Changes at the lab bench:
interdisciplinary art and life's new design

by

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Abstract

In this thesis I examine contemporary interdisciplinary theory and practice in art, design, citizen science and synthetic biology. I explain the differences between three main knowledge distinctions of synthetic biology, and identify prominent artists, designers, and citizen scientists who are creating new modes of labour therein. I locate this research in Isabelle Stengers' notion of the Ecology of Practices, which I connect to my own art practice as a DIY textile crafter. In the DIY Body Project installation, which took place at the Ontario Science Centre and online at diybody.org, a space is created for the public to generate its own evolving narrative of what a synthetic body can mean, look like and function as. The exhibition does this without promoting a specific rhetoric of the body as human, the synthetic as machine, or the biological as computable as is often seen in biotechnology discourse.

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To Catherine, Kendra, Dad and Attenborough.

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Chapter 1: Introduction

Synthetic biology today is considered to be an emerging field of biotechnology, and in particular, a new approach to genetic engineering that uses synthetic DNA, standardized configurations of molecular components of cells, computational science and engineering principles to manufacture novel living organisms. [1] It is largely understood as (though debated by some[2]) a novel paradigm of biotechnology separate from more standard forms of genetic engineering.[3] Where traditional genetic engineering has focused on single gene transplantations since the 1970s, synthetic biology uses the sequencing, synthesizing and entire-genome processing capacities of 21st century biocomputation to invent unprecedented forms of life.[4] To date, synthetic biologists work predominantly with simple viruses and bacteria, engineering them to produce metabolic byproducts that enable us to initiate more economic or renewable relationships with the biosphere, such as through the making of

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[1] Often referred to as "emerging", synthetic biology has in fact been used as a term to describe scientific practices that are concerned with the creation of artificial life from non-living materials since as early as 1905. French biologist Stéphane Leduc is credited as the first scientist to experiment with synthetic biology (albeit a different version of it than exists today) when he created inorganic gardens capable of growth, *Les Jardins Chimique* through his invented method involving the mixture of oils, inks and metals.
Leduc, Stéphane. 1912. La biologie synthétique. A. Poinat.

[2] Benner, Steven A., Zunyi Yang, and Fei Chen. 2011. Synthetic biology, tinkering biology, and artificial biology. What are we learning? Comptes Rendus - Chimie 14 (4) (201104): 372-87.

[3] The scope of my study of synthetic biology and thus understanding of its definition and framing is limited to that of North America and Western Europe, with the exception of the Art-Science iGEM team from Bangalore, which will be mentioned further on in the paper.

[4] Bud, Robert. 2001. History of biotechnology. In *History of Biotechnology*, 524-538. John Wiley & Sons.

cheap drugs or alternative energy sources.[5] The field is also leading us to re-engineer naturally occurring organisms at the genetic level, or in other words, to understand how to build what already exists through synthetic means, and make modifications to their genomes as applicable to project goals. In its mainstream acceptance, synthetic biology is understood as a systems biology approach to creating new types of life along three separate axes: genetic device construction, whole-genome engineering, and protocell creation, which I will explore the differences between in full detail in chapter two.[6]

For my Master's project I am investigating the cultural implications of contemporary interdisciplinary practices in synthetic biology, which increasingly includes the work of artists, designers and "citizen scientists." As a scientific practice, synthetic biology is deeply concerned with the *design* of new genetic material and living organisms, which has attracted many artists and designers to the field who think about design from a more traditional creative education that focuses on aesthetics, critique, and interactivity, for example. Additionally, DIY or "do-it-yourself" biologists are forging new non-institutionalized ways to practice synthetic biology, which I consider in my project because of the way they mutate the normative practice of biotech, as I will explain.

Interdisciplinary collaborations between artists and scientists are gaining stability through their increasing institutionalization and growing canonization in creative practices like bioart, speculative design and design fiction. Each of these are creative practices that merge scientific expertise with art or design methods to make interdisciplinary art or design works from the convergence of these specialized knowledge-distinctions. While bioart uses biotechnology as a medium for art production or subject of work, speculative designers

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[5] Balmer, Andew, and Paul Martin. 2008. *Synthetic biology: Social and ethical challenges.* Nottingham: Biotechnology and Biological Sciences Research Council, 1.

