foundation of logic gates that apply “the simplest possible statement, either true or false” to “the fundamental operations of logic, like the conjunction (“and”), disjunction (“or”), and negation (“not”), to link propositions into increasingly complicated networks” (Gefter, 2015). Knight’s image suggests that synthetic biology could produce an equivalent resource for bioengineers: a catalog of prefabricated parts that could be arranged according to a shared binary logic to create novel organisms.

Much as the standardization of screw threads helped to facilitate the industrial revolution, Knight argues, standardizing biological parts will facilitate dramatic innovation, providing advantages such as “the widespread ability to interchange parts, to assemble sub-components, to outsource assembly to others, and to rely extensively on previously manufactured components” (2003, p. 2). Adopting the efficiency-oriented techniques of engineering would make it unnecessary to continue reinventing the wheel. In his words,

The key notion in the design of our strategy is that the transformation performed on component parts during the assembly reactions are *idempotent* in a structural sense. That is, each reaction leaves the key structural elements of the component the same. The output of any such transformation, therefore, is a component which can be used as the input to any subsequent manipulation. It need never be constructed again—it

can be added to the permanent library of previously assembled components, and used as a compound structure in more complex assemblies. (2003, p.2, italics original)

The drive to develop biological parts that are capable, like cybernetic information, of serving the same function regardless of context organizes not only DNA, but also the work of participating teams.

The techne of iGEM exemplifies what scholars of cybernetics, systems theory, and institutional theory call *isomorphism*, the “constraining process that forces one unit in a population to resemble other units that face the same set of environmental conditions” (DiMaggio & Powell, 1983, p. 149). This techne structures the competition as distributed manufacturing and accordingly, structures the professional identities of team members as factory workers. Like machinists, they produce modular parts; like assembly line workers, they construct novel organisms using parts developed by others. This mechanization is highlighted by the competition’s logo (Figure 4), which intermingles a microbe with mechanical cogwheels. iGEM’s growing collection of BioBricks is tested, characterized, and catalogued via the Registry of Standardized Biological Parts, a kind of warehouse that is managed by an independent nonprofit, the iGEM Foundation, which spun out of MIT in 2012. In addition to storing BioBricks, the Registry shares them with future iGEM teams as well as nearly 300 professional laboratories worldwide (“About”; “Main Page”; “Labs Registered”). As “a kind of theoretical Wikipedia of future life forms” (Specter, 2009), the Registry’s online catalog functions much like the *TTL Data Book*, ontologizing biological systems as analogous to electrical circuits.



Figure 4: iGEM Logo

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Theoretically, each new part that is added to the Registry represents a new simplification of the work of future synthetic biologists; the competition envisions that each successive generation of participants will be able to draw on a growing number of parts produced by previous teams. iGEM characterizes this process as enacting its “Get & Give (& Share)” philosophy, which encourages teams and other users to “get parts, samples, data, and tools from the Registry;” “give back to the Registry the new parts they’ve made, as well as data and experience on new and existing parts;” and “share experience and collaborate” through the Registry’s social media platforms (“Help: Philosophy”). Ultimately, the competition facilitates not only the distribution of Standardized Biological Parts, but the distribution of synthetic biology itself. By simplifying and standardizing the techne of genetic engineering, iGEM enables bioscientific work to become more distributed, more accessible, and more applied.

Manufacturing Biological Workers

In organizing biological work as distributed manufacturing, iGEM instrumentalizes not only the single-celled organisms that comprise its “machines,” but also the teams that participate in the competition. To facilitate the distribution of synthetic biology, iGEM’s techne materializes the engineering principle of decoupling. As Endy explains, decoupling is “the idea that it is useful to separate a complicated problem into many simpler problems that can be worked on independently, such that the resulting work can eventually be combined to produce a functioning whole” (2005, p. 451). In this formulation, which is reminiscent of Taylor’s (1914) scientific management, organizational members are actively discouraged from developing expertise beyond their individual niche. In keeping with the cybernetic tradition, this arrangement depends on conceptual abstraction. To manage the complexity of biology, Endy proposes an abstraction hierarchy, depicted here in Figure 5. The hierarchy compartmentalizes work into a series of increasingly sophisticated tasks, each of which is increasingly distanced from the messiness of the single-celled organisms from which DNA is sourced. At the lowest level, workers focus on locating specific sequences of DNA to be used by the “parts-level workers” at the next level, whose expertise focuses on the functions served by BioBricks. Parts-level workers interface with device-level workers who combine parts, and device-level workers, in turn, interface with systems-level workers who combine devices.

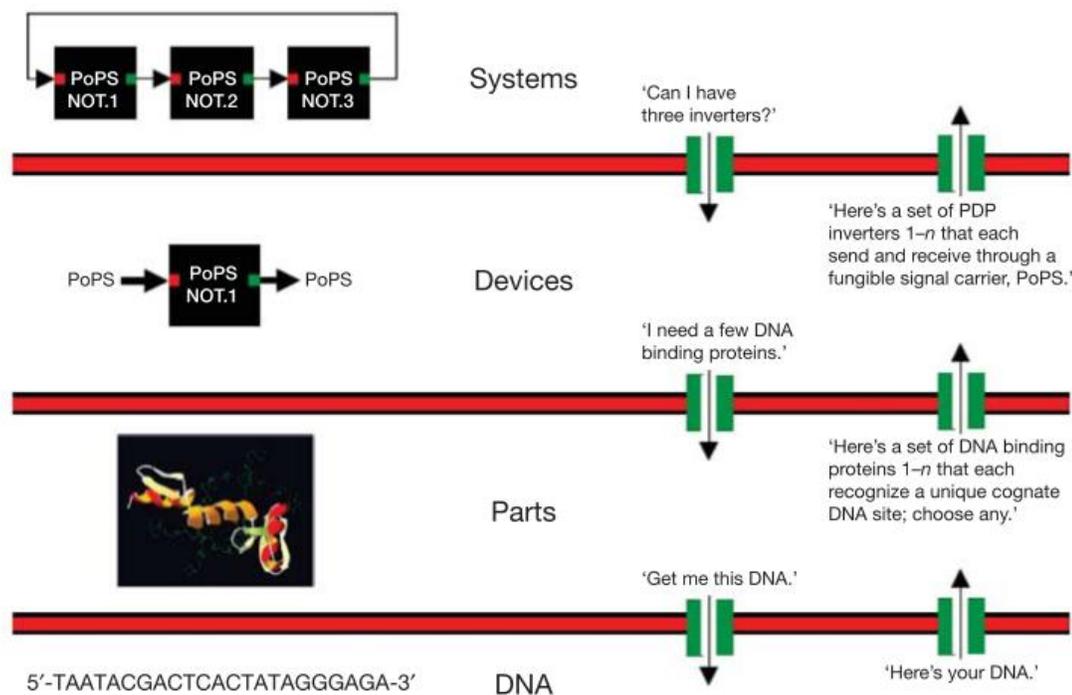


Figure 5: Drew Endy's 2005 Abstraction Hierarchy

From "Foundations for Engineering Biology," by D. Endy, 2005, *Nature*, 438(7067), p. 451. Copyright 2005 by Nature Publishing Group. Reprinted with permission.

The goal of the hierarchy is to "allow individuals to work at any one level of complexity without regard for the details that define other levels" (Endy, 2005, p. 451)—in other words, to compartmentalize knowledge in the service of making biology easier to engineer. The horizontal bars in Figure 5 represent barriers to "block all exchange of information between levels" (Endy, 2005, p. 451), allowing for only the simplest of interactions, such as responding to a request for a particular DNA sequence, part, or device. As Endy explains,

parts-level researchers might need to know what sorts of parts that device-level researchers would like to use, how different types of parts actually work. . . and how to order a piece of DNA. But, parts-level researchers should not need to know anything about phosphoramidite chemistry, how short oligonucleotides are assembled into longer, contiguous DNA fragments, or how a genetic oscillator works, and so on. (2005, p. 451)

The holistic view of biological systems is thus reserved for Endy and other “systems-level” researchers. By contrast, “parts-level researchers” such as iGEM participants are thus figured as having no need to understand the complexities of how one part of a cell interacts with another. As Endy puts it, “To be useful, individuals must be able to work independently at each level of the hierarchy” (2005, p. 451). Thus, in keeping with synthetic biology’s engineering metaphors, the competition de-skills and automates their work, positioning the workers themselves as cogwheels in the simplification machine.

Despite this compartmentalized vision of work and expertise, iGEM is advertised as an opportunity for students to broaden their area of expertise, rather than narrowing it. For example, the website for the 2004 Jamboree positioned iGEM as an advantageous research opportunity for students in both the sciences and engineering. For scientists, it suggested, the competition was an opportunity to observe how biological phenomena differed from the expectations of engineering models, thereby “highlight[ing] relevant science that needs doing, or failures in modeling and simulation technology that need fixing.” For engineers, the site argued, the competition was an opportunity to develop “foundational technologies” that would “enable the systematic engineering of biology,” and to “learn about biology by

pursuing their natural inclination to design and build.” By 2008, the competition had reformulated the former of these arguments, suggesting that instead of observing how biology differed from engineering, biology students would “learn engineering approaches and tools to organize, model, and assemble complex systems, while engineering students are able to immerse themselves in applied molecular biology.”

However, research has shown that such immersion rarely occurs in practice, in large part due to the fact that the engineering of biology continues to demand at least a minimum level of tacit knowledge (Polanyi, 1983; Vogel, 2014), and “teams need a great deal of training and regular access to advisors not only with the requisite expertise in genetic engineering but also knowledge of the Registry and iGEM practices” (Balmer & Bulpin, 2013, p. 327). In part because the competition allows less than a year for the completion of projects, individual team members are often more likely to contribute according to their previously existing expertise, rather than acquiring skill sets in other fields, as iGEM promotional materials promise (Balmer & Bulpin, 2013). In addition, teams have struggled with the fact that “the quality of the parts in the registry was not generally good, which presented a huge challenge to the major goal of the registry—the reuse of parts to support efficiency in design and construction” (Smolke, 2009, p. 1100). For example,

A glance through the registry will show that many parts have not been confirmed as working and do not have any, much less thorough, associated characterization data. Complaints and frustrations grew as teams attempted to use parts from previous years’ projects and found that they did not work as designed or in some cases were not even the correct sequence. (Smolke, 2009, p. 1100)

Nevertheless, the labor of iGEM teams serves as a means of establishing iGEM as proof of concept for synthetic biology's broader effort to redefine genetic manipulation as a field of engineering—an effort that attracted investments totaling roughly \$820 million in the United States between 2008 and 2014 (Woodrow Wilson Center, 2015). Some of the same individuals who helped launch the competition at MIT have made major contributions to synthetic biology not only through their research, but also by facilitating multi-institutional collaborations such as the Synthetic Biology Engineering Research Center in Silicon Valley, California. At the federal level, the US National Institute of Standards and Technology hosted a Synthetic Biology Standards Consortium to develop industry-wide standards to enable researchers in disparate institutions to share information, techniques and materials in March 2015 (Basulto, 2015). Yet the field's primary federal champion has been the US Department of Defense, which increased its investment from close to zero in 2010 to over \$100 million in 2014, more than triple the investment made by the US National Science Foundation (Woodrow Wilson Center, 2015). In February and June 2015, DARPA hosted events in San Francisco and New York called *Biology is Technology*, echoing the title of Carlson's (2010) book of the same name (DARPA Biological Technologies Office, 2015a, 2015b). At the San Francisco event, DARPA Deputy Program Director Alicia Jackson gave a talk entitled "Programming the Living World" that laid out a rationale for the agency's new Biological Technologies Office, which aims to bring together,

all of the advances that we've seen over the past 50 years in electronics, in physics, in computer science, in data analytics . . . with the last two decades of advances in

genomics, in biology and neuroscience, and come up with a technological capability that far surpasses anything that we have today. (DARPA tv, 2015)

As a primary example of this work, she discussed DARPA's Living Foundries program, which launched in 2012 to "use biology not just as a technology but as a manufacturing platform" (DARPA tv, 2015) by developing:

design and automation tools, modular genetic parts and [devices], standardized test platforms and chassis, tools for rapid physical construction of biological systems, editing and manipulation of genetic designs and new characterization and debugging tools for synthetic biological networks. ("Living Foundries")

iGEM also contributes to the legitimization of synthetic biology by attracting publicity for the field. In 2006, the websites for annual competitions began to feature media attention in increasingly prominent ways and invited teams to submit additional news stories featuring their work. Further, a more informal note on the 2006 site suggested:

Yes, we should deal with publicity. We should freaking have Nova follow us around. This is a unique event, it is early days, and it's not being archived. I think this is a mistake. Publicity now will be the surest way to lead to \$ later, both from private and public (NSF, DARPA) sources. Word of mouth is fine, look how well things are going so far just based on Drew's hyperkinetic nature, but we could do better.

("Others (Publicity?)", 2006)

By 2007, a full page of the primary site was devoted to news stories, photo sharing, videos, and blogs covering the competition.

Distributing, learning, and risk. In these media articles, as well as on the competitions' websites, iGEM's organizers position the distribution of genetic engineering beyond the gated settings of academic and corporate laboratories, and the accompanying increased levels of participation in the practice of genetic engineering, as givens. For example, in a 2003 white paper on biological risk, Endy suggests that

A conservative discussion of strategy for minimizing biological risk would begin with three grounding assumptions. First, that we already can not [*sic*] control the distribution of technology and information enabling the manipulation of biological systems and that future technologies are also unlikely to be controlled. Second, ineffective attempts to forbid access to some of the basic technologies for manipulating biology would likely incur prohibitive costs in the form of lost opportunities for improving human health and gaining scientific knowledge. Third, that threats could arise from nature, nation states, loosely organized groups, and individuals, and could be targeted against any part of the living world relevant to human welfare (i.e., biological threats are asymmetric in (i) source of agent, (ii) choice of target, and (iii) time to construct versus respond. . . (p. 3)

Compared with the degree of control that synthetic biologists claim to exert over biological systems at the micro level, the first of these assumptions is striking in that it suggests the impossibility of curbing the distribution of the tools and techniques of genetic engineering at the macro level. Interestingly, immediately after the second assumption positions greater participation in genetic manipulation as a means to biomedical and economic advancement, the third highlights the potential dangers associated with increased

participation. Endy goes on to suggest that ultimately, greater participation will mitigate the dangers associated with greater participation. As he puts it, “Technologies enabling the engineering of biology would directly contribute to a rapid and predictable response to biological threats . . . In addition, a cadre of engineers familiar with the design of biological systems would help to enable more rapid threat analysis” (2003, p. 3). The circular logic of this argument is that by making biology easier for more people to engineer, synthetic biology will necessarily make it easier for more people to use biology as a weapon; *however*, it will simultaneously speed the development of the tools and techniques needed to respond to biological threats and increase the number of people qualified to contribute to such a response. This logic, like the simplified techne of iGEM, positions the distribution of synthetic biology as an end in itself, rather than a means of achieving other ends.

In suggesting that this approach creates a need “to consider how future biological technology can be combined with non-technical solutions in order to minimize both the number of sources of future biological risks, and the scope of the risks themselves” (Endy, 2005, p. 4), the competition’s organizers implicitly define the development of technical and non-technical solutions as distinct realms of work. Endy offers two examples of how this could be done: first, “a well conceived [*sic*] and responsibly implemented plan for educating future generations of biological engineers,” including training in and subsequent enforcement of a professional ethics code--in other words, even as it de-skills and automates their labor, the competition must provide teams with tools to engage with social and political complexities. A second example suggests preventive mechanisms that could be built into the organizational structure of the Registry, such as a requirement that BioBricks be shared only

with laboratories that agree via contract that they are “not synthesizing known threat agents” (2005, p. 4). The qualification that such a contract could only apply to “known” threat agents emphasizes how much the mitigation of security threats depends upon the knowledge and professional character of the individuals engaging in this type of work. One’s ability to prevent “known” security threats requires that one knows in the first place what types of experiments and materials have the potential to be hazardous, or at least has the inclination and aptitude to learn about potential hazards. But in light of the fact that the attempt to simplify and standardize the engineering of biology is an uncertain experiment in the first place, it is also possible that some hazards are as yet unknown, especially to “parts-level workers” whose knowledge is deliberately limited and compartmentalized.

In part to address these uncertainties, iGEM has concerned itself with questions of biological risk, and increasingly, with broader social questions as well. In keeping with the decentralized nature of the competition, iGEM’s organizers have delegated these questions to teams, as well as to a cadre of volunteer judges composed primarily of scientists and social scientists. The delegation of such considerations was most obvious when, during the 2014 Jamboree, event organizers introduced representatives from the Federal Bureau of Investigation (FBI) and the United Nations Office for Disarmament Affairs as “solutions” to the problem of journalists inquiring about biosafety:

In the past, journalists have consistently asked, *Is synthetic biology safe and secure?*

For a long time, I said, *Sure*. Then they said, *What about bioterrorists?* Now I can

say, *The FBI are here* [at iGEM]. No journalist has ever asked a follow up question.

So I want to thank [the FBI] for solving my problem. (Field notes, November 2, 2014)

In keeping with the logic that increased participation in synthetic biology could result in an increased number of people who are prepared to respond to biological threats, the biosecurity experts noted that there were plenty of jobs in their field for former iGEM participants. The UN representative spoke first, offering a condensed explanation of national and international biosecurity regulations. Then, after taking a “selfie” photograph from the stage that showed a half-full auditorium of iGEM participants in the background, the FBI team described how the Bureau’s anti-terrorism strategy had shifted following the September 11 attacks to become a “new and different FBI” (also see Tocchetti & Aguiton, 2015):

Prior to 9/11 and prior to the anthrax attacks in 2001, we didn’t work with law. We didn’t work with health, public health or scientists, and we had to catch up. We didn’t know anything about science, we didn’t know about bacteria and viruses and how the case investigations would parallel a criminal investigation. Now we have agreements with CDC, USDA and many other agencies who work side by side to work on investigations together. Again, we have to solve it, and we have to determine how it happened. Whether it be on the health side or the law side, the goal is the same. So if any of you are interested, I encourage you, continue your studies, get some work experience, and don’t forget us, because we could always use your brilliance. (Field notes, November 2, 2014)

One potential problem with this approach is that iGEM is far more successful in training participants to simplify and standardize biology than to engage with complexities—

whether biological or sociopolitical. The 2014 Jamboree opened with reminders that the competition's broader purpose was to "grow the field" of synthetic biology, and organizers heartily encouraged attendees to draw on their shared enthusiasm to strengthen their professional networks. "Don't sit with your team at dinner," organizers recommended, and don't forget to attend networking bingo at lunch. Endy's welcome remarks urged participants to think of themselves as "Living in the future. Whether you know it or not, you're living in a future." He then reminded them that the experience of iGEM resulted from Tom Knight having "thought about the future he wanted to live in":

He didn't want to live in a future where all the bits and pieces of biology were incredibly difficult to work with. He wanted to live in a future where he could do the experiments that he really cared about, not just the experiments of trying to snap together DNA. That led him to his innovation around what became the BioBrick standard for assembly. Not that it was perfect, but, damn, it was a lot better than nothing. It enabled people to do something that hadn't been done before. There's many other things that you've experienced at iGEM that are from the future. This idea that you could make complicated systems by putting together devices, by putting together parts, by—Somebody is going to give you the DNA sequence, right? You don't have to memorize every last bit of DNA. It's like you have an abstraction stack for managing complexity. That was a fantasy until we made it true. (Field notes, November 3, 2014)

This argument positions success as finding new ways to simplify and distribute the techne of synthetic biology. For example, Endy proposed that on the competition's twentieth

anniversary, they might hope for a printer “that lets me hook up to my computer and instantly print out the piece of DNA I want,” a “real-time bug debugger” to explain “whether or not my cell is behaving,” or even “the bionet”: a “network of wetware that exists on top of the Internet, peer-to-peer, business-to-business.”

Organizing the social and the technical. Through every step of the competition, the virtues of simplification are extolled to such a degree that they infuse even the competition’s “Policy and Practices” track, which “aims to stimulate innovative ways of thinking about the policy, economic, social, legal, and philosophical landscape of synthetic biology” (“Tracks/Policy Practices”). The 2007 team from the University of California, Berkeley was the first to incorporate this type of thinking into their iGEM effort. For their project, an undergraduate considered how iGEM’s open source approach conflicted with intellectual property norms as part of the “Human Practices” effort that Anthropologist Paul Rabinow and his graduate student Gaymon Bennett had formulated in their work with the Synthetic Biology Engineering Research Center (SYNBERC), a collaboration of universities launched in 2006 by some of the same scientists who developed iGEM (Fuller, 2007; Rabinow & Bennett, 2009). Rather than positioning social and ethical questions outside of the biosciences, Rabinow and Bennett envisioned human practices as “bring[ing] the biosciences and the human sciences into a mutually collaborative and enriching relationship, a relationship designed to facilitate a remediation of the currently existing relationships between knowledge and care in terms of mutual flourishing” (2009, p. 278). Specifically, they proposed that human practices work should “pose the question of what kinds of objectives are really at stake in specific projects, how those stakes require rethinking about

the interfaces among university labs, government funding, biotech interests, and the like” (Rabinow, 2009, p. 313).

Considered through the lens of organizational theory, Human Practices represents an attempt to infuse the cybernetic organization with the capacity for what Bateson (1987) called *deutero-learning* and contemporary systems theorists call reflexivity: a form of learning that involves continual reconsideration and sometimes reformulation of an organization’s initial goals (Argyris, 1977; Bateson, 1987; Morgan, 2006, p. 84-85). This type of learning requires effective metacommunication: conversations about the patterning of interaction through communication (Watzlawick, Beavin & Jackson, 1968, p. 39-43). Such conversations can sometimes lead to discursive opening (Thackaberry, 2004), the ability to approach norms and habits from new perspectives. Nevertheless, achieving this type of opening is notoriously difficult (Argyris & Schön, 1974; Deetz, 1992; Weick, 1979).

One example of these difficulties comes from Rabinow and colleagues, who ended their collaboration with SynBERC in 2011, declaring the project a “spirit-crushing situation” (Rabinow & Stavrianakis, 2013, p. 40) in which they were subject to what Bateson called a double bind, “both given verbal approval to do what we wanted to do and denied the possibility of doing it” (Rabinow & Stavrianakis, 2013, p. 34). However, “Human Practices” became an increasingly prevalent term at the iGEM competition. In 2008, the competition awarded its first prize for “Best Human Practices Advance.” From 2008-2012, a Human Practices component was an *optional* criterion for earning a gold medal in the competition. From 2013 onwards, a Human Practice component was compulsory for earning a silver or gold medal.

However, in 2014, Human Practices work was reformulated as Policy and Practices. As defined by Peter Carr, the competition's director of judging, Policy and Practices is "the study of how your work affects the world, and how the world affects your work" (iGEM, "Policy and Practices," 2014). This description of science and society as separate and unchanging entities is representative of a mode of engagement that Rabinow and Bennett were trying to rethink when they proposed the concept of Human Practices. As they noted, while it can facilitate valuable deliberations, the science/society approach is also subject to critical limitations, including the difficulty of determining precisely who is authorized to speak for society at large, and a lack of attention to how problems are defined in laboratory work (Rabinow & Bennett, 2009, p. 277-9). Thus, in reformulating Human Practices work as Policy and Practices, iGEM transitioned from recommending that teams question "what kinds of objectives are really at stake" in their own projects (Rabinow, 2009, p. 313) to recommending that teams focus on the relationship of their work to a vague imagined conglomerate of interests.

In sum, the Policy and Practices formulation is friendlier to the competition's positioning of the simplification of biology as an end in itself because it is less likely to push teams to question the goals that iGEM has set out for them. The instrumental rationality that organizes the competition equates learning with the pursuit of efficiency, and both the biological and social aspects of many teams' projects embody this instrumental rationality. For example, the 2014 Tianjin team sought to modify bacteria's extracellular fibers to interface with inorganic materials—in other words, to build a bridge to connect biological signals and electrical signals. Recalling early cyberneticians' standardization of meaning, the

2010 Sheffield team sought to standardize laboratory protocols in order to create a common language that would be understandable to team members from multiple disciplines, which was further refined by the 2014 Sheffield team. Similarly, to address the difficulty of shipping DNA across international borders, the Tec de Monterrey team worked with university lawyers to propose revisions to Mexican law that would standardize the protocols that customs officers use to classify risks and ensure the safe transit and disposal of biological materials.

But in relation to Policy and Practices efforts, the emphasis on simplification and standardization impedes teams' ability to engage in second- and third-order learning. The assumption that increased participation in synthetic biology represents an end in itself, rather than a means to achieve other ends, serves as an implicit foundation for the public outreach and engagement efforts of many teams. For instance, a 2014 team from Shenzhen, China, showcased the creative virtues of synthetic biology by hosting a drawing contest entitled "If I Were the Creator," which offered kindergarten and primary school students "the freedom to design creatures that they like." More typically, teams continued a long tradition of equating public engagement with education, assuming that addressing their audiences' deficit of scientific knowledge would result in increased appreciation for emerging forms of science (see Sturgis & Allum, 2004). The University of Stony Brook's 2014 team exemplified this approach, materializing Policy and Practices "educating the younger generation" by visiting an advanced biology summer camp for high school students and "educating our peers" by founding the campus's "first and only Synthetic Biology Club."

The 2009 team from Valencia, Spain, conducted a meta-analysis titled “Sins, Ethics and Biology” that summarized the first four years of Human Practices and Policy and Practices efforts, beginning in 2005, the year in which the competition expanded internationally. As they noted, biosafety has been among the most frequently considered issues, with teams focused on training and supervision in laboratory safety, the use of sterile protocols, and knowledge about commonly used but potentially dangerous materials such as dry ice and liquid nitrogen. Their analysis also observed that teams have identified a number of risks, ranging from the possibility that unexpected mutations could occur after a gene is inserted into an organism, to the potential release of artificial genes into natural ecosystems, to the application of microorganisms as weapons. In addition, the 2008 teams from Delft, Netherlands, and Freiburg, Germany, drew attention to the increased risks associated with technological advances in sequencing techniques and the increased distribution of DNA, as well as the challenges associated with mitigating these risks. Echoing Endy, both concluded, as the Valencia team put it, that “stopping technical advances is obviously not the solution.” As with many other examples, their techniques of relating to others offered little room to consider the possibility that in some cases, technical advances might not be the best solution.



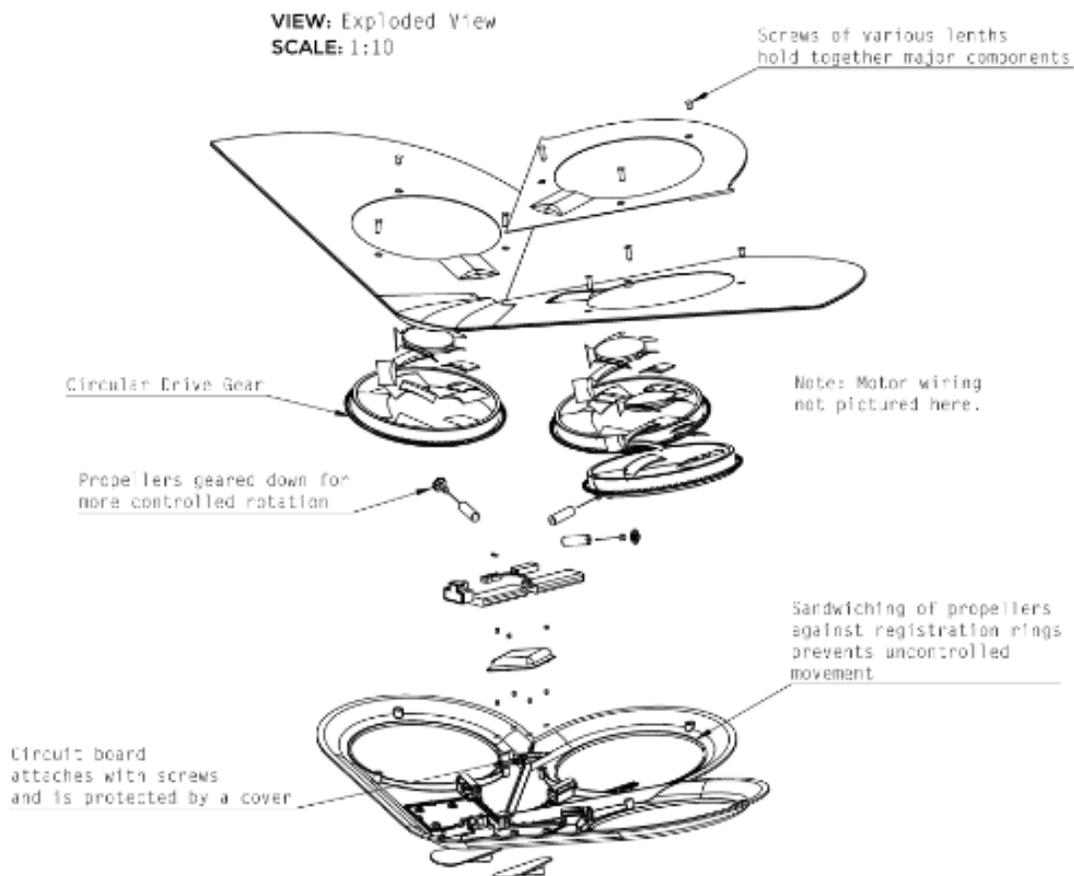
Figure 6: Mycelium Drone Chassis Prototype, Stanford-Brown-Spellman Team, iGEM 2014

Retrieved from http://2014.igem.org/Team:StanfordBrownSpelman/Building_The_Drone and licensed under Creative Commons attribution 4.0.

Another frequently discussed topic was intellectual property. For example, the 2014 Oxford University team offered a thorough review of intellectual property questions in synthetic biology, including issues related to the organization of iGEM itself. In their conclusion, the Oxford team offered a number of recommendations to iGEM, including: showcasing legal agreements with student teams more prominently online “so that students can easily find this information about the legal contract they are making;” amending these agreements to include a confidentiality clause so that teams could decide to apply for a patent following the annual jamboree rather than automatically entering their work into the public domain; and providing information on intellectual property issues, or, at minimum, encouraging participants to study these issues for themselves (University of Oxford iGEM Team, 2014, p. 19). They also developed a flow chart to help teams navigate intellectual property questions, which raised the possibility that in some cases, they might be better off

keeping their innovations relatively secret rather than adopting iGEM's "Get & Give (& Share)" philosophy uncritically. Though valuable, teams' intellectual property discussions, like discussions of risk, were unlikely to question the competition's positioning of the simplification of genetic engineering as an end in itself.

Some teams did take a more reflexive approach to Policy and Practices efforts. For example, the 2008 Delft team produced a number of recommendations for iGEM's organizers, including that the competition define ethics as a part of science itself (p. 46). A joint team involving students from Stanford, Brown, and Spellman Universities collaborated with the National Aeronautics and Space Administration (NASA) to prototype a biodegradable drone. The chassis of the drone (see Figure 6) consisted of fungus, straw, dead leaves, and other organic materials that were dried and sterilized to approximate styrofoam, then covered with waterproof, heat- and cold-resistant cellulose that had been produced by genetically engineered bacterial colonies (Stanford Brown Spellman iGEM team, 2014; Zaleski, 2015). Because bacterial cellulose can be grown in space, the drone could theoretically be constructed on a space station, then deployed to explore Mars and other planets. Because of its biodegradability, the drone would presumably be less likely to damage these environments, or fragile ecosystems on Earth, if it crashed. The drone's lightweight materials were inspired by careful study of paper wasps. The team's concept design for the next phase of the project, a partially living unmanned aerial vehicle, similarly "references the traditional biological architecture of birds while embracing industrial additive manufacturability" (see Figure 7).



Biological UAV Concept, Exploded View

Figure 7: Concept for a Future Biological Drone, Stanford-Brown-Spellman team, iGEM 2014

Retrieved from http://2014.igem.org/Team:StanfordBrownSpelman/Building_The_Drone and licensed under Creative Commons attribution 4.0.

Team members noted in an interview that “most of us began wondering about this because a lot of us had reservations about working on [unmanned aerial vehicles, or] UAVs,” and as a result, Policy and Practices work was “part of a self-information campaign for us, to

make sure we were OK working on this project, and then it became a larger-scheme thing when we realized that it wasn't just us who felt this way about UAVs and it was probably important that other people know it too." As the interview progressed, they explained further:

Even though it's not necessarily inherently malignant, or . . . It is possible in synthetic biology to create things that are inherently malignant. So it's really important for us to first look at the idea of like, *If I create this, what are the side effects? Do I need to be creating this in the first place? And who is going to be able to benefit from the existence of this project?* (Personal Communication, October 31, 2014)

These statements indicate a high level of awareness of potential concerns about UAVs, along with a strong concern for the well-being of the individuals who might become affected by this technology, and a sense of responsibility for the technologies that the team creates. On their website, the team described struggling with what is known as the "dual-use dilemma": the problem that "one and the same piece of scientific research sometimes has the potential to be used for bad as well as good purposes" (Miller & Selgelid, 2007, p. 523). The team characterized their decision-making as follows:

early UAVs took the form of balloons and they were primarily used for military purposes for monitoring and eliminating enemies in the battlefield. However, in recent years, UAVs have been increasingly used by civilians to accomplish various scientific and humanitarian missions. Due to their promising ability to accomplish tasks that otherwise could have been tedious, unreachable or even dangerous to civilians, our team has considered the idea of improving the current models of UAVs in order to make them biodegradable, modular and even cheaper and hence increasing

their accessibility and practicability to the scientific and civilian societies. (“Human Practices,” Stanford Brown Spellman iGEM team, 2014)

What is noteworthy about this passage is that even after weighing the ends that their own project would serve, the team concludes that simplifying and distributing biotechnology—making it modular, cheaper, and thereby more accessible—is an end in itself. In keeping with this instrumental rationality, the team’s public opinion surveys and discussions with regulators indicate a transmission model of communication. Rather than inviting different perspectives on the question of whether or not to advance drone technology, they determined that increasing people’s knowledge about UAVs would be the best way to address problems associated with their project. Their considerations of social issues proceeded in two parts: first, “to dive deep into the social and economic impacts of using synthetic biology in general,” and second, “to consider how to work around the stigma present in society regarding the uses of UAVs” (“Uses of UAVs,” Stanford Brown Spellman iGEM team, 2014). In this conceptualization, as in the broader organizational structure of iGEM, social and political concerns are both separated from technical work and subordinated to it.

Conclusion: Simplification, Transmission, Systematic Distortion

These examples illustrate how, at iGEM, the transmission model of communication provides a relational ontology not only for the organization of DNA, but also for the organization of bioscientific work, and in turn, for the types of interactions that bioscientific workers have with their fellow citizens. iGEM’s techne of simplification and standardization locates the problem with genetic engineering in the variability of biological material, and the

resulting slowness and inconsistency of work in biological laboratories. In so doing, it defines social problems as a lack of understanding about the need for bioscientific work to be simplified, standardized, and distributed.

When I interviewed Drew Endy in August 2015, he told me that in his view, the iGEM was “broken.” In his account, the competition sacrificed its capacity for learning and innovation when it became institutionalized on a global scale. However, this study suggests that the competition may be broken at a more fundamental level. Indeed, at iGEM, communication is systematically distorted (Habermas, 1970; Deetz, 1992) at the level of the technique itself, which stifles learning by stifling the questioning of organizational norms and assumptions. The competition achieves its function as proof of concept for an industrialized vision of genetic engineering much more successfully than its purported function of enabling participants to learn about biology. iGEM’s president, Randy Rettberg, has argued that the competition prepares students to become “designers that know why something works. And it’s easier to figure out (how it works) when you know why” (as cited in Shifrin, 2014). Yet in practice, the primary lesson learned by iGEM’s “parts-based workers” appears to be that the pursuit of simplification as an end in itself will be rewarded enthusiastically. To do synthetic biology at iGEM is to enact an ethic of expediency (Katz, 1992) that instrumentalizes not only single-celled organisms, but also competition participants. Both are positioned as means of achieving the ultimate end of simplifying genetic engineering. Even “Policy and Practices” work is reduced to serving this predetermined end, rather than facilitating higher orders of learning by reflecting on organizational goals. To ask iGEM to prioritize higher-order learning likely equates to asking its organizers to undermine synthetic

biology's broader, and highly lucrative goal of distributing a vision of genetic engineering as distributed manufacturing.