[6] O'Malley, Maureen, Alexander Powell, Jonathan Davies, and Jane Calvert. 2007. Knowledge-making distinctions in synthetic biology. BioEssays 30 (1): 57-65.

create interactions and objects that confront people with possible futures in hope of raising public debate or consideration of them. Meanwhile, critical designers create interactions and objects that more pointedly critique various technologies, systems, or futures, and thus operate similarly to critical art works.[7]

The rhetoric that scholars and researchers in synthetic biology use focuses on the invention of "biological machines" that can carry out precisely designed functions that offer us new opportunities for the future, particularly in the health care and renewable energy sectors.[8] Synthetic biology's potential applications include the production of biosensors to sense toxins in the environment (like oil spills), the creation of cheap vaccines to fight off significant lethal diseases (like malaria), and the production of cheap biofuels (like that made by Amyris).[9]

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[7] In this paper I focus on art-science and citizen science collaborations that reflexively position themselves as attached to synthetic biology and the people in its field. There is however, a very rich history of artists, designers, DIY scientists and professional scientists working together in other fields, even very closely related biotechnological ones. Some prominent research laboratories working across the arts, sciences, and citizen participation in this way that have influenced my thinking but not fallen under my scrutiny in this project are bioartist Jennifer Willet's Incubator Lab, which works across ecological science and art, and bioartist Tagny Duff's Fluxmedia Lab, which deals with digital media, biology and art. There have also been many histories of interventionist strategies in citizen science that range from the AIDS epidemic in the 1980s and 1990s to academic research laboratories like the Mobile Media Lab at OCAD University. One particular experience I had that has influenced my thinking about work across art, science and citizen science was my involvement in the bioARTCAMP residency at the Banff Centre in 2011. Organized by Jennifer Willet, the residency brought scientists, artists, and theorists together on a camping expedition to collaborate on projects and have discussions about the mobilizations in theory and practice made possible when these fields collide. I have understood the distinctions between bioart, critical design, speculative design, and DIY science to be full of overlap along a blurred continuum, as expressed through recent casual conversation with several practitioners of each distinction.

[8] International Risk Governance Council. 2008. *Synthetic biology: Risks and opportunities of an emerging field.* Geneva: International Risk Governance Council, 1.

[9] Amyris is the first synthetic biology company to go on the public market, which produces synthetic algae that create biofuel as their metabolic byproduct. http://www.amyris.com;

Synthetic biologists are creating organisms alien to the non-synthetic species that have co-evolved on Earth over millions of years, and their work stands to intervene in significant ethical questions that already exist within other forms of genetic engineering, such as cloning, GMOs and stem cells.[10] Not surprisingly, these types of questions are also intertwined with radical and dangerous possibilities brought forth in discourse on biosafety, biowarfare, biopiracy, intellectual property, and geo-engineering.[11] As the science grows in its sophistication, the activities of this field are likely to have penetrating implications for all living things, from the philosophical to the mundane.

Research Objectives

We are in a moment when the breadth of synthetic biology's widespread integration into society as a new technological mechanism for designing and creating novel forms of life is still being contested. In this thesis I will make a theoretical contribution towards understanding to what extent artists and designers intervene in the field to innovate its uses for a social reality or conceptual understanding of life that might not be possible had it been imagined by scientists alone.

As well, I will expand my analysis of existing contemporary art and design that is involved in synthetic biology to consider its theoretical and practical relationship to my own artistic practice, that being textile art, and in particular, DIY or "do it yourself" approaches

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Schmidt, Markus. 2009. Chapter 6 do I understand what I can create? Biosafety issues in synthetic biology. In *Synthetic biology: The technoscience and its societal consequences.*, ed. Schmidt Markus; Kelle, Alexander; Ganguli-Mitra, Agomoni, 1-189. Netherlands: Springer.

[10] Parens, Erik, Josephine Johnston, and Jacob Moses. 2009. *Ethical issues in synthetic biology: An overview of the debates.* Washington: Woodrow Wilson International Center for Scholars, 3.