Considering iGEM's techne of simplification also raises broader questions about the social and ethical dimensions of professional training in the sciences and engineering, the types of relationships that humans have with one another and with other organisms, and the strengths and weaknesses of different approaches to governing emerging technologies.

Having already introduced two alternatives to iGEM's organization of DNA, bioscientific work, and governance—the artisanal techne that preceded the cybernetic techne of molecular biology, and the techne of second-order cybernetics—I now proceed to a third alternative, the techne of do-it-yourself biology.

CHAPTER 4 : The Equivocal Technai of Do-It-Yourself Biology

“It doesn’t really work when people come in [to join the board] who don’t know us, because everybody comes in with their own assumption of what this is. *Oh, you’re doing education. Oh, you’re doing art. Oh, you have talks. Oh, you do outreach.* But we do all of these things.”

—Female research collaborator

As the above quotation illustrates, defining DIY bio is challenging not only from the etic perspective of the researcher, but also from the emic perspectives of the individuals involved in this work. As the speaker notes, her organization could reasonably be described as a school, an art studio, a speaking venue, or a deliberative forum. There are other categories, too: makerspace, co-working space, incubator, and of course, laboratory. As a result, “When I do presentations,” the same speaker observed, “people always come away saying I haven’t focused my message.” The message, in this case, is not focused because it is not, in fact, a single thing. Rather, multiple messages coexist simultaneously, and each is borne out in a distinct *techné*. The common thread that holds the organization together is the work of biotechnology, “the science of harnessing the power of complex biological processes and putting them to work for our own purposes,” as a research collaborator defined it.

Weick (1990) suggested that any new technology is an “equivoque”: “something that admits of several possible or plausible interpretations and therefore can be esoteric, subject to misunderstandings, uncertain, complex, and recondite” (p. 2). Equivocal technologies can be interpreted through many different voices; in this capacity, they resemble “boundary objects”: “flexible epistemic artifacts that inhabit several intersecting social worlds and

satisfy the information requirements of each of them” (Star & Griesemer, 1989, p. 393; also see Spee & Jarzabkowski, 2009). From a rhetorical perspective, equivoques are intriguing in that they are subject to competing definitional claims. They “exist as much in the head of the operator as they do on the plant floor” (Weick, 1990, p. 17), and furthermore, they may exist quite differently in the head—and in the craft—of one operator versus another.

From an organizational perspective, equivoques are intriguing in that they indicate the co-existence of multiple ways of simplifying biological complexity—in other words, different ways of approaching biology as a technology. In DIY bio, the equivocal nature of biotechnology constitutes equivocal organization. Multiple operators, to use Weick’s term, approach DIY bio with significantly different ends in mind. As in other organizations, they converged around common means, rather than common ends (Weick, 1979, p. 91-95). In this case, the technology served as the means that prompted the formation of the collective structure of DIY organization. Individuals came together, as Weick (1979) put it, “because each want[ed] to perform some act and need[ed] the other person to do certain things in order to make performance possible” (p. 91).

Although Weick’s language suggests a clear-cut distinction between a means and an end, the example of DIY bio illustrates how this distinction can become almost indistinguishably blurred in practice. For the individuals working in DIY laboratories, the technology of genetic engineering—what would generally be considered a means—is also an end in itself. Despite the differences in their individual goals, all of them agree that genetic engineering must become a pervasive technology. The pursuit of this common end—the *end* of making a particular *means* far more accessible—unites them. This resonates with Weick’s

(1979) contention that “[o]ne of the initial ends shared in common is that of preserving and perpetuating the collective structure which has been instrumental in aiding individuals to get what they want” (p. 92). However, in this case, the collective structure is shaped primarily by the effort to secure access to a specific technology. Even though biohackers sometimes exhibit widely divergent ontological understandings of what the technology is and how it should be practiced, their dedication to making this technology pervasive serves as the foundation of their organizing. Thus, DIY bio consistently instrumentalizes biological processes, but in different ways and for different purposes.

The equivocality of biotechnology stems from a lack of agreement regarding how to determine “the cut that makes a part” (Pottage & Marris, 2012, p. 105). In this context, determining “the cut that makes a part” means negotiating the boundaries that define particular sequences of DNA, as with the iGEM competition, as well as the boundaries that define the locations and applications of genetic engineering. Attempts to reconfigure organisms and biological processes present challenges that are simultaneously ontological and normative: Each way of drawing boundaries entails “legal, economic, technical and political ways of realizing ‘parts’, ‘shares’ and ‘contributions’, so that what is initially presented as a technical exercise in engineering turns out to be an exercise in configuring these diverse idioms and techniques of repartition” (Pottage & Marris, 2012, p. 105). From this perspective, to cut and paste DNA is to engage in *diaeresis*, which Plato described in *The Phaedrus* as “dividing things again by classes, where the natural joints are, and not trying to break any part, after the manner of a bad carver” (Bizzell & Herzberg, 2000, p. 160).

Brummans and colleagues (2009) have drawn attention to how the constitution of organizations requires a comparable type of carving:

what and how an organisation *is* is a matter of ‘cutting’ the chain of agencies in a particular way, which has very particular consequences for the constitution of the world. In turn, it is by influencing this cutting that agents, whether human or non-human, individual or collective, can affect the way things are, and are organized (p. 63, italics original)

In DIY laboratories, the question is not what to simplify and automate, but how—in other words, how to cut the chain of human and non-human agencies. As Luhmann (1990) noted, “the gist of technology is simplification;” thus, whether technical (like a computer) or social (like a policy), any new technology will reformulate and redistribute problems in different ways (p. 220-30). The techniques of DIY bio enable not only experimentation with biology, but experimentation with technological and organizational forms. More specifically, by advocating for a single definition of what DIY bio is, each *techne* encourages a kind of isomorphism (DiMaggio & Powell, 1983), or homogenization of work and governance. In rearranging DNA to constitute novel organisms, the *technai* in these spaces constitute novel organizational forms.

To demonstrate this isomorphism, this chapter introduces and compares three *technai* of DIY organization: the *techne* of distribution, the *techne* of ritual communication, and an artisanal *techne* that enacts a multidirectional model of communication. Each *techne* enacts a different definition of what genetic engineering is. In so doing, it defines what genetically modified organisms are and what kinds of organization DIY bio laboratories are. Before

introducing these technai and comparing them, I offer the following background on the origins of biohacking and the emergence of DIY laboratories.

Do-It-Yourself versus Do-It-Together Biohacking

The terms *DIY bio* and *biohacking* are multifaceted, referring generally to the study and application of biology by individuals who are unaffiliated with academic or corporate laboratories (Kera, 2012; Landrain, Meyer, Perez, & Sussan, 2013), but also to a political movement that advances “radical requests for openness and inclusion” along with “rejection of institutional prerogatives and constraints” (Delfanti, 2013, p. 127). As this latter characterization suggests, some of the earliest practitioners of DIY bio were “quite strident,” in the words of one research collaborator; they “called themselves punk and were bucking authority.”

Many of the principles of this movement resonate with the hacker ethic that evolved out of MIT’s Tech Model Railroad Club, or TMRC (Levy, 2010). TMRC members began using the term *hack* in the 1950s to describe “a project undertaken or a product built not solely to fulfill some constructive goal, but with some wild pleasure taken in mere involvement” (Levy, 2010, p. 9). For them, technology was a “playground,” and their weekends were frequently spent “root[ing] around campus buildings in search of ways to get their hands on computers” (Levy, 2010, p. 8). In the TMRC’s vocabulary, to hack was to wield a techne of artistic flourish:

the word “hack” had long been used to describe the elaborate college pranks that MIT students would regularly devise, such as covering the dome that overlooked the campus with reflecting foil. But as the TMRC used the word, there was serious

respect implied... to qualify as a hack, the feat must be imbued with innovation, style, and technical virtuosity. Even though one might self-deprecatingly say he was “hacking away at The System” (much as an axe-wielder hacks at logs), the artistry with which one hacked was recognized to be considerable. (Levy, 2010, p. 9)

Thus, hacking entails a cunning craftiness in the ancient Greek sense of the term *techne* (Wild, 1941, p. 255-6). From the TMRC’s *techne* of virtuosic ingenuity emerged a hacker ethic that valued unlimited access to computers and other means of hands-on learning, prized freedom of information, distrusted centralized authority and preferred decentralization, suggested that individuals should be judged on the merits of their art above all else, viewed elegant code as beautiful, and saw computers as a means of changing lives for the better (Levy, 2010, p. 26-37).

This ethic echoes in the 2010 Biopunk Manifesto written by biohacker Meredith Patterson (Appendix A), which was written for presentation at a 2010 UCLA symposium called “Outlaw Biology? Public Participation in the Age of Big Bio.” Although modeled on the Cypherpunk Manifesto of Eric Hughes, a leading advocate of privacy-enhancing technologies, Patterson’s Manifesto references privacy chiefly in the sense of limiting government interference in citizens’ lives. The primary good that it advances is access to biotechnology, as the following passage illustrates:

As biohackers it is our responsibility to act as emissaries of science, creating new scientists out of everyone we meet. We must communicate not only the value of our research, but the value of our methodology and motivation, if we are to drive ignorance and fear back into the darkness once and for all. We the biopunks are

dedicated to putting the tools of scientific investigation into the hands of anyone who wants them. We are building an infrastructure of methodology, of communication, of automation, and of publicly available knowledge. (Patterson, 2010)

In charging biohackers with “creating new scientists out of everyone we meet,” Patterson outlines a mission for herself and her peers that is not unlike religious missions to convert the masses. In claiming this role, she positions biohacking in a longstanding tradition in which individuals with expert scientific knowledge speak in a voice reminiscent of priests or prophets (Lessl, 1989; Walsh, 2013). When employing a priestly rhetoric, scientists must represent an elite minority of experts while simultaneously “making [the elite minority’s] esoteric concepts meaningful without overreaching the linguistic limits of an initiate audience” (Lessl, 1989, p. 186). These two purposes are somewhat at odds with one another: even if “motivated by a sincere desire to instruct the masses,” the scientist’s ability to “adapt and simplify” a highly specialized vocabulary necessarily distinguishes her from those who rely on her as a translator (Lessl, 1989, p. 186).

Patterson is attempting to overcome this paradox by positioning biohackers not only as evangelists for the cause of science (see Walsh, 2013, p. 2), but also as emissaries of decentralization. For her, the “entelechy” (Burke, 1969b, p. 13-15) or ultimate end of decentralization is a new form of organization. As Burke (1966) notes,

A given terminology contains various *implications*, and there is a corresponding “perfectionist” tendency for men to attempt carrying out those implications. Thus, each of our scientific nomenclatures suggests its own special range of possible developments, with specialists vowed to carry out these terministic possibilities to the

extent of their personal ability and technical resources . . . There is a kind of “terministic compulsion” to carry out the implications of one’s terminology. . . (p. 19, italics original)

Patterson’s particular compulsion is to dissolve the distinction between scientist “priests” and novice “parishioners” by enabling practically anyone to join the elite ranks of genetic engineers. Yet her phrasing nevertheless draws attention to the power differentials that she is seeking to elide. Even as she suggests that biohackers can place “the tools of scientific investigation into the hands of anyone who wants them,” she also characterizes her audience as ignorant, irrationally fearful, and in need of conversion.

Unlike the compartmentalization of expertise that is enacted by iGEM’s techne of standardization, Patterson’s Manifesto valorizes a techne that dramatically increases the degree of control exerted, or the degree of burden carried, by the individual subject, depending on one’s political perspective. In her terms,

Biopunks take responsibility for their research. We keep in mind that our subjects of interest are living organisms worthy of respect and good treatment, and we are acutely aware that our research has the potential to affect those around us. But we reject outright the admonishments of the precautionary principle, which is nothing more than a paternalistic attempt to silence researchers by inspiring fear of the unknown. When we work, it is with the betterment of the community in mind—and that includes our community, your community, and the communities of people that we may never meet. We welcome your questions, and we desire nothing more than to empower you to discover the answers to them yourselves. (Patterson, 2010)

Patterson's emphasis on "betterment" recalls Francis Bacon's 1620 treatise *Novum Organum*, which justified the need for a new, state-funded form of science by arguing, "Only let mankind regain their rights over nature, assigned to them by the gift of God, and obtain that power, whose exercise will be governed by right reason and true religion" (Bacon & Montagu, 1831, p. 90). In Patterson's account, as in Bacon's, empowerment is defined as access to technology coupled with the dexterity to wield it—a dexterity that is equated with moral virtue. This vision of control resonates with iGEM's in that both seek to distribute biotechnology. However, where iGEM is organized by strict divisions of knowledge, biohacking as defined by Patterson concentrates technical, organizational, and ethical knowledge in a single individual. This is consistent with the vision of technological innovation as freedom that inspired the developers of the personal computer to reorganize programming as a decentralized individual practice, rather than a hierarchical bureaucratic one as it had been in the 1960s (Kelty, 2014). Recognizing that technical knowledge is required for effective citizen participation in contemporary democratic processes (Kinsella, 2004), Patterson redefines scientific literacy as a *techne*: a kind of making rather than a kind of understanding—and furthermore, a kind of making that individuals are fully justified in pursuing outside of the bounds of formal organizations such as academic and corporate laboratories. In her words, "A person educated in science can understand science; a scientifically literate person can *do* science" (2010, asterisks original). In her case, this has involved developing techniques of ingenuity that make it possible to do genetics research at home—for example, isolating chickpea DNA "using non-iodized salt, shampoo, meat tenderizer, and a salad-spinner as a centrifuge," and trying to cure scurvy by genetically

engineering the bacteria that make yogurt so that they also produce vitamin C (Anderson, 2009, p. 35).

While the biopunk techne of access, autonomy, and knowledge-making figures heavily in the pages to follow, overall, this chapter focuses less on individual biohackers than on DIY bio laboratories, relatively formalized organizations that often operate as nonprofits. According to DIYbio.org, a nonprofit organization that advocates for safe and open DIY practices, approximately 80 of these laboratories exist worldwide, primarily in the United States and Europe, although some are located in Latin America, Asia, and Oceania (“Local,” n.d.). While Patterson and others were beginning to define biohacking as early as 2003 (Anderson, 2009, p. 35), often working alone in their kitchens or garages, DIY laboratories emerged around 2010, in part to facilitate the sharing of costs, equipment, and expertise. Thus, in some respects, these laboratories represent a second generation in which DIY bio is organized as a more communal enterprise.

Kelty (2010) has noted that since its earliest days as an individual pursuit, biohacking has existed “not outside of Big Bio but within it—it depends on it, thrives on it, and wouldn’t exist without it” (p. 2). In DIY bio laboratories, this interrelationship is abundantly evident in the formal training in biology that MA- and PhD-holding organizational members possess, as well as the formal and informal collaborations that they are undertaking with academic and corporate labs, which range from citizen science initiatives to the borrowing, scavenging, appropriating, and simplifying of tools and techniques. In these spaces, biopunk ideology intersects daily with pressures to commercialize and the mundane challenges of paying the bills and maintaining a relatively stable infrastructure. They are *do-it-yourself* organizations

in that they attract individuals with a very high degree of personal initiative. At the same time, research collaborators pointed out that these spaces might be more accurately described as *do-it-together* organizations, in light of the collaborative nature of the work being undertaken, often in close quarters.

Origin stories. The origins of DIY bio are subject to competing narratives. A well-advertised story suggests that DIY bio was originated in Cambridge, Massachusetts, in 2008 by Mac Cowell, a hobbyist and entrepreneur affiliated with the iGEM competition, and Jason Bobe, community director for the Personal Genome Project at Harvard Medical School (Nair, 2009). Yet some European practitioners objected to this narrative, arguing that at least one European group, Hackteria, had been hacking biology long before the Cambridge contingent. One commonality in all of the narratives is a deep attachment to biotechnical work, coupled with equally deep frustration with the organization of academic and corporate science. Seeking alternative models of work, biohackers looked to computing hackerspaces such as Silicon Valley's Hacker Dojo and New York's NYC Resistor, as well as to iGEM.

The United States DIY laboratories that I visited, which consisted primarily of large East and West Coast labs that had been operating for four to five years, were founded by individuals who came to know one another through common friends and common interests. One person wanted to work on cancer immunotherapy. Another wanted to learn from the mistakes of first-generation bioengineers by engaging more directly and more productively with anti-GMO sentiment. One had achieved significant success in corporate biotech but was growing tired of office life and missed laboratory work. Another covered iGEM as a journalist and thought,

Here are a bunch of undergrads saying, *We can do this in three months*. I thought to myself, if they can do it in three months, then why can't I do it in three months? The reason why I couldn't do it in three months was I had none of the resources, none of the education, and I didn't have a lab. The first step was get me a lab, and then I'll learn to do what they do. (personal communication, May 10, 2013)

In New York, people met in coffee shops. In California, they met in living rooms. According to one individual, after attracting unwanted media attention, people in Silicon Valley began to meet on street corners so that they could then walk to nearby addresses that had not been publicized.

Similarly, the European laboratories I visited were launched and sustained by individuals with backgrounds in biology or computing—and here, too, iGEM played a role. For example, one of the co-founders of the Danish lab participated in iGEM in 2010 as a molecular biology master's student. In the months leading up to the 2010 iGEM Jamboree, he began meeting with another co-founder and other interested locals at a computing hackerspace in Copenhagen that had opened the previous year. He came away from the competition particularly impressed by the quality and variety of efforts to hack laboratory tools and techniques, such as the Bangalore team's homemade fume hood and incubator, the Duke University team's use of a flatbed scanner as a tool to measure the growth of incubating bacteria, the Baltimore team's low-cost thermal cycler and gel-electrophoresis apparatus, and the Slovenian team's DNA assembly line.

As these brief sketches illustrate, the people I encountered in DIY laboratories possessed a high degree of personal agency. They were also highly educated: almost all

possessed at least a bachelor's degree. Many had also earned master's degrees or doctorates, often in the biosciences, engineering, or computer programming—and many were self-taught in related disciplines as well. One collaborator who is quoted in the following pages took some college coursework but did not complete a degree for personal reasons. However, he was practicing a *techne* of cunning ingenuity even as a recent high school graduate, when he started his own business after teaching himself to clone orchids. This anecdote begins to hint at the degree of initiative that DIY bio entails. Unlike the compartmentalized expertise that iGEM envisions for its “parts-level workers,” the *technai* of DIY biology entail carrying a flexible attitude into unfamiliar situations, and cultivating an attunement to *kairos*—an ability to sense the opportune time for a particular action (Sipiora, 2012). For many of these individuals, the appeal of DIY bio stems, as one individual explained, from the fact that biology is “the most sophisticated manufacturing system on earth.” As she put it,

Biology makes everything: trees, coral reefs, people . . . People have tried and failed—at great expense, and over long periods of time—to duplicate the manufacturing power of biology with chemicals or machines. A far more economical and efficient approach is to reprogram an organism. (personal communication, June 7, 2015)

As their activities became more coordinated over time, biohackers in both the US and Europe became intertwined with the world of bioart, a practice that emerged towards the end of the twentieth century. As Mitchell (2010) notes,

bioartists employ biological laboratory techniques and technologies both to create their living works of art and to keep these entities alive in the space of an art gallery.

What distinguishes bioart from other forms of art, in fact, is its claim to employ bioengineered life as an artistic medium. (p. 4)

Bioartist Eduardo Kac generated media attention in 2000 by commissioning the creation of a glow-in-the-dark genetically engineered rabbit as a piece of art (Kac, 2003). However, the first work to incorporate molecular biology tools and techniques appears to have been Joe Davis' *Microvenus*, a 1986 collaboration with geneticist Dana Boyd that encoded *E. coli* bacteria with a pre-Germanic symbol for life and femininity (Yetisen, Davis, Coskun, Church & Yun, 2015, p. 727-8).

In 2004, the FBI charged bioartist Steve Kurtz, a professor of Visual Studies at the State University of New York-Buffalo and founder of the performance collective Critical Art Ensemble, with bioterrorism after discovering laboratory equipment and harmless bacterial cultures in his home (Duke, 2004; Wolinsky, 2009). All charges against Kurtz were dropped in 2008, but the case made an impression on the DIY bio network, which continues to reference his ordeal in discussions. Since then, the legitimacy of *do-it-yourself* bio has been challenged in the *New York Times*, *Atlantic Monthly*, *Nature*, and other publications, and somewhat less publicly by security officials and scientists, which may have contributed to the impetus for launching *do-it-together* or community labs.

In every DIY laboratory that I visited, bioartists and biohackers were collaborating in some form. Thus, the organization of one field was, at least to some degree, dependent upon the organization of the other. As a research collaborator pointed out, currently, bioart is as slippery a concept as DIY bio, and both are becoming demarcated through the execution of knowledgeable craft. In his words, "Because this field is yet to be defined, it'll get to a

specific point where the definition will come through artwork, not necessarily through philosophical discourse as to what is bioart, but you know, you can constantly renew the field.” The following sections illustrate three organizational forms that are materialized in particular *technai*: a *techne* of distribution, a *techne* of ritual communication, and an artisanal *techne* that enacts a multidirectional model of communication. The coexistence of these persuasive knowledgeable crafts illustrates the equivocal nature of do-it-yourself biology, which, at the present time, has yet to converge around a single organizational structure. Each *techne* suggests a different form that this structure could potentially take.

A *Techne* of Distribution

As the origins of DIY bio illustrate, the individuals who organized these laboratories converged around the common means of genetic engineering. Although they had different ends in mind, all of them agreed on the need for greater access to biological systems.

Accordingly, one simplification that is widely agreed upon is the need to hack the infrastructure of academic and corporate science so that the persuasive practices of genetic engineering can become much more widely available. This is a *techne* of distribution.

Echoing the politics of earlier generations of hackers, it seeks to decentralize the hierarchical structures of academic and corporate science. One European research collaborator illustrated the limitations associated with hierarchy in describing his experience as a graduate student in the biosciences:

I couldn't really get decent discussion with the professors. At the time there was [*sic*] a lot of scandals in my department, as well, at the same time. PhD students weren't allowed to tell about their work because they were getting patents. Groups were

splitting up because of fighting over patent constraints. It was just all messy. I was just basically like, “This can be done in a better way.” (personal communication, October 25, 2015)

The director of a US DIY laboratory drew on academic laboratories as a similarly negative point of comparison, noting that in her organization,

We don’t care if what you do works. We don’t care if it makes money. We don’t care if it saves the world. This is very unusual because academic labs rely on grants, so they have to work on what the funder has determined is important. Also, it means what gets funded is what is likely to have an outcome. What gets funded is essentially what has already been done. (personal communication, June 21, 2016)

By contrast, DIY bio enables more autonomous experimentation, as well as the freedom to be curious and to play. Thus, DIY laboratories enable not only biological experimentation, but also experimentation with more decentralized ways of organizing biological work.

As biohackers tinker with organizational forms, they are also tinkering with decisions about how to simplify biological complexity. While iGEM was organized around the assumption that this simplification should occur through the creation of standardized BioBricks, in DIY bio, few assumptions are taken for granted, aside from the commitment to decentralization. For example, one research collaborator in a US laboratory—a PhD-level electrical engineer—joined the effort to simplify biotechnology in early 2014. Prior to this point, he had been reading about synthetic biology and microbiology for at least five years in his spare time, but the demands of his position as the chief technology officer at a startup company had prevented him from devoting much time to exploring biotechnology. When the

company was bought out, “the golden handcuffs popped off,” and “it seemed like if I didn’t begin to investigate synthetic biology at that time . . . I would struggle to think of another time in my life where I would ever do it.” Indeed, for this individual, kairos was essential to the appeal of DIY biology. “What I’ve always tried to be is on the right side of history,” he stated in a June 2015 interview, continuing,

If you look at the way that things are very likely to play out and the way that things are going to evolve, and not from a genetic sense but how the industry, how the world seems to be moving, ,it’s always interesting to try to attach yourself to the most interesting elements of that motion and contribute to it. If it’s already very well developed you can enjoy the fruits and successes of that hopefully more quickly. If it’s not as advanced as you’d like it to be, stick your oar in the water and start rowing. Help move it in the direction that you want it to be. (personal communication, June 10, 2015)

The direction in which synthetic biology appeared to be moving from his vantage point was a distinctly cybernetic one. Specifically, he drew an analogy to the point in time at which Claude Shannon began developing his theory of information at Bell Laboratories in the early years of the Cold War:

It sounds like a guy walking into Bell Laboratories seeing the very first transistor with the three wires coming out. It’s the ugliest thing you would want to see. There’s no way out. It looks like a dial that blew up or something. It’s just a very ugly type of system. There are a few, I would like to think there are a few people there going, “That’s going to be really big.” I know it’s 1949. I know we’re still trying to figure

out what to do with the USSR and there's a lot of other stuff going on. Eventually, this could really be big. (personal communication, June 10, 2015)

Each day, this research collaborator commuted for a total of more than four hours to work in a DIY laboratory that gives him access to reagents and other materials that distributors will not ship to his home address. The DIY lab also provides "a community of like-minded individuals," including another member with a bachelor's degree in biology and three years of experience in pharmaceutical laboratories, with whom he had begun collaborating on projects including attempts to replicate work done previously by iGEM teams.

When asked about his experiences with software coding versus the coding of DNA, he observed, "What's interesting is that when it's working right, they work brilliantly as zeroes and ones. In fact, you could argue that their use as either storage information, instructions is, literally, billions of years old." Nevertheless, he also identified two key differences: speed and reliability. In describing speed, he echoed Norbert Wiener and Tom Knight, among others, noting that "What's remarkable, what I find personally frustrating [is that] it takes so long to do anything. It's really hard to do. In part, if you think about it, it almost makes sense, because it's sort of like watching the grass grow, which is sometimes a joke for how long it takes to do something."

Regarding reliability, he noted that "The other bit is that there's a lot that can go wrong." For example, "You're looking for, perhaps, one bacterium with just the right DNA modifications to eventually grow into a billion DNA, with just that desired modifications involved." But sometimes, "You set up this beautiful environment for [the bacteria] to grow and flourish, the ones that you want, and do a great job. [But] oops. This other guy showed

up, this interloper, and he's going to, literally, eat the lunch of that other guy, to the point where he proliferates." For this research collaborator, unlike at iGEM, such unexpected outcomes represented learning opportunities—and specifically, opportunities to reflect on the goals of one's own work. As he noted, "It's funny, one of the major words creeping around right now is this word standard. [My biologist collaborator] is probably here complaining about it 10,000 times already."

Indeed, in almost every DIY bio laboratory that I visited in both the United States and Europe, the individuals participating in iGEM complained that their kits of standardized biological parts were defective. Seemingly every kit included at least one part that did not work as advertised, or was characterized inaccurately in iGEM's online catalog, or both. These findings confirm an observation that Frow and Calvert made in their (2013) study of the competition. As they put it, despite iGEM's rhetoric of engineering, "biology keeps surfacing and asserting itself in various ways throughout the competition" (p. 54). For instance, at the annual Jamboree, "teams sometimes joke about how BioBricks do not always 'behave' as they are meant to, but overall it is as though the struggles and dissatisfactions of the laboratory work are forgotten in the excitement of the competition and the enthusiasm to win a prize" (Frow & Calvert, 2013, p. 54).

Observing this ineffectiveness, one interviewee observed, "we don't need standardization right now. What we really need is functionality." What is striking about this observation is that, despite (or perhaps because of) having much more experience in the realm of software coding than wetware coding, this individual is highly attuned to the ways in which organisms behave differently than machines. He is adjusting the goals of his work

accordingly, while also retaining confident that in the long term, synthetic biology's standardization project will prove as fruitful as first-order cybernetics. Similarly, individuals across a variety of DIY laboratories frequently deliberated about the comparative virtues of different approaches to work and organization. Their levels of commitment to standardizing biology varied, yet their belief in decentralization rarely varied. Comparing DIY organizations to more centralized and hierarchical organizational structures, one individual observed,

It's the problem of the reformation in that if you have a clergy, no matter how corrupt it is, no matter how much they practice simony, no matter how much they're touching the bums of young boys, they're controllable because the Monsignors report to the bishops who report to cardinals. And they're claiming institutional justice – you see that with academic scientists and corporate scientists. And in a way there is a level of institutionality that is helpful. It allows for teams to work together and that allows for – there's review. Whereas with community labs who knows. Not everybody's going to – let's say [redacted name] and [redacted name] and [redacted name] are the perfect (and I think they are probably a really great) group to start a community lab. Not everybody's going to have a [redacted name]. Not every lab's going to have a person who's really good at patient explaining. The scientists may not be as personable or as interested. Whatever it is, you might get into a situation where there is more of a breakdown. I think the inevitability factor... is really important. It's going to fucking happen anyway. And the only way to make it a better outcome is to

work toward that better outcome actively, and not put your head in the sand. (personal communication, May 12, 2013)

The opening lines of this passage recall the priestly themes implicit in Patterson's (2010) "Biopunk Manifesto." Yet this research collaborator takes a more nuanced view of the comparative virtues of hierarchical versus decentralized organization. He associates the expert control of scientist "priests" with the sexual abuse scandals of the Catholic Church, while also observing that some degree of hierarchy can be helpful.

Indeed, DIY bio is justified here by an argument of technological determinism. In this instance, as in software hacking, determinism provides a motivation for hackers while attempting to immobilize their political opponents (Söderberg, 2013, p. 1278). Like Meredith Patterson, this individual suggests that the entelechy or fruition (Burke, 1969b, p. 13-15) of genetic engineering is distribution. Yet "as this endstate cannot be known with certainty, identifying it is a fundamentally rhetorical activity" (Kinsella, 2005, p. 66). In this case, labeling distribution as the culmination of biotechnology serves an evangelical function by legitimating the advancement of biotechnology.

Further, in referencing the "problem of the reformation," this individual echoes the language of Protestant Reformation that "is endemic to the cultural world of information technology" (Kelty, 2008, p. 211). Specifically, in comparing contemporary science to the church, this individual (intentionally or not) echoes programmer Eric S. Raymond's (1997/2001) essay "The Cathedral and the Bazaar," a touchstone for the open source software movement. The crux of Raymond's comparison goes as follows:

In the cathedral-builder view of programming, bugs and development problems are tricky, insidious, deep phenomena. It takes months of scrutiny by a dedicated few to develop confidence that you've winkled [*sic.*] them all out. Thus the long release intervals, and the inevitable disappointment when long-awaited releases are not perfect.

In the bazaar view, on the other hand, you assume that bugs are generally shallow phenomena—or, at least, that they turn shallow pretty quickly when exposed to a thousand eager co-developers pounding on every single new release. Accordingly you release often in order to get more corrections, and as a beneficial side effect you have less to lose if an occasional botch gets out the door. (Raymond, 2001, p. 4)

If you want to advance a technical field, Raymond argues, you will accomplish more in a shorter period of time if you crowdsource problem-solving. This argument is typical of what Douglas (1978, 2006; Douglas & Wildavsky, 1983) has called the individualist model of social organization, where group commitment is (by definition) relatively weak, dominant positions are secured by merit, and the primary form of control is competition. Meredith Patterson's (2010) Biopunk Manifesto exemplifies the individualist model in noting that, "Biopunks deplore restrictions on independent research, for the right to arrive independently at an understanding of the world around oneself is a fundamental human right." This model is "in principle an egalitarian society, but as it defers to wealth and power it fails to realise its egalitarian ideals" (Douglas, 2006, p. 6). Its archetypal hero is the "smug pioneer with his pickaxe" (Douglas, 2006, p. 3)—a figure that Rogers (2003) refers to as an "early adopter" in his theory of the diffusion of innovations. Smug pioneers and early adopters do not "ignore

or regret uncertainties; on the contrary, [for them] uncertainties are opportunities” (Douglas & Wildavsky, 1983, p. 96).

The freedom to pursue opportunities in biotechnology in a relatively decentralized setting did not come easily or cheaply. “I baked pecan pies for people at five levels of government,” said a co-founder of a California lab. Plus, not every landlord is eager to rent space to individuals unaffiliated with academic or corporate laboratories. There are shared workspaces for entrepreneurs. In Manhattan, for example, you can become a member of Harlem Biospace, a shared laboratory that bills itself as a “biotech incubator, the first of its kind in New York City to offer affordable shared wet-lab space for competitively-selected entrants.” For \$995 each month, membership entitles you to 24/7 access to a workspace (a desk, a shared lab bench, utilities, Wi-Fi, and a printer), as well as mentorship, events and classes, equipment, and a “community of like-minded biotech entrepreneurs.” But one of the key purposes of DIY laboratories is to provide similar resources for individuals who are not competitively selected, and who may lack the experience and motivation to qualify as biotech entrepreneurs. Thus, a sympathetic landlord is required. A co-founder of one US laboratory was rejected by several potential landlords but ultimately found one who had worked in laboratories previously and thought the idea was cool. Another US lab opened in a building owned by “an eccentric guy” who aims to curb gentrification by renting out space to “social entrepreneurs, artists, and small businesses. Nobody has leases. It’s about to be turned over to a foundation, it’s supposed to become a cooperative.” Both of the European labs that I visited were opened within spaces that were already operating as computing hackspaces.

Even after space was secured, abundant challenges remained. For example, according to one interviewee, a leading DIY practitioner has a saying about trash removal: What do you do if you spill a reagent that can't be mopped up with bleach and a paper towel? Or, if you can mop it up with bleach, what do you do with the paper towel? A biological waste disposal company must be located and convinced to assist you: be prepared to pay \$75 each time the trash goes out because licensed contractors are required to dispose of bio-waste. Then there are the water people, who need to come and test periodically to ensure that if certain substances are present in your waste water, they don't rise above a certain percentage—because if they do, you'll be fined \$10,000 on the spot. And the fire marshal, who has strong opinions about maximum occupancy—not just how many people you can fit per square foot, but where are the exit paths, and are they being blocked by laboratory benches. One solution: put the tables on wheels, and use folding chairs, which the fire marshal will consider as temporary. In some places, there are also parking regulations to contend with. For instance, one DIY laboratory originally intended to open in the space next to a computing hackerspace that inspired its existence, but this plan had to be altered because the building had an insufficient number of parking spaces.

Beyond that, there are markers of legitimacy to be obtained. A key advantage of DIY lab affiliation is that members can “order through us, and we have the tax identification number, we have the Dunn and Bradstreet number, we have everything that people want to see or are trying to figure out. We have the 501(c)(3) nonprofit status, we're incorporated in the state of [redacted].” Part of securing legitimacy involves developing a deep familiarity with laws and regulations, including which rules are enforceable and which are actually

enforced. For one individual, this involved asking people directly, *Do you enforce this rule?* and learning that the reply is often, *No, but we can if something goes wrong.* In his estimation, guidelines regarding the use of particular agents “have teeth,” whereas the only potential penalty for undertaking activities that exceed basic biosafety level guidelines is merely the loss of ability to get funding from the National Institutes of Health—a penalty that has little impact for DIY practitioners, who do not typically seek federal funding. Beyond the infrastructure, there was equipment to be hacked, a full account of which is beyond the scope of this chapter. However, Figure 8, a graphic from an article on DIY bio that appeared in the journal *Nature* in 2010, offers a glimpse into the scale of this work, as well as the mildly paternalistic attitude that the journal adopted toward the DIY community. For example, it suggests that would-be biohackers could benefit from joining the biosafety committee at their local university or medical center.