[11] Segelid, Michael J. 2007. *A tale of two studies: Ethics, bioterrorism, and the censorship of science.* Garrison, NY: Hastings Center, 1, p. 35.

to crafting with fabric.[12] I have developed a textile art practice through this research project and have approached it through a determinedly DIY craft perspective. In this research-creation project, I've created an interactive DIY textile installation that focuses on creative pedagogical methods through which to engage youth in learning about synthetic biology and citizen science movements, both of which are topics that I unpack in this written thesis. The work is exhibited at The Ontario Science Centre from March 16th – August 12th 2012; accompanying information can be found online at diybody.org.

I take seriously the thought from theorists and creative practitioners Kember and Zylinska that there is the ever-increasing possibility for the arts and sciences to perform each other, often in increasingly diversifying media contexts. Working with science and theory through creative media, as I do in the DIY Body Project, "first and foremost is an epistemological question of how we can perform knowledge differently through a set of intellectual-creative practices that also 'produce things'."[13] The attempt I make here is to 'produce things' that are critical, educational, and humorous rather than repetitive, conformist, and scientific as they relate to mainstream discourse in synthetic biology.

I investigate herein the specificities of the artistic evolution of DIY craft alongside that of synthetic biology, pointing to their overlapping interests and processual engagements between the creator (artist/synthetic biologist) and their material technologies of craft (sewing patterns, blueprints, fabric/ DNA synthesizer). I elaborate particularly in my investigation of the importance of the formal arrangement of parts as it applies to biological

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[12] This is a combination of techniques used by many artists, a very notable one being Mike Kelley.

[13] Kember, Sarah and Zylinska, Joanna. 2009. Creative Media: performance, invention, critique. In: Maria Chatzichristodoulou, Janis K. Jeffereies and Rachel Zerihan,eds. Interfaces of Performance. England and USA: Ashgate, p 10.

components in synthetic biology as well as modular crafting in my argument for art and design's importance as creative tools for "thinking practices."[14]

I aim to use my understanding of interdisciplinarity between art and design in synthetic biology in order to develop a theory of how synthetic biology's focus on the rewriting and rearranging of DNA for desired physiological effect in synthetic organisms blurs the boundary between the artificial and the real as organic life gets re-made through inorganic means.[7] In doing so I investigate how the blurring of such boundaries can engage the public in nuanced thinking about the effect of biotechnology on our future state(s) of living in this world. Importantly, feminist philosophers have argued that boundaries, such as those I am interested in blurring (across disciplines and definitions of natural/real, for example) are never transgressed without responsibility; there is always a politics of difference at play. Consequently, I consider the specific relationalities that are created between scientists, artists, designers and DIY biologists in the emerging field of synthetic biology that does not treat all of their attachments as equal, but asymmetrical phenomena arising from specific material-discursive intra-actions in the world.[15]

Synthetic biology and the bioindustrial paradigm

The American economist Jeremy Rifkin gave a public address in 1998 stating that we have moved from the Industrial Era into the BioTech Century where "genes are the raw

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[14] Stengers, Isabelle. 2005. Introductory notes on an ecology of practices. Cultural Studies Review. 11 (1): 183-196.

[15] Barad chooses the word "intra-actions" to describe material-discursive cuts; linguistic and physical events that generate boundaries between things and create meaning in the world. They are beyond mere descriptors of reality in a semiotic sense, but are at the same time language-as well as atomized, particle shifting, *physical processes* that bring the world into being in specific configurations, that a combination of individual agents are always responsible for. Barad, Karen. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Duke University Press, 2007.

resource for the next century."[16] He claimed that the futurists had done humanity a disservice by writing books about the looming "Information Age". This only prepared us for the power of computational science and artificial intelligence rather than the power vested in real beating bodies enabled through our biotechnological practices. In most cases of contemporary biotech, "Information Age" technologies are crucial to the in vivo or in vitro success of their products, largely being the genetic technologies that allow us to recombine DNA and design the genetic function of living materials and simple organisms. Rifkin was correct in identifying the power of biotechnology in the 21st century, but it is only so through the mass processing capacities of computational science that allow us to read and rewrite the genetic code.

Indeed, informational and biotechnological tools in combination are carving a new mode of manufacturing that in many cases displaces industrial platforms of fabrication. This is well justified in our contemporaneous state of resource depletion, war, and climate change resulting from our unwieldy and rapacious engagement with the environment's natural resources through industrial technology. As we've progressed from the industrial era into new advancements, we currently find that we have not so much exceeded the power of the information age with biotechnology, but in their combination a revelatory engagement with the world through technologies of a computational and biological essence has occurred.