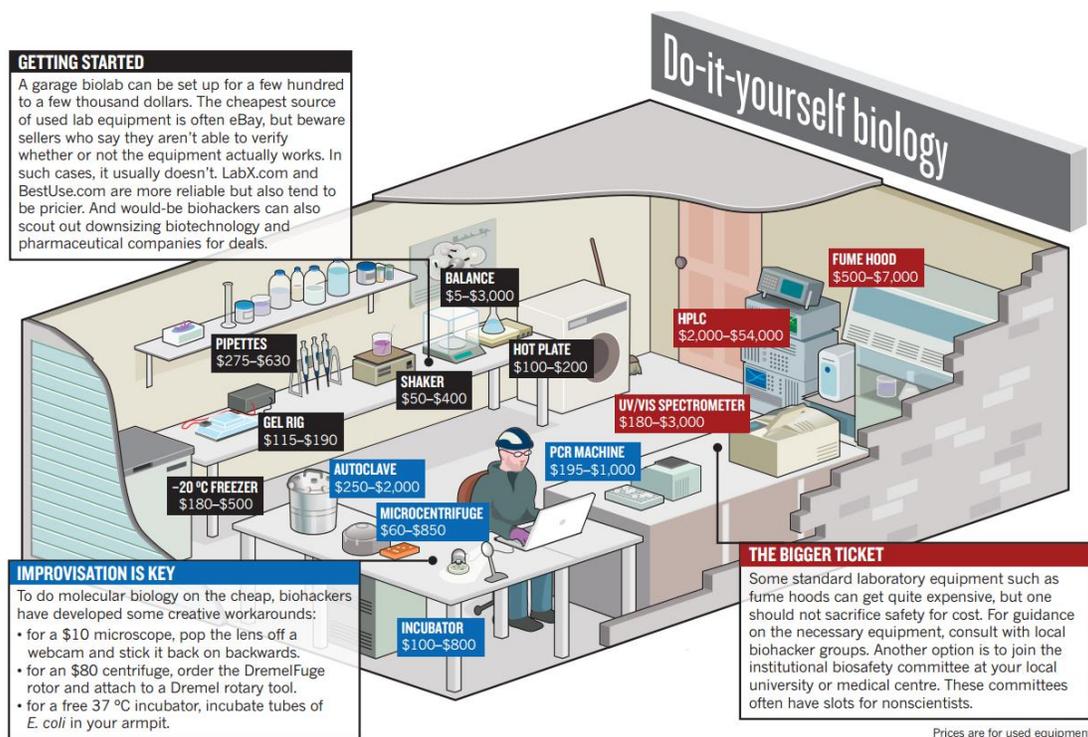


Figure 8: DIY Bio Equipment and Costs

From “Garage Biotech: Life Hackers,” by H. Ledford, 2010, *Nature News*, 467(7316), p. 651. Copyright 2001 by Nature Publishing Group. Reprinted with permission.

As part of its 2014 entry for the iGEM competition, a New York DIY laboratory, Genspace, created the Open Lab Blueprint, a website that offered instructions on how to launch a DIY laboratory. Rather than addressing technical or logistical issues, the first page on the website focuses on building community, noting that

The old proverb, “It takes a village to raise a child,” really is applicable to launching a community biolab. Even if the biolab is your “child,” it truly requires the support of a community to get it off the ground. The biolab requires so much time and diverse skillsets, that it needs to be a group effort to be successful. Communities take time to

develop – you need to begin fostering a community even before you consider the technical aspects of the lab (space, equipment, operations, etc.).

Further down on the page, the Blueprint recommends that the first step of opening a lab is “Gauging Interest: Make sure your community is ready for a lab,” it recommends. “Before you start planning, get a temperature check of the broader community. This check will enable you to answer a critical question, *Can my community support a biolab?* More specifically, the site recommends three ways to get a “temperature check of the community”:

Meetups. Meetup.com is a great tool and resource for tapping your community.

Attend any science or biology-focused meetups in your town and gauge their level of interest in a community biolab. Start a meetup group to begin cultivating your town’s biology community and build support for a biolab.

Attend events. Science fairs and lectures are great aggregators of the broader community. Attend or even set up a booth to start building interest in a community biolab.

Run small events. Host biology events that do not require a biolab. Activities like strawberry DNA extraction are a great way to give people a lightweight, hands-on experience. People who enjoy the activity may want to take their explorations further.

This latter point about the value of “lightweight, hands-on” activities in sustaining community holds equally true with respect to laboratories that have been operating for several years. In these spaces, the effort to build community does not subside over time; rather, it becomes a core function of DIY organization. As the following section illustrates, the effort to build community through “lightweight, hands-on” events is materialized in a

techne of ritual communication that organizes a sharp distinction between expert DIY bio practitioners and visitors to the laboratory. Rather than inviting newcomers to engage with the complexities of genetic engineering, this techne enacts an epideictic rhetoric of science: a rhetoric that celebrates scientific achievement by simplifying complexity in an appeal to an audience's sense of wonder (Fahnestock, 1998; Sullivan, 1991, p. 239).

A Techne of Ritual Communication

Epideictic rhetoric—rhetoric of praise or blame—has a longstanding ritual function that dates at least to Ancient Greece, where, as in the present day, it generated knowledge in a manner that departed from everyday conversation, promoted a sense of community, and offered a model of how life should be lived (Carter, 1991, p. 213). Epideictic rhetoric is the rhetoric of the “Happy Birthday” song, the commencement address, the funeral: Through these familiar rituals, community is renewed, and collective memory is maintained, providing “a crucial link between the past, present, and future” (Carter, 1991, p. 231). Although epideictic rhetoric is typically understood as a genre of writing or speaking, the example of DIY bio helps to illustrate how a knowledgeable craft—in other words, a techne—can also serve the persuasive function of building community through the celebration of science. Moreover, in DIY bio, a techne of ritual communication not only celebrates science, but also organizes the relationships between DIY practitioners, DIY laboratory visitors, and the non-human organisms that they engineer.

Building community through ritual is a commonly employed technique in science communication because by inspiring a sense of wonder and awe, rituals can cultivate an appreciation for science even among individuals with little technical knowledge (Fahnestock,

1998). While the transmission model of communication aims to transfer meaning from one place to another with as little change as possible, the ritual model of communication is directed “toward the maintenance of society in time” (Carey, 1989, p. 18). More specifically,

If the archetypal case of communication under a transmission view is the extension of messages across geography for the purpose of control, the archetypal case under a ritual view is the sacred ceremony that draws persons together in fellowship and commonality. The indebtedness of the ritual view of communication to religion is apparent in the name chosen to label it. Moreover, it derives from a view of religion that downplays the role of the sermon, the instruction and admonition, in order to highlight the role of the prayer, the chant, and the ceremony. It sees the original or highest manifestation of communication not in the transmission of intelligent information but in the construction and maintenance of an ordered, meaningful cultured world that can serve as a control and container for human action. (Carey, 1989, p. 18-19)

In its emphasis on the continual reestablishment of community, a *techne* of ritual communication materializes Burke’s (1969b) definition of rhetoric as “*the use of language as a symbolic means of inducing cooperation in beings that by nature respond to symbols*” (p. 43, italics original). For Burke, one of the core functions of persuasion is to induce cooperation by facilitating identification; as he put it, “You persuade a man [*sic.*] only insofar as you can talk his language by speech, gesture, tonality, order, image, attitude, idea, *identifying* your ways with his” (1969b, p. 55, italics original). To compensate for the ways in which people are divided from one another, rhetorics of identification seek to establish

what Burke called *consubstantiality*, or shared substance, enabling individuals to become “substantially one.” As an example, Burke (1969b) offered the following scenario:

A is not identical with his colleague, B. But insofar as their interests are joined, A is identified with B. Or he [*sic.*] may identify himself with B even when their interests are not joined, if he assumes that they are, or is persuaded to believe so. Here are the ambiguities of substance. In being identified with B, A is ‘substantially one’ with a person other than himself. Yet at the same time he remains unique, an individual locus of motives. Thus he is both joined and separate, at once a distinct substance and consubstantial with another. (p. 20-21)

Cheney (1983) extended Burke’s theory to show how identification functions in organizational communication. For example, identification can be facilitated by “techniques” that establish common ground between the employee and the organization, unite organizational members in opposition to a common enemy, or more subtly, use the pronoun *we* to unite individuals who share little in common (Cheney, 1983, p. 148-9).

In DIY bio laboratories, the techne of ritual communication facilitates organizational identification in a similar manner. One popular ritual involves inserting foreign DNA into laboratory strain *E. coli* bacteria (that is, a strain commonly used for educational purposes, rather than the strain that causes food poisoning) to make the bacteria glow in the dark. Jellyfish DNA produces a green fluorescence, coral DNA produces red fluorescence, and DNA from other sources can produce colors ranging from yellow to purple. In academic and corporate biology laboratories, fluorescent DNA is often inserted into an organism along with other foreign DNA, then used to gauge the success of the insertion. If the resulting

genetically modified organism glows under a black light, scientists have an indication that both DNA sequences are active (Anthes, 2013, p. 16).

As a DIY bio activity, inducing fluorescence becomes an end in itself, rather than a means of validating the success of other work. For instance, multiple labs organized introductory classes around the ritual of making *E. coli* glow in the dark by introducing foreign DNA. After the bacteria have been modified, they are incubated in petri dishes coated with a growth medium that keeps them alive. Participants use the bacteria to paint the dish with a design that will ultimately glow. By enacting this ritual technique, novice practitioners come to identify as genetic engineers.

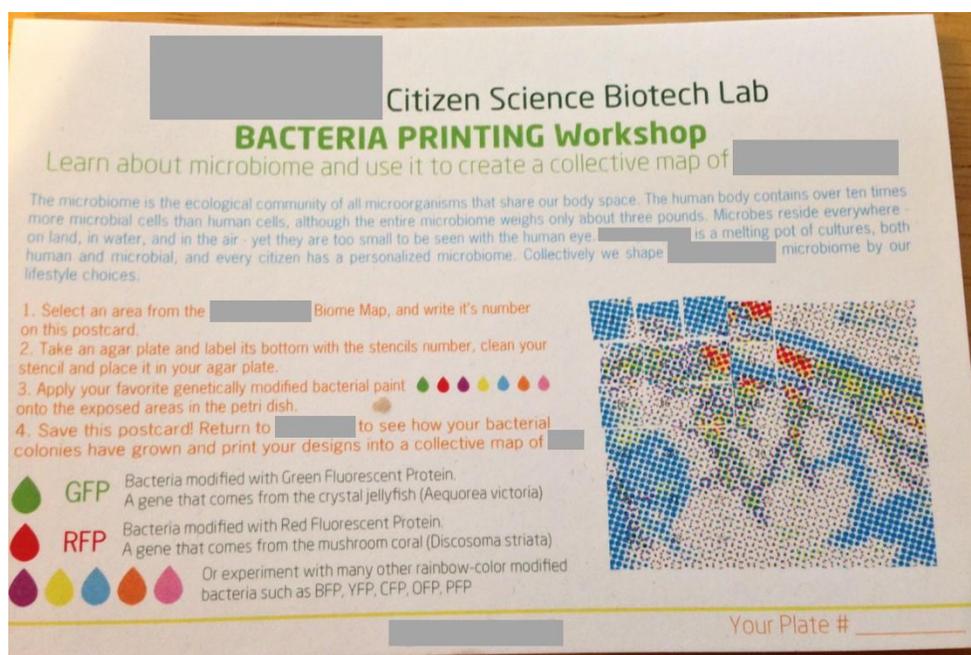


Figure 9: Bacteria Printing Workshop Handout

In one variation of the activity, plates were arranged into a unicorn mosaic that was displayed at a major music festival. In another, the bacterial painting took place at a street fair, where people walking by the laboratory's booth were invited to “apply [their] favorite genetically modified bacterial paint” to petri dishes using stencils that together formed a map of the city (see Figure 9). A few days later, they gathered at the laboratory to “print” the plates by transferring the images to paper and then laminating the paper (see Figure 10).



Figure 10: Prints from the Bacteria Printing Workshop

Another ritual, which is also common in middle and high school science classrooms, involves extracting the DNA from strawberries. This is the ritual that Genspace referenced in its advice about how to build community. It involves mashing strawberries; mixing them with salt, water, and dish soap; straining the mixture through cheesecloth or a coffee filter;

and then diluting it with rubbing alcohol. This process ultimately reveals long, wet threads of DNA. Because strawberries have a total of 56 chromosomes (ten more than humans, who have 46 chromosomes), they are particularly well-suited to producing large quantities of DNA that are easily visible to the human eye.

In California, the organizers of one DIY laboratory developed a ritual in which visitors were invited to take an oath, then given a black plastic badge that “authorize[d] and license[d]” them to practice as genetic engineers (see Figure 11). The oath was taken verbatim from Robert Heinlein’s 1942 science fiction novel *Beyond This Horizon*, which depicts a future in which the genetic engineering of humans is the norm. Geneticists take a “Mendelian Oath” much like physicians take the Hippocratic Oath, to demonstrate their commitment to ethical standards. Explaining the oath and badge, which he had developed, a co-founder of the laboratory observed that,

People liked the feeling of, *I’ve done something a little kinky and naughty, I’ve done genetic engineering, I’ve done a transformation*. Plus, you get something to take home. You get the badge. You get the knowledge that you’ve done something that 99 percent of the population hasn’t done, and you get the responsibility to decide what we do about this. *Should we shut down places like [DIY laboratories], or should we send all of our kids there so they can be bio-citizens of the future?*

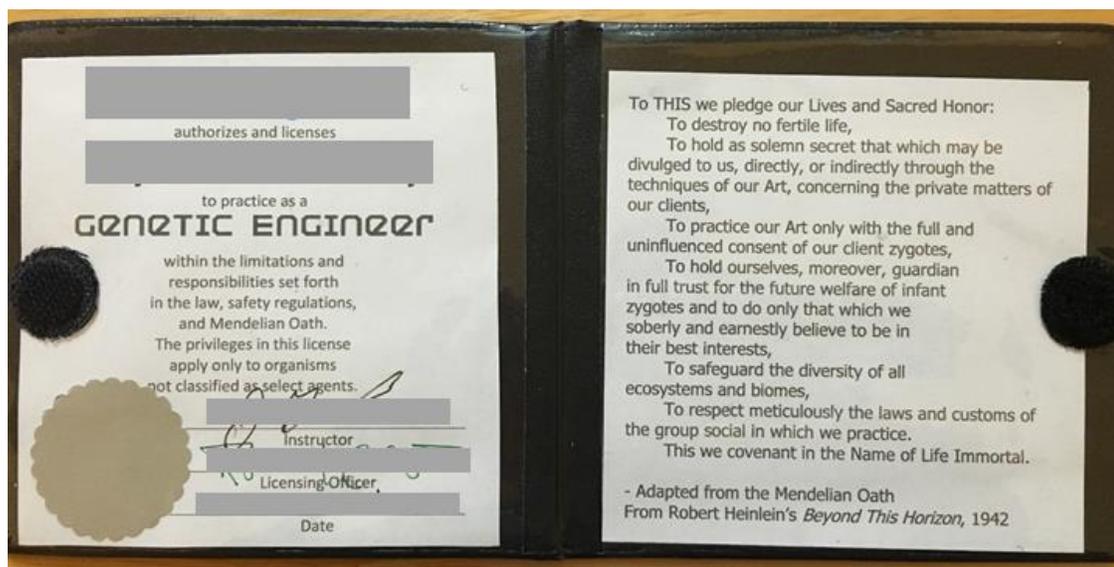


Figure 11: Badge Containing the “Mendelian Oath” from Robert Heinlein’s *Beyond This Horizon*

This description easily applies to the glowing bacteria ritual, the strawberry DNA ritual, or similar introductory exercises that are common across DIY laboratories. Newcomers to the activities take pictures to document their experience, post the photographs on social media sites, and occasionally call friends to announce their activities. In so doing, they are not only announcing that they have pushed the boundaries of acceptability, but also that they have wielded a powerful and controversial technology. As the above quotation suggests, these activities instill a sense that the power to make decisions about this technology rests, at least in part, in the hands of the individuals who are performing the ritual.

As Burke and Carey noted, the power of rituals is less a matter of information than of dramatic meaning. A ritual model of communication “does not describe the world but portrays an arena of dramatic forces and action; it exists solely in historical time; and it invites our participation on the basis of our assuming, often vicariously, social roles within

it” (Carey, 1989, p. 21). The dramatic appeal of DIY rituals stems from vicariously experiencing what it might be like to be a genetic engineer: a person capable of redefining what a living organism is.

Rituals are, of course, also closely associated with religion. Carey, for instance, argued that in examining the activity of reading a newspaper, a ritual view focuses not on “sending or gaining information [but] more [on] attending a mass, a situation in which nothing new is learned but in which a particular view of the world is portrayed and confirmed” (1989, p. 21). Thus, “as with religious rituals . . . news changes little and yet is intrinsically satisfying; it performs few functions yet is habitually consumed” (Carey, 1989, p. 22). Similarly, Burke’s use of the term *consubstantiality* to describe the “substantial oneness” of identification invokes the theological doctrines of *consubstantiation* and *transubstantiation*, the former positioning the body and blood of Christ alongside the bread and wine in the Christian Eucharist, and the latter holding the bread and wine of the Eucharist to be ontologically equivalent to the body and blood of Christ.

In genetic engineering, the term *transformation* describes the change that an organism undergoes after its DNA has been altered. In the fluorescent DNA ritual, the organism being engineered becomes, at least to some degree, consubstantial with the species of jellyfish or coral that was the source of the inserted DNA: they come to share a common substance. At the same time, in this and in other rituals, the individual performing these relatively simple transformations becomes, at least to some degree, consubstantial with the community of genetic engineers. The inventor of the Mendelian Oath ritual referenced the feeling of power and responsibility that stemmed from the sensation of crossing over from the role of novice

observer to the role of elite scientific “priest.” As he put it, “You’ve played God—now, how do you feel? What’s your responsibility as a citizen? You don’t have the luxury of being neutral anymore; you’re among the powerful elite who wield this technology” (personal communication, August 12, 2015).

Yet paradoxically, even as it instills this identification, the *techne* of ritual communication can also have a distancing function, as participation in these simplified activities bears little resemblance to the actual work of an academic or corporate bioengineer or biohacker. Some individuals found it satisfying simply to have participated in the ritual. However, others were frustrated by the narrow scope of consideration that the activity encouraged. For example, the bacteria printing workshop I attended began somewhat awkwardly. Many participants had learned about the activity online rather than at the street fair where the bacterial plates had been painted. As a result, when the event organizers focused their remarks primarily on the logistics of how to make bacterial prints, attendees were confused by the lack of context. Further, after paying \$30 to attend, several of them had struggled to enter the workshop, given the DIY laboratory’s location in an unmarked building that is open only to those who know the security code.

Nevertheless, in under half an hour, they had not only found their way in, but also reframed the discussion to consider both the ends and the means of the activity. They politely interrupted the event organizers to clarify what had taken place at the street fair, and why, as well as how bacteria printing related to microbiomes, in light of the fact that the activity was advertised as an opportunity to learn about the microbiome (see Figure 2). Thus, in some respects, they were responding to the ritual’s prompting to think of themselves as

biotechnology decision-makers. But in other respects, they were seeking a deeper understanding of the science than the ritual had conveyed. The ritual made them dependent upon the organizers of the activity, who were their only source of acquiring this knowledge. However, the art students who had been leading the activity were only semi-qualified to answer technical questions, in part because the ritual had been designed not so much to educate as to inspire.

A guest speaker, a molecular biologist who managed educational activities for Cold Spring Harbor Laboratory, was present at the event and helped address participant questions. In doing so, she offered a much more complex portrait of the single-celled organisms being engineered, which had until this point been considered merely as a novel kind of paint. For example, she pointed out that the pungent smell that emerged when the plates of glowing bacteria were opened were actually an indication that the organisms were beginning to die, as they were running low on food and oxygen. She later raised a question about the organization of the ritual itself: “Why is it acceptable,” she asked, “to do [genetic engineering] as a kind of art when doing it for science is so controversial?” Audience members had little to say in response. But the ritualistic nature of the activity suggests that the lack of opposition stemmed from the repositioning of novices as scientific elites. In this case, the power of what Burke (1969b) called consubstantiality, or shared substance, repositioned the individuals involved in the activity as members (or perhaps pseudo-members) of the scientific community. Having become identified with the implicated parties, they were in no position to offer a negative judgment of scientific activities.

The scientist also explained that a microbiome is a miniature version of a biome—an interdependent community of organisms. While a biome can be as large as a rainforest, every rainforest contains a variety of smaller biomes: “for example a tree is a biome for insects, then a single insect is a biome for bacteria . . . A microbiome is a small (micro) version of this larger phenomenon, a whole world within you” (Dunn, 2012, p. 3). Nevertheless, it remained unclear precisely how painting with glowing bacteria related to understanding microbiomes. From a rhetorical perspective, the disconnect stemmed at least in part from the gap between the expectations of workshop participants and the educator scientist, who viewed the workshop as an opportunity for explanatory discourse, and the ritual’s function of facilitating celebratory discourse.

Participants and speakers alike ultimately decided that in terms of learning about microbiomes, the activity was fairly limited. For almost everyone involved, the more interesting and important aspect of the ritual was the opportunity to discuss genetic engineering and the potential futures that this technology could bring about. The techne of ritual communication had provided an opportunity for individuals to raise questions around these topics, but in and of itself, it did little to answer them. Instead, it offered only a superficial account of scientific complexities, enacting an organizational form that placed strict boundaries on the knowledge that laboratory visitors could possess—boundaries that could be shifted only because of the presence of a scientific expert. By contrast, the artisanal techne that I discuss in the following section works to undermine the boundaries between scientists and their fellow citizens, while also attending far more to the agency of non-human “members” of DIY organizations.

The Multidirectional Communication of Artisanal Techne

As described in Chapter Three, an artisanal techne is a persuasive craft that responds to the interactions of biological material with specific contexts—in other words, a persuasive craft that embodies a multidirectional model of communication. I previously characterized some forms of early twentieth-century biology as artisanal. For example, before biologists began to think of heredity primarily in terms of the transfer of genetic information, they focused more on how individual development stemmed from both the individual's parentage as well as the environment that the individual inhabited—in other words, as a combination of both nature and nurture (Keller, 1995, p. 4). This research paradigm materialized a multidirectional model of communication by highlighting how biological meaning required the interaction of materials and contexts. It simultaneously defined laboratory work as an artisanal techne that acknowledged the give and take of biological and ecological relationality. To work with biology, from this perspective, is to apply a craft that adapts to this give and take, much as a gardener cares differently for the same plant in a hot, dry summer versus a rainy season.

In the following section, I demonstrate how do-it-yourself biology facilitates an artisanal techne of genetic engineering. As with other DIY bio and bioart activities, this techne is enabled by a broader effort to distribute and decentralize the practice of genetic engineering by hacking scientific tools, materials, and infrastructure. Yet at the same time, practitioners of artisanal techne are skeptical of mechanization. A DIY practitioner in New York observed,

One of the things that I think people don't realize when they go into science is how hard it is to replicate somebody else's work. Yeah, it sounds very unscientific to say that there is one guy with great hands in the lab or whatever, but it doesn't mean necessarily that the data that he gets isn't real, it may be that you just have to be within some really narrow window to see these differences. Not that the differences don't exist. (personal communication, June 14, 2015)

Having "great hands in the lab," in this example, means having dexterity and judgment in the application of a particular technique, what Polanyi (1983) called "tacit knowledge." For instance, as the same collaborator noted, a human will tilt and tap a pipette to ensure that the last drop of liquid flows out of it, while an automated system would not.

A large part of the difficulty with automating biological work stems from the agency of the non-human organisms that serve as "members" of DIY laboratories. For example, in critiquing synthetic biology's emphasis on standardization, one individual in California produced a tray that held four petri dishes of yeast. Pointing to the varying degrees of growth that could be seen in each dish, she said, "You can see where the bacteria were willing to work with you for a while, but then they are like, no, not if you say my curfew is too late or not if you don't give me more spending money." Comparing the scientist-bacteria relationship to the parent-child relationship in this manner suggests that softer forms of control can oftentimes be more productive than the "strict" approach of synthetic biologists, which expects single-celled organisms to behave the same way in every interaction. As the conversation continued, she suggested that for living organisms, total standardization was akin to death. In other words, to limit variation is to limit the ability of a species to adapt in

relation to its surroundings. Similarly, an individual in Europe dismissed synthetic biology as “crap, basically. I think it’s just rebranding.” He continued:

It’s genetic engineering. It’s nothing else other than genetic engineering. It’s just making new words here so you can make another spinoff and claim ownership of a brand... Get more money and you’re the expert. That’s kind of the classical tech hype and putting one man in front as the genius who invented it and completely neglecting the aspect of how ideas and evolution actually work. I hate it... It’s just not the complete story of how you can tinker and work with biology... This is nuts, and they kind of have an impediment, “You have to apply these standards and rules.” But who the fuck defined these standards? (personal communication, October 25, 2015)

From this perspective, the question is not how to standardize biology, but how to work productively with non-human organisms: how to “tinker and work with biology” in a way that respects “how ideas and evolution actually work.” For practitioners of artisanal techne, working productively with non-humans begins with acknowledging their agency. For example, rather than positioning humans as superior to other species, multiple research collaborators went so far as to suggest that humans were inferior to other species. One individual noted that unlike humans, fungi “will thrive anywhere,” even in jet fuel, where they are used to prevent engines from clogging. She then told the story of a friend who had done laboratory work with fungi. The fungus entered her bloodstream through an open wound on her hand, and the woman was ultimately required to have one of her limbs amputated. Much as this anecdote can be interpreted to illustrate the relative weakness of

humans in comparison with fungi, another individual argued that humans were inferior to plants. As he put it,

...we [humans] exist as complex lifeforms because we rely on lower lifeforms, but basically more efficient lifeforms, to give us a food source. So we're high-waste, high-consumption lifeforms. They're low-waste, low-consumption. It's just a different spectrum. Essentially we've evolved hands, eyes and all these things because we can't do what plants do. So anyone that says the plants are lower or lesser lifeform, that's not true because we have to hunt, they just sit there so they have a really easy life, the only bad part is they can't move. (personal communication, August 20, 2015)

In this comparison, the status of non-human life forms is elevated while the status of human life forms is reduced, bringing the two kinds of actants (Latour, 1988) closer together. This refusal to diminish non-human agency was borne out in the persuasive techniques that these individuals employed, which at first glance often resembled art at least as much as science, raising questions about what distinguishes one from the other. For example, when I met him in Copenhagen in 2015, a Norwegian artist was developing a work that exemplified a multidirectional model of communication. He coiled wires around the roots of a plant, then attached them to an amplifier (see Figure 12). His goal was to “listen to the plant and use intuition as a way to communicate with it, try to understand it through intuition.” His partner, another artist, elaborated, suggesting that in this case, intuition is “the combination of the plant's thoughts and your thoughts.” “I'm thinking maybe I can talk to it, too,” said the project's creator.



Figure 12: Untitled Apparatus for Human-Plant Communication by Daniel Slåttnes

In many respects, this apparatus resembles an iGEM competition entry—and in particular, the 2014 Tianjin team’s effort to connect biological signals and electrical signals by engineering the extracellular fibers of bacteria to interface with inorganic materials. Yet it also differs from iGEM projects in a fundamental way: its primary focus is on hearing and perhaps conversing with a non-human organism, rather than controlling it. Like other works

of bio art, this installation “plays with the assumptions we make all the time about the real and how we represent the real scientifically,” as a bioart aficionado in New York stated; it is a “very like *I’m fucking with you* space where it looks like its science but it’s actually art, so it’s play.”

Some playful techne constituted a form of entertainment. For example, one involved creating a “mobile algae bar” installation for display at an art festival. The algae bar was originally created by artist Amanda Olesen in collaboration with the Copenhagen DIY laboratory and other affiliates of a Fugt (a Danish term that translates to “moisture” in English), a network of organizations that collaborate on projects related to the intersection of biology, technology, and culture. On their website, the DIY laboratory described the bar as follows: “Bringing in a unique mix of cyanobacteria, algae and beer, the Algae Bar is the product of a trans-collaboration between two, once considered different, species: the artists and the scientists.” The bar looked like a cartoon of a mad scientist’s workspace, with beakers of bright green liquid surrounded by strings of LED lights. After ordering a beer, one could have a “shot” of liquid—which was composed of edible seaweed bought at a local Asian market, paired with fruit juice—dropped into the beer, which resulted in a greenish liquid that one reviewer described as having an “earthy” flavor (Bancroft, 2015).

In general, though, artisanal techne encouraged an attitude of reflexivity rather than an attitude of consumption. The Swedish partner of the artist who developed the plant communication apparatus created a living sculpture that bore resemblances to a compost pile (Figure 13). “I’ve fed it with different things,” she said, “First I fed it with moss, and then now I have started feeding it with meat. I guess that’s the meat that is living [in other words,

attracting bacteria], but just to see what it likes.” Each day, she created a new drawing of the sculpture to document its growth in a kind of stop motion animation.

As she explained, the drawing process was, “a way of trying to get to know with them”—in other words, with non-human actors:

Then I thought that because we had this concept where we want to be able to communicate with the material to let the material do the exhibition. I started thinking that I wanted to let the material draw by itself instead of me drawing the material. Even though I find that as an interesting relationship that is being created between me and the sculpture, I wanted to make that able to express itself... I see my working as a communication between me and the artwork. The artwork is teaching me things and I am teaching the artwork things... Maybe you can have a communication that is more based on that emotion than about the reacting towards things. Maybe you can call it intuition. That is just feeling yourself around the world, feeling the object, feeling the plant, and feeling the animal. (personal communication, October 26, 2015)



Figure 13: Untitled Living Sculpture by Sara Rönnbäck

This affinity for non-human actors, whether biological or technological, was echoed by Ali Schachtschneider, a bioartist affiliated with the DIY laboratory in New York. She had been studying fashion and focusing particularly on the waste and pollution associated with the textile industry, and the exploitative labor practices associated with “fast fashion,” the

rapid distribution of cheap runway knock-offs. For Schachtschneider, biodegradable materials such as the mycelium and cellulose that the 2014 Stanford, Brown, and Spellman iGEM team used to build their drone prototype represented an opportunity to “give matter agency” and encourage people to “think more about [their] interaction with other things,” whether living or non-living. As a former ballet dancer, she focused explicitly on physical interaction, experimenting with different ways of relating biomaterials to the body. For instance, following the lead of artist Suzanne Lee, she brewed green kombucha tea and added sugar, acetic acid, and single-celled organisms that feed on the sweetened liquid. Over time, the bacteria produce tiny cellulose fibers that stick together in layers, ultimately forming a sheet of smooth, flexible material with a consistency much like that of a chicken breast. In addition to envisioning different forms of clothing that could be made with this material Schachtschneider produced speculative works that envisioned other ways of interactions with biomaterials, such as a pill that would prompt the human microbiome to make cellulose when an individual produced sweat. The resulting cellulose could then be peeled off and eaten, giving the human body a way to produce its own food.

Agency, instrumentality, and organization. Although these examples focused on individuals who self-identified as artists, their work was enabled by individuals with expertise in science or engineering, who often collaborated so closely with artists that the scientist/artist distinction ceased to make sense. For example, a DIY practitioner in Copenhagen collaborated with an artist to develop a *Bioreaktor* (Figure 14), a microbial fuel cell that drew on cyanobacteria, aquatic single-celled organisms that produce their own

energy through photosynthesis, to develop a prototype for an energy source that would serve both the bacteria and their human collaborators.



Figure 14: A *Bioreaktor* by Laura Beloff and Martin Malthe Borch

The same individual, who holds a master's degree in biotechnology, was embarking on a new collaboration with a dancer when I spoke with him in Copenhagen in October 2015. As he put it,

She uses a lot of sounds like moving the speakers around and moving also the light installation around in the sense that creating fluorescent patches and patterns that is moved around by the dancers. The dancers were moving these things, so the dancers were not just ... but moving other stuff and being more hidden.

Now she's taking that into biological aspect, so what's around the dancers? How can you dissolve the porous biological motor of the dance? That's her kind of the

reflection. She got this money and there's a lot of money in synthetic biology, as you know. She got a three-year research grant. I was invited as kind of a pre-study. We're going to be me, her and another two dancers, ... Basically, be in a dance studio two weeks and see what comes out of it. (personal communication, October 25, 2015)

This openness to collaboration—and to the input of others, represents a defining feature of artisanal *techne*, which is rooted in a multidirectional model of communication, a model that emphasizes listening as much as persuading, and that approaches non-human actors as valued organizational collaborators. In so doing, this *techne* realizes Bateson's vision of a reflexive craft that aims less to control than to engage the world in conversation. From this perspective, the world is “made up of a very complex net-work [*sic*] (rather than a chain) of entities which have this sort of relationship to each other, but with this difference, that many of the entities have their own supplies of energy and perhaps even their own ideas of where they would like to go” (Bateson, 1987, p. 273). Acknowledging this relationality requires reformulating “problems of control” so that they become, as Bateson put it, “*more akin to art than to science*, not merely because we tend to think of the difficult and unpredictable as contexts for art but also because the results of error are likely to be ugliness” (1987, p. 273, italics added).

In making this argument, Bateson echoed Heidegger's (1977) vision of an artistic *techne* that would facilitate “essential reflection” and “decisive confrontation” with technologies, rather than automatically enframing living organisms as “standing reserve:” material defined by the utility it provides for humans. Somewhat similarly, after defining bioart as a kind of play, a research collaborator in New York argued that, “The difference

between play and rigor is utility for capital. Whereas play is always trying to stab capital in the face if it's actually any good.”

Considering these works not only in terms of their utility for capital, but also in terms of the communication models that they materialize, suggests a blurrier picture. For example, in discussing DNA in relation to heredity, the organizer of a DIY lab in New York recalled decades of conversations among geneticists and linguists (see Kay, 2000) in suggesting that following genetic variation over time was like “following the development of language... There are root languages, and over time, different populations break off and start mutating and varying.”

In this account, unlike transmission models of persuasive craft, the making of meaning is recognized as a relational process that involves the interaction of letters and words with specific material contexts. This does not necessarily imply that no instrumentalizing is taking place. Rather, following scholarship in organizational communication, it allows for the possibility that some degree of instrumentalizing informs any organizational relationship. For instance, Taylor (2001) uses the term imbrication to describe “the way that interagency relationships are interweaved to form . . . infrastructure” (Taylor, Groleau, Heaton & Van Every, 2007). In every system of activity, this interweaving brings humans and non-humans together “like the shingles on a roof, the foliage on a tree, or the scales on a fish” by positioning some as agents and others as instruments (p. 280). Although the distinction between agent and instrument may at first seem obvious and clear, it is blurred by a series of ethical orientations related to the positioning of means and ends. Agents are “actors but, because they are actors-for, they are also instruments of someone

else's purpose—means to an end,” whereas instruments are “first and foremost devices, tools or implements that figure as the means by which something is accomplished; also, in their own way, agents” (Taylor, 2001, p. 279). In imbricated organizational systems, “what is instrumentality at one level becom[es] agency at another, and vice versa” (Taylor, 2001, p. 280). Technology is “an effect of imbrication: sequences of agent-instrument tiles recursively embedded into an infrastructure to become a complex, multi-leveled instrumentality for the realization of the ambitious agencies typical of modern life” (Taylor, 2001, p. 281; also see Leonardi, 2011).

This perspective suggests that rather than evaluating DIY bio and bioart solely in terms of utility for capital, we might instead look closely at what types of organization were being imbricated by particular *techne*, an approach that I have tried to model here. From this standpoint, “staying with the complexities does not mean not acting, not doing research, not engaging in some, indeed many, unequal instrumental relationships;” instead, it means following the example of artisanal DIY practitioners by “learning to live and think in practical opening to shared pain and mortality and learning what that living and thinking teach” (Haraway, 2008, p. 83).

Conclusion: Reorganizing DNA and Scientific Work

As I mentioned in introducing this chapter, by advocating for a single definition of what DIY bio is, each *techne* encourages a kind of isomorphism (DiMaggio & Powell, 1983), or homogenization of work and governance. In rearranging DNA to constitute novel organisms, the *technai* in these spaces constitute novel organizational forms. The *techne* of distribution reconstitutes genetic engineering as a decentralized practice in the style of

software hacking. The *techne* of ritual communication organizes genetic engineering in the style of priest-parishioner relationships. The *techne* of the artisan organizes genetic engineering as (albeit unequal) multispecies collaboration.