We have become accustomed to the speed at which we develop new technologies and the force with which they in turn change our lives. There have been differences in the dramatic energy of the impact, or seemingly unstoppable succession of inventions in

[16] Rifkin, Jeremy. April 9, 1998. The BioTech century. Lecture. San Francisco: Bay TV.

particularly limited durations of time, as articulated by Moore's Law for example.[17] As we cope with being constantly flabbergasted with our advances by way of treating our innovations as the everyday, our reactions take a contemporary tone that normativizes such progress, yet technohype and the human emotional regard towards technological advancement have never been not so.

Biotechnology is an area of human imagination, experimentation and invention that we often consider in terms of futurity. We look onward, making educated guesses and critical speculations about the future to come based on the biotechnological present that we have constructed. We devote much less room however to the discussion of past biotechnologies as compared with the impending future(s) they bring, which one may focus on as transhumanist, cyborg, immortal, sustainable, non-affected by biotechnology (for hopeful Luddites), or willful for the present to stay the same through time. But what do we lose when we look only forward and forget to look back?

Reflection, the act of looking back known in physics as the return of light or sound waves from a surface, has useful metaphoric slippage in the realm of ideas, where thoughts and opinions are formed as a reflection resulting from meditation on a subject. It is as though meditation creates a space for the bouncing back of light upon the subject of thought, revealing new knowledge about one's relation to it. In computer programming, reflection is a word used to describe a computer program's ability to modify its own structure and behaviour at run time based on observations it makes about itself while running. This suggests a type of reflexive computation and processual engagement with its own practices of execution. In thinking about how we fundamentally enframe the world

[17] Moore's Law states that the number of transistors possible to engineer on a computational circuit board doubles every two years, and so the rapid acceleration of the power of computer technology increases at an exponential scale over time.

through our technologies as Heidegger[18] would have it, or instead use them to reveal the world as Pickering[19] argues, it is crucial to look backwards in hopes of understanding the strange pastiche of events and practices that have led us to our current status as makers and users of our technologies. It is just as important to reflect on our technologies as much as it is to predict future scenarios that use them in order to best prepare ourselves to alter their fruition through critical engagement if need be, or simply know how to welcome them into society with an appropriate celebratory tone.

Biotechnology has little demand on it to be understood from a historical perspective. The cultural currency it seems to carry, beyond its life-saving effects in the present day or industry changing innovations, lies in the articulation of how it will continue to do so, and with what means. This is most simply demonstrated through its popular use as a sci-fi trope through which the future gets illustrated in novels and films.

Mainstream discourse runs thin on how we have arrived at our current biotechnological paradigms, though the work of many insightful scholars like Bruno Latour[20] for example and other Science and Technology Studies scholars has been critical in unwinding the socially coded histories of scientific practices. These scholars have demonstrated how scientists function within culturally constructed frameworks just like the rest of us, and how science creates artifacts that too are heavily inscribed with human subjectivities.[21] The importance in understanding the histories of particular biotechnologies that have shaped the present is not because they have necessarily inherent value as historical

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[18] Heidegger, Martin. 2009. The question concerning technology. In Technology and values: Essential readings., ed. Craig Hanks, 99-113John Wiley and Sons.

[19] Pickering, Andrew. 2010. The cybernetic brain: sketches of another future. Chicago: The University of Chicago Press.

[20] Latour, Bruno. 1987. Science in action. Cambridge: Harvard University Press.

[21] Ibid.

subjects, but rather it is to understand how people of another time imagined the future of their world as they knew it using the technologies they were developing at a specific moment and location in history. In effect, understanding biotechnological history is a retroactive approach to understanding what we normally understand quite well about biotechnology, that being how we situate human hope in its abilities to change the world in future states.

Understanding the space for creatives in the synthetic biology lab

Today we find ourselves in a moment of being profoundly "post-", ranging between posthuman, postfeminist, postmodern and even post-postmodern; we are semantically and conceptually beyond modes of thinking and being in the world that adapt to any single paradigm that was once formerly adhered to or supported.[22] Similarly, we exist in a world that is beyond