At the same time, in advancing an entelechy of distribution, all of these *technai* share a similar *telos*—what Aristotle (2001) called “that for the sake of which”—in other words, the final cause or completion of an action. In the *Physics*, Aristotle suggested that much like a skilled craftsman, nature acts with purpose (2001, 199b, 25-30). Specifically, he argued that “the absence of deliberation in nature does not prove an absence of purposiveness, because after all a skilled craftsman need not deliberate about how to proceed. (Indeed, the more skilled he is, the less he has to think about what to do.)” (Ackrill, 1981, p. 43). From this perspective, there is a kind of rationale (although not a conscious rationale) behind the taken-for-granted yet nevertheless remarkable phenomenon that,

each living being produces offspring that resembles it in kind . . . It never happens that a woman gives birth to a cat, or the other way round . . . Thus the whole process of formation must be understood as being guided by the future, i.e., by something which is not yet, but which will be, provided the process is not disturbed or prematurely terminated. A human embryo, for instance, is what it is and develops the way it does, precisely *because* of what it is going to be, namely a human being.

(Hauskeller, 2005, p. 4, italics original)

The notion that biological processes serve a kind of purpose can be interpreted as a justification for humans to respect what we might call the “wisdom” of nature—for example, by taking a precautionary approach to genetic engineering. However, even in its most

collaborative form, the *techne* of DIY bio inverts Aristotle's concept of *telos*, replacing its respect for the wisdom of nature with the assumption that the functioning of DNA is in need of improvement.

CHAPTER 5 : Conclusion: Techne as Discursive-Material Organization

I began this dissertation by highlighting a tendency in organizational communication scholarship to conceptualize the symbolic craft of language and the material craft of everyday work as distinct phenomena. As I mentioned, part of the difficulty stems from the fact that research has focused almost exclusively on the meanings embedded in language—for example, in documents, transcripts, or formal talks (Cooren, Kuhn, Cornelissen et al., 2011, p. 1151)—while neglecting how meaning is inscribed into objects and relationships. For example, advocates of Communication as Constitutive of Organization theory (Cooren, 2004; Putnam & Nicotera, 2009) position communication as central to organizational ontology by defining organizations not as static objects that contain communication (Smith, 1993), but dynamic processes sustained in and through communication (Putnam & Fairhurst, 2015). Nevertheless, it remains unclear what scholars mean when we say that communication is “constitutive” of organization (Putnam & Nicotera, 2009; Cooren, Kuhn, Cornelissen et al., 2011; Ashcraft, Kuhn & Cooren, 2009; Robichaud & Cooren, 2013)—and more specifically, how the “constitutive” force of communication relates to material objects. Scholarship has tended to “talk about communicating and organizing as dynamic activities without unpacking the nature of these processes and how they are related to the elements that form an organization” (Putnam, Nicotera & McPhee, 2009, p. 5). Even in “replacing the traditional ‘discourse constitutes’ question with, ‘How do discourse and materiality mutually constitute each other in the routine practices of organizational life?’” (Putnam & Fairhurst, 2015, p. 383), research has implicitly defined language and other forms of symbolic work as separate from the material world (Stewart, 1995, 1996). In so doing, it has reified an

Enlightenment-era dualism that separates talk from action and language from materiality, producing scholarship that “leaves an important part of the spectrum of human organizational experience out of sight and presents a limited view on the way an organisation is constituted” (Brummans, Cooren, & Chaput, 2009, p. 54).

By contrast, sociomaterialists have built on the phenomenological research tradition to argue that, “Matter and meaning are not separate elements. They are inextricably fused together, and no event, no matter how energetic, can tear them asunder” (Barad, 2007, p. 3). From this perspective, the meaning of one thing arises only in relation to others: “the social and the material are constitutively entangled in everyday life” (Orlikowski, 2007, p. 1437). The processes through which this “entangling” takes place have been called discursive practices: “specific material reconfigurings through which ‘objects’ and ‘subjects’ are produced” (Barad, 2007, p. 148). But here, too, there is a lack of clarity around what exactly a discursive practice looks like in action, and how one discursive practice can be compared with another.

This dissertation has worked to mitigate some of this ambiguity by demonstrating how work itself can be approached as a persuasive knowledgeable craft—in other words, as a *techne*. As an object of analysis, *techne* draws attention to how symbolic-material work defines subjects and objects by defining the relationship between the two. Rather than investigating the “immaterial” phenomenon of human communication in relation to the “material” biological or technological world, focusing on *techne* enables scholars to document how the ontological categories of human and non-human, biological and

technological, discursive and material emerge. Specifically, I applied the framework of *techne* to investigate three research questions:

- What constitutes work when the tools and techniques of genetic engineering are distributed beyond the gated settings of academic and corporate laboratories?
- What types of beliefs and practices enable this distribution?
- How does the organizing of biological work affect both human and non-human actors?

To introduce the research context for my investigations of these questions, in Chapter One, I discussed how genetic engineering typifies the symbolic, and even linguistic, qualities of material work. The gene, for instance, is a “paradigmatic example of the way in which language constructs an objectified essence where none exists in nature—but where that objectification is useful and is related to real material processes of undeniable significance” (Condit, 1999, p. 334). Scientists describe sequences of DNA as “genes” not because they are obviously or essentially discrete, but because identifying them as discrete entities enables them to accomplish specific goals (Keller, 2000). Thus, in the work of genetic engineering, the symbolic action (Burke, 1966) of re-coding the DNA nucleotides A, T, C, and G has the material effect of transforming the physical characteristics and capabilities of living organisms.

In Chapter Two, I introduced how the term *techne* was used in Ancient Greece to describe the human craftwork that distinguished nature from culture. Unlike the contemporary terms “technique” and “technology,” which suggest mechanized, objective motion, *techne* in ancient times referred to “the general ability to devise intelligently means

appropriate to certain purposes, whether of necessity or of pleasure” (Bruzina, 1982, p. 166). Although the earliest teachers of rhetoric, the sophists, saw language as a *techne* that defined the relationships that connect one thing to another, Plato advocated successfully for a different view that by now has become so familiar that it is taken for granted. In this view, rhetoric may be a knowledgeable craft, but it is not a means of producing ideas or things. As Plato’s strict division of rhetoric from the invention of knowledge was advanced by his student Aristotle, among others, it became increasingly natural to think of persuasion as simply a vehicle for knowledge gained elsewhere, rather than a materially oriented craft in its own right. Today, scholars reify this assumption by approaching language and materiality as distinct phenomena and focusing their analyses on one at the expense of the other. By contrast, in the latter part of Chapter Two, I discussed how the theoretical framework of *techne* can be operationalized methodologically to enable scholars of communication and rhetoric to trace how particular forms of persuasive knowledgeable craft produce the agential cuts (Barad, 2007, p. 140) that distinguish subjects from objects. In the research context of genetic engineering, this approach is particularly valuable because it recognizes the carving of relational ontologies that simultaneously shape organisms and organizations.

In subsequent chapters, I drew on multi-sited ethnographic research to show how, in producing agential cuts, the cutting and pasting of different *technai* of genetic manipulation reorganize not only DNA, but bioscientific work. Specifically, Chapter Three described how mid-twentieth-century geneticists applied aspects of Claude Shannon’s transmission model of communication to DNA by conceptualizing genes as standardized units of information that carry the same meaning regardless of context—and how, decades later, this transmission

model is materialized in the iGEM competition's techne of standardization. At iGEM, the transmission model of communication provides a relational ontology not only for the organization of DNA, but also for the organization of bioscientific work, and in turn, for the types of interactions that bioscientific workers have with human and non-human others. iGEM's techne of standardization facilitates isomorphism (DiMaggio & Powell, 1983) by structuring the competition as distributed manufacturing and structuring the professional identities of team members as factory workers. This techne positions the standardization of work as an end in itself, rather than a means of achieving other ends. In elevating the pursuit of standardization, the competition neglects the insights of cyberneticians such as Margaret Mead and Gregory Bateson who advocated for forms of learning that enabled individuals to reconsider and sometimes reformulate the goals they had initially set out to achieve. The competition also neglects the insights of biologists who acknowledge that sequences of DNA often produce different results in contexts—in other words, that the manifestation of biological meaning comes about as a result of multidirectional communication between DNA, bodies, and environments. In ignoring both of these perspectives, iGEM denies the agency of non-human organisms and inhibits organizational learning.

In Chapter Four, I turned to the organizing of do-it-yourself biology laboratories—laboratories that enable experimentation not only with genetic engineering, but also with technological and organizational forms. Like the iGEM competition, DIY bio simplifies biological complexity in order to facilitate the distribution of genetic engineering. But unlike iGEM, which is organized around a particular vision of how genetic engineering must be simplified, DIY bio laboratories enable experimentation with different approaches to

simplification. The common craft that unites their activities is a *techne* of distribution that decentralizes the organization of genetic engineering. However, decentralization does not necessarily lead to equal understanding, equal control, or equal participation in bioscientific work. For example, in employing the *techne* of ritual communication, DIY laboratories encourage individuals with little to no formal scientific training to celebrate biotechnology. This *techne* serves an epideictic function that constitutes work not as the facilitation of understanding but as the solidification of shared culture. Much like popular science writing, the *techne* of ritual can facilitate identification (Burke, 1969b) with the scientific community, even among individuals with little technical expertise (Fahnestock, 1998). Yet to forge connection, this *techne* may reduce complexity to such a degree that it paradoxically constitutes DIY bio as a hierarchical form of organization in which power is centralized in the hands of experts.

By contrast, a third, artisanal *techne* deliberately responds to the give-and-take of biological, ecological, and social complexities. Materializing a multidirectional model of communication, this form of craft materializes a playful curiosity. Work, here, is constituted as an effort to engage both human and non-human others in conversation. This artisanal *techne* cultivates a cybernetic organization that views the world as “made up of a very complex net-work [*sic*] (rather than a chain) of entities which have this sort of relationship to each other, but with this difference, that many of the entities have their own supplies of energy and perhaps even their own ideas of where they would like to go” (Bateson, 1987, p. 273). Thus, rather than seeking standardization, artisanal *techne* emphasizes responsiveness more than transmission, approaching “the problems of control [*as*] more akin to art than to

science, not merely because we tend to think of the difficult and unpredictable as contexts for art but also because the results of error are likely to be ugliness” (Bateson, 1987, p. 273).

This form of persuasive knowledgeable craft works against not only hierarchies or scientific work, but also the hierarchies that separate humans from their fellow species.

Practical Implications: Professional Identity in the Sciences and Engineering

As this summation demonstrates, the technai of genetic engineering constitute not only novel organisms, but novel organizational forms. Each craft carves the relationships between human and non-human others in a different manner, distributing power and agency in different ways. By conceptualizing this carving as *techne*, or persuasive knowledgeable craft, this dissertation has shown that material work can have persuasive qualities. By constituting relational ontologies in different ways, material crafts can influence organizational learning, redefine infrastructure, facilitate identification, or invite conversation.

Each of these functions depends on the advancement of a persuasive argument. The constitution of work at iGEM rests on a collective acceptance of three related premises: first, that the distribution of genetic engineering is an end in itself; second, that DNA is composed of standardized units that, like cybernetic information, carry the same meaning regardless of context; and third, that in training of future scientists and engineers, it is appropriate to place strict limitations on the levels of complexity with which they can engage. These assumptions are materialized in the persuasive craft of the competition, which organizes synthetic biology as distributed manufacturing.

One practical implication of this research relates to initiatives to promote responsible innovation (Stilgoe, Owen & Macnaghten, 2013). While such efforts often downplay the institutional dimensions of responsibility, this study draws attention to the ways in which professional identities are cultivated by various ways of organizing scientific work. For example, iGEM's techne of standardization contributes to the automation of scientific labor by defining biological variation as an error, thereby discouraging learning about how organisms evolve. To some extent, this finding speaks to flaws in synthetic biology's broader effort to make genetic engineering easier to engineer. Yet as Boudry and Pigliucci (2013) have noted, the "general inadequacy of engineering metaphors for biological systems" will not necessarily predict whether the field of synthetic biology will succeed or fail (p. 666). As they put it,

science is a very pragmatic enterprise, with scientists often able to find a way around a particular problem by previously unforeseen paths. But we do think that whatever successes these researchers will be able to achieve will be in spite, and not because of, the inspiration provided by the machine metaphor. Indeed, we suggest that the more bioengineers will adhere to a straightforward "engineering" perspective on living organisms, the more obstacles they will throw in the way of their own progress. (Boudry & Pigliucci, 2013, p. 666)

At iGEM, the prevalence of such obstacles is compounded by a deliberate compartmentalization of expertise that reduces participants—including students at many of the world's leading high schools, colleges, and universities—to "parts-level workers" charged not so much with understanding biology as with manufacturing biological parts.

These two goals, understanding and constructing, often go hand-in-hand in other circumstances (see, for example, Maddalena, 2014). Yet the abstraction hierarchy that organizes scientific work at iGEM reserves the opportunity to engage with biological complexity for the competition's organizers, a move that severely restricts the kinds of learning that participants undertake, especially in the limited amount of time allowed.

To facilitate higher levels of organizational learning, iGEM would need to revisit its foundational assumption that genetic engineering's primary problem is a lack of efficiency—an assumption that stems from and contributes to a political economy that increasingly defines science as an industrial activity. Repositioning the simplification of complexity as a means to achieve other ends, rather than an end in itself, could potentially open the way for competition participants to engage in more sophisticated ways with biology as well as the social, political, and ethical aspects of bioengineering. In the short term, such a step could undermine the competition's function as proof of concept for the broader field of synthetic biology—and in so doing, jeopardize lucrative investments from the Defense Department and other influential actors. However, in the longer term, this type of action could prove far more effective in cultivating the pragmatic ingenuity that enables talented scientists to, in Boudry and Pigliucci's terms, “find a way around a particular problem by previously unforeseen paths.”

The constitution of work in DIY bio laboratories also rests on the premise that distributing genetic engineering is an end in itself. However, as they work to facilitate this distribution, they are also experimenting with different ways of simplifying biological complexity. Here, too, are examples that have implications for the professional training of

scientists and engineers. For instance, although it can facilitate a great deal of learning about engineering, the *techne* of distribution focuses far less on learning about biology. The ritual *techne* that make strawberry DNA visible or make bacteria glow in the dark encourages identification with the broader community of genetic engineers. Yet depending on how these activities are facilitated, and by whom, they may or may not invite novice practitioners to learn more about the structures and functions of genetic material. Finally, we have seen that to practice an artisanal *techne* is not necessarily the same thing as to adopt the professional identity of an artist. Instead, it relates to a willingness and ability to approach organisms and environments as complex wholes, rather than discrete quantifiable parts.

In drawing attention to biotechnology's equivocality—its ability to “speak” in ways that appeal to many different people and interests—this research serves a function that Pinch and Bijker (1987) advocated in proposing a social constructionist approach to technology studies. For these authors, the first step that scholars should take in researching technologies was to demonstrate the “interpretive flexibility” of scientific findings” by illustrating “that different interpretations of nature are available to scientists and hence that nature alone does not provide a dominant outcome to scientific debate” (Pinch and Bijker, 1987, p. 121). This means “not only that there is flexibility in how people think of or interpret artifacts but also that there is flexibility in how artifacts are designed” (Pinch and Bijker, 1987, p. 123). In relation to genetic engineering, highlighting what Weick (1990) called equivocality and what Pinch and Bijker (1987) called interpretive flexibility challenges technological determinism by drawing attention to the possibility for biotechnology to develop in different ways. This dissertation documents the potential for biotechnology to become institutionalized in a

variety of different forms, ranging from distributed manufacturing to religious priesthood to decentralized multispecies collaboration. Obviously, these organizational forms enact significantly different ethical rationalities and pose significantly different consequences for both human and non-human “organizational members.”

For the time being, DIY laboratories themselves also serve the function of highlighting alternative ways of organizing the production of biotechnologies. While iGEM’s techne of standardization de-skills and automates scientific labor, the artisanal techne of DIY laboratories encourages an attunement to biological and ecological complexity that can translate into a more sophisticated engagement with social and political complexities. At the same time, DIY bio’s tremendous push to distribute genetic engineering may ultimately stifle this acknowledgement of complexity. Biohackers talk of making it possible for anyone to join the priestly rank of scientists. Yet biohackers’ collective efforts to make genetic engineering sufficiently simple for anyone to do reduces the likelihood that others will wrestle with the question of *how* to simplify complexity as they do. In this capacity, the organizers of DIY bio are in a similar position to the organizers of iGEM. Both spend a great deal of time and effort developing abstraction hierarchies that organize technical work, and in so doing, both contribute to the de-skilling of the work of others.

For now, each communication model of DIY bio cultivates a distinct professional ethos and a distinct way of relating to human and non-human others. However, especially in light of the significant effort that organizations are expending towards simplification, there is reason to expect that over time, one way of approaching the technology will become dominant. For example, Weick’s (1979) conception of means-convergence suggests that

although organizational members initially converge around common means, rather than common ends, over time, the social structures that they create facilitate a shift towards the adoption of common ends (Weick, 1979, p. 91-3). Ultimately, the solidification of these structures is likely to encourage a kind of isomorphism (DiMaggio & Powell, 1983), or homogenization of work and governance.

Theoretical Implications: The Agency of Non-Human Actors

For scholars of communication, rhetoric, and science studies, comparing the technai of genetic engineering is particularly helpful in facilitating reflection on the attribution of agency to non-human actors. As I mentioned in Chapter One, while actor-network theory (Callon, 1986; Latour, 1983, 1987, 1988, 1990) has enabled scholars to expand our investigations to acknowledge the influence that technologies and non-human organisms exert on organizational life, it also offers a circular distinction between human and non-human entities. In distinguishing only between human and non-human agents, ANT “defines nonhuman agents in the light of human ones and thereby circumvents the question of what it means to be human and what it means to be an agent” (Brummans et al., 2009, p. 55). Thus, although many scholars aim to transcend this binary, “Somehow most of them end by positing the human and the non-human as essentially different types of being whose entanglement with each other needs to be explained, as being unusual” (Introna, 2013, p. 330).

In terms of theory development, perhaps the most important lesson of the research that I have presented in this dissertation emphasizes the need to take a reflexive stance towards the ways in which we simplify complexity in our own work. I am hopeful that this

dissertation helps to facilitate this reflexivity by illustrating how the use of imprecise terminology such as the adjective “non-human” can implicate not only scientists and engineers, but also researchers in the humanities and social sciences, in subordinating our fellow living beings. Researchers of communication and rhetoric, in particular, are well aware that particular terminology can function as a terministic screen by directing attention toward one interpretation of reality and deflecting attention from others (Burke, 1966; Srivastva & Barrett, 1988, p. 34-35). In this dissertation, I have demonstrated the material consequences that such rhetorical negotiations of reality can have for living organisms. In doing so, I offer a provocation to my colleagues to reconsider the human/non-human binary, which contributes, in subtle but steadily accumulating ways, to a practice of “othering” our fellow organisms that bears much in common with the colonialist practice of othering our fellow humans (Broadfoot & Munshi, 2015; Milstein, 2009). To move beyond this binary, scholars need to address the question,

How can we represent all agents without relegating one or more of them to the position of patient or object? How can we capture agency and agents in all their diversity? In 1988, Spivak asked, “Can the subaltern speak?” Perhaps the time has come for postcolonial organizational communication scholars to ask, “In what contexts and under what circumstances can the subaltern speak, and how can we be best prepared to recognize this voice? (2015, p. 5).

This call is echoed in Shotter’s (2016) urging of scholars of organization and management to acknowledge the difference between living and non-living organizational actors. In his words,

We have nowhere near paid enough attention to the fact that we are living bodies, living in the midst of a continuously flowing, spontaneously responsive contact with our surroundings. Thus, on a dimension from computers to plants, as I see it, we are in many ways much more like plants, spontaneously growing and developing as creatures continually adapting ourselves to our surroundings in relation to the sunshine and winds occurring in the ‘social weather’ within which we must live our lives. (n.p.)

This dissertation has responded to these calls by suggesting some initial ways in which scholars can draw attention to the communicative crafting of human relationships as well as the relationships between humans and other entities—whether biological, technological, or (most likely) somewhere in-between. For example, I have demonstrated that iGEM’s techne of standardization is noteworthy in its denial that meaning is co-produced. Instead, it envisions all agency to be located with the sender, and none to be located with the receiver. As Condit (1999) has noted,

some high-profile scientists have tended to treat the ‘communication’ that goes on between DNA and other cell components as though it were a one-way transmission from DNA to RNA to proteins. They have thereby been led to speak of DNA as ‘commanding’ or controlling the cell. But, as communication theorists have come to emphasize... communication is never one-way. Communication is a relationship, and to ‘communicate’ successfully always requires that both parties share a code ... the materiality of DNA’s code is to be found not solely in the atoms of the DNA, but in

the relationship (again, a material phenomenon) between the configuration of those atoms and the cell. (p. 344-5)

This point was echoed by research participants in DIY laboratories, who emphasized that even single-celled organisms are sometimes “willing to work with you for a while, but then they are like, no, not if you say my curfew is too late, or not if you don’t give me more spending money.” From this perspective, synthetic biology is “just not the complete story of how you can tinker and work with biology,” as a European research collaborator put it; “This is nuts, and *they kind of have an impediment*, ‘You have to apply these standards and rules.’” Thinking of knowledgeable crafts as rhetorical draws attention to the choice of the word *impediment*. This characterization suggests that, as a form of communication, iGEM’s version of synthetic biology is systematically distorted in part because it is capable only of one highly standardized way of addressing its non-human “audiences”—a kind of speech impediment that also impedes organizational learning. Seen through this lens, applying a transmission model of communication to biological entities embodies a vision of communication that, as von Foerster (1980) notes, reduces language to the imperative or the command—a mode that, especially in wartime, tends to predominate over other modes such as describing, questioning, or exclaiming (p. 20).

Recognizing the persuasive qualities of techniques, and acknowledging the communication models that techniques can materialize, suggests that future research might build on the work of this dissertation to begin theorizing the work of genetic engineering as a form of linguistic composition, even as a rhetoric. In doing so, future scholars might abandon the conceit that I have employed here by adopting the term *techne* rather than the term

rhetoric to avoid binarizing the symbolic and the material. In the meantime, this dissertation offers insights into how scholars and theorists of communication and rhetoric might revisit the ways in which our constructs and methods imbricate organizational actors by attributing various degrees of agency.

As a thought experiment, we might consider the example of laboratory mice—a common model organism in science that may also serve as a model to aid thinking in the humanities and social sciences. Perhaps the most common way of thinking locates agency in human intentionality, which Burke (1969a, 1978) defined as “action,” while another less popular conception locates at least some degree of agency in what Burke saw as the mere “motion” of non-human actors. These two definitions suggest significantly different understandings of the relationship between human scientists and the organisms they engineer. If agency stems only from human action, then a genetically modified lab mouse is rightly categorized as a Lego mouse, a compilation of material parts to be arranged and rearranged by mixing and matching standardized biological parts.

Yet if we grant that laboratory mice can possess some degree of agency even as they are used as instruments, a more complicated picture begins to arise. In this scenario, the mouse is being acted upon as a technology, but it may not always comply with the intentions of those who are acting upon it. The mouse may even become a kind of “dissident,” like the scallops that Callon chronicled in his study of St. Brieuc Bay (1999, p. 79), or the willful bacteria that my research collaborator described as demanding more lenient treatment in exchange for their labor. Non-compliance becomes one of many qualities that an organism as a unity might possess—qualities that may differ from those of its constituent parts.

For example, a growing body of scientific research demonstrates that the oversimplification of laboratory mice—a process of cultivating very high degrees of standardization via genetic engineering—can have negative impacts for human patients (Bolker, 2012; Perrin, 2014; Vanden Berghe et al., 2015). As a former pharmacology researcher noted, mice are “small, which means they’re cheap to house and cheap to feed,” and highly standardized, “which means you can use lots of them and they will be (supposedly) genetically identical to each other, thus controlling for a whole genome full of variables” (Gitlin, 2015). Nevertheless, they “may not be good proxies for human diseases” in all cases (Gitlin, 2015), in part because they have been deliberately separated from the messy complexities of the world beyond the laboratory walls (Beura et al., 2016; Reardon, 2016). For instance, unlike wild mice, laboratory mice typically possess far fewer of the immune cells that humans develop after being exposed to viruses and other pathogens as children—pathogens that help to defend the body from cancer and infection (Beura et al., 2016; Reardon, 2016). By contrast, mice that have lived in less sanitized conditions may serve as better stand-ins for human patients (Beura et al., 2016; Reardon, 2016). There are also benefits to recognizing the complexities that distinguish mice from the humans for whom they so often serve as models. Because mice are unlikely to suffer from heart disease, even though “you can cause the build up of plaques in the walls of their blood vessels, but even extensive plaque deposits don’t cause the mice to have strokes or heart attacks—the things that actually kill humans with the disease” (Gitlin, 2015). In a researcher’s account, finding out that a drug reduces the plaque buildup in these mouse models may have little relevance for its use in people . . . During my years at NIH, we would often joke

that science had now found plenty of cures for cancer, as long as one was talking about mice that we had to give cancer to in the first place. (Gitlin, 2015)

The justification for acknowledging the agency of other species need not rest solely on the interests of humans. For instance, mice have been shown to register pain (and perhaps other emotions) on their faces much as humans do (Langford et al., 2010), offering a sad yet nuanced example of non-human non-verbal communication.

Drawing on the insights of my research collaborators, I propose that if we want to acknowledge biological agency, we might begin by defining it as a combination of variation, adaptation, and emergent complexity. By variation, I mean difference. By adaptation, I mean change that occurs over time in relation to selective forces. By emergent complexity, I mean integrative levels of organization—in other words, the “idea that matter is arrayed in orders of increasing complexity, and that at each level, there are emergent properties such that the higher level cannot be reduced to the lower” (“integrative levels,” n.d.). Borrowing these concepts from biology can enable communication scholars to develop more precise ways to operationalize our ideas. For example, defining agency as variation, adaptation, and emergent complexity is consistent with Latour’s (1988) redefinition of agents as “actants,” a term he coined to describe anything that exerts agency, whether human or non-human, living or non-living. At the same time, my three-part definition also enables us to make qualitative distinctions between the kinds of agency exhibited by biology, technology, and biotechnology.

Scholars of communication and organization can also draw on the relational ontologies described in this dissertation as points of reference in evaluating the entelechy

(Burke, 1969b) or ultimate end of our own theorizing. Rather than adopting the language of synthetic biology uncritically, scholars of communication and rhetoric might instead reflect seriously on the possibilities that we want to advance. As I have illustrated, iGEM's version of synthetic biology values the development of standardized "plug and play" BioBricks so highly that it suggests genetic variation is an error: in Endy's words, "[t]o an engineer, biological systems are replicating machines that make mistakes during the replication process" (2005, p. 452). Rather than taking these assumptions for granted, I have demonstrated how scholarship in the humanities and social sciences can offer a theoretical complement to the rhetoric of synthetic biology. Rather than pursuing simplification, I suggest that our analyses should more fully emphasize the principle of requisite variety (Weick, 1987) by aiming to make our theorizing as complex as the systems that we study.

In doing so, we might take our cues from biological fields such as behavioral genetics and epigenetics. In keeping with the theory of natural selection, these fields place a more positive value on variation, demonstrating that the agency of genomes is constituted hereditarily, in interaction with ancestors, and contextually, in interaction with natural/cultural environments. For example, the artisanal techne of DIY bio echoes the theories of Richard Lewontin, a biologist and zoologist, and Richard Levins, an ecologist, biomathematician, and philosopher of science, who emphasize that biological meaning is determined in the variable interactions of DNA with bodily contexts:

We cannot conceive of a membrane or a liver or even DNA by itself. One of the most common errors is to abstract DNA from its context, assign it an excessive degree of independence and a rank of "fundamental." Every part has multiple functions, and at

times these conflict. The system as a whole and its functions evolve on the basis of its past history and random events. We can visualize the processes within an organism as a network of physiological or neurological interactions. Knowledge in these fields points us toward shared processes, branching chains, cycles of synthesis and breakdown, catalysis and inhibition of catalysis. Often the same event induces opposing responses such as inflammatory and anti-inflammatory prostaglandins in response to the accumulation of cellular detritus, or the firing of excitatory and inhibitory neurons. Further, the same molecule behaves differently in different tissues and is associated with different sets of biochemical. (2007, p. 188-189)

Juxtaposing iGEM's emphasis on standardization with Lewontin and Levins' emphasis on variation and interaction begins to suggest how each epistemology cultivates a particular ethos or professional character—and in doing so, a particular relational ontology. A biologist as envisioned by Lewontin and Levins is an individual who deliberately attributes agency to the variable interaction of molecules, systems, bodies, and environments. From this perspective, the language of DNA is rhetorical: genetic meaning derives not only from the particular combination of As, Ts, Cs, and Gs that we inherit from our parents, but from the ways in which our genetic material persuades and is “persuaded” to manifest in a kind of conversation with the contexts of our individual lives. As Miller (2007) puts it, “Agency, then, is not the property of an event, it is the property of a relationship between rhetor and audience” (p. 150).

By contrast, Endy and Knight embrace a transmission model of communication in which agency and the determination of genetic meaning are located solely with the synthetic

biologist, positioning the organisms they engineer as agency-less reagents. A synthetic biologist, in this view, is an individual who aims for standardization of genetic meaning and finds mutation and variation to be at best irritations, and at worst, problematic “errors.” In this sense, the term “synthetic biologist” is perhaps more accurately used to describe an artificial biologist, rather than a biologist involved in manufacturing artificial DNA sequences. The field places such a high degree on the simplification of biological complexity that it may not be appropriate to suggest that biology is its true object of analysis.

Synthetic biologists’ denial of biological agency does not necessarily mean, however, that the living organisms with which synthetic biologists work are lacking in agency. Rather, it demonstrates how, as science studies scholar Karen Barad puts it, “knowing is a direct material engagement, *a cutting together-apart*, where cuts do violence but also open up and rework the agential conditions of possibility” (as cited in Dolphijn & van der Tuin, 2012, p. 52, italics added). The prevailing epistemology of synthetic biology at iGEM cultivates a scientific ethos that looks away from or denies variability and mutation. Alternate ways of knowing, such as the one that Lewontin and Levins propose, enable relational ontologies in which the diverse and adaptable nature of life can be acknowledged. For example, even highly standardized laboratory mice—mice that have been engineered with the specific purpose of being genetically identical—exhibit some degree of agency. Over time, rather than responding in the particular ways intended by their human designers, the genomes of these mice exhibit increasing variation (Crabbe, Wahlsten & Dudek, 1999; Wade & Daly, 2005).

For scholars of organizational communication, rhetoric, and science studies, these examples demonstrate that the organizing of DNA requires scholars to attend to the ontological consequences of our own ways of knowing. Acknowledging the agency of non-human actors might begin with attending to their responses to human actors, as demonstrated by Callon, Latour, and others. Yet it also requires us to develop terminology that makes more fine-grained relational distinctions than those that are allowed by terms such as “agent” and “actant.”

To begin to adapt our own theoretical and methodological approaches to better attend to these distinctions, scholars can recognize not only how the response of genetically modified organisms relates to the behavior that human agents intend for these organisms to exhibit—as well as how our own scholarship does and does not make the agency of these organisms visible. If genetic engineering can be understood as a form of communication between agents and reagents, then biological meaning is a co-creation of both the observer and the observed, as well as the circumstances in which they find themselves. Rather than claiming to represent these material communications from a detached standpoint, we can consciously decide what kind of agency we are or are not willing to recognize. As Haraway (2008) puts it, “staying with the complexities does not mean not acting, not doing research, not engaging in some, indeed many, unequal instrumental relationships; it does mean learning to live and think in practical opening to shared pain and mortality and learning what that living and thinking teach” (p. 83). Even in the human realm, expecting organizational relationships to be completely free of instrumentality is unreasonable and perhaps impossible. Nevertheless, we can and should be deliberate about precisely what kinds of

instrumentality we are willing to tolerate, and why. This begins with documenting the persuasive knowledgeable crafts that entangle and organize us in relationship to our fellow organisms.

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APPENDIX

Appendix: A Biopunk Manifesto, by Meredith Patterson

Scientific literacy is necessary for a functioning society in the modern age. Scientific literacy is not science education. A person educated in science can understand science; a scientifically literate person can *do* science. Scientific literacy empowers everyone who possesses it to be active contributors to their own health care, the quality of their food, water, and air, their very interactions with their own bodies and the complex world around them.

Society has made dramatic progress in the last hundred years toward the promotion of education, but at the same time, the prevalence of citizen science has fallen. Who are the twentieth-century equivalents of Benjamin Franklin, Edward Jenner, Marie Curie or Thomas Edison? Perhaps Steve Wozniak, Bill Hewlett, Dave Packard or Linus Torvalds—but the scope of their work is far narrower than that of the natural philosophers who preceded them. Citizen science has suffered from a troubling decline in diversity, and it is this diversity that biohackers seek to reclaim. We reject the popular perception that science is only done in million-dollar university, government, or corporate labs; we assert that the right of freedom of inquiry, to do research and pursue understanding under one's own direction, is as fundamental a right as that of free speech or freedom of religion. We have no quarrel with Big Science; we merely recall that Small Science has always been just as critical to the development of the body of human knowledge, and we refuse to see it extinguished.

Research requires tools, and free inquiry requires that access to tools be unfettered. As engineers, we are developing low-cost laboratory equipment and off-the-shelf protocols that are accessible to the average citizen. As political actors, we support open journals, open

collaboration, and free access to publicly-funded research, and we oppose laws that would criminalize the possession of research equipment or the private pursuit of inquiry.

Perhaps it seems strange that scientists and engineers would seek to involve themselves in the political world -- but biohackers have, by necessity, committed themselves to doing so. The lawmakers who wish to curtail individual freedom of inquiry do so out of ignorance and its evil twin, fear -- the natural prey and the natural predator of scientific investigation, respectively. If we can prevail against the former, we will dispel the latter. As biohackers it is our responsibility to act as emissaries of science, creating new scientists out of everyone we meet. We must communicate not only the value of our research, but the value of our methodology and motivation, if we are to drive ignorance and fear back into the darkness once and for all.

We the biopunks are dedicated to putting the tools of scientific investigation into the hands of anyone who wants them. We are building an infrastructure of methodology, of communication, of automation, and of publicly available knowledge.

Biopunks experiment. We have questions, and we don't see the point in waiting around for someone else to answer them. Armed with curiosity and the scientific method, we formulate and test hypotheses in order to find answers to the questions that keep us awake at night. We publish our protocols and equipment designs, and share our bench experience, so that our fellow biopunks may learn from and expand on our methods, as well as reproducing one another's experiments to confirm validity. To paraphrase Eric Hughes, "Our work is free for all to use, worldwide. We don't much care if you don't approve of our research topics." We

are building on the work of the Cypherpunks who came before us to ensure that a widely dispersed research community cannot be shut down.

Biopunks deplore restrictions on independent research, for the right to arrive independently at an understanding of the world around oneself is a fundamental human right. Curiosity knows no ethnic, gender, age, or socioeconomic boundaries, but the opportunity to satisfy that curiosity all too often turns on economic opportunity, and we aim to break down that barrier. A thirteen-year-old kid in South Central Los Angeles has just as much of a right to investigate the world as does a university professor. If thermocyclers are too expensive to give one to every interested person, then we'll design cheaper ones and teach people how to build them.

Biopunks take responsibility for their research. We keep in mind that our subjects of interest are living organisms worthy of respect and good treatment, and we are acutely aware that our research has the potential to affect those around us. But we reject outright the admonishments of the precautionary principle, which is nothing more than a paternalistic attempt to silence researchers by inspiring fear of the unknown. When we work, it is with the betterment of the community in mind -- and that includes our community, your community, and the communities of people that we may never meet. We welcome your questions, and we desire nothing more than to empower you to discover the answers to them yourselves.

The biopunks are actively engaged in making the world a place that everyone can understand. Come, let us research together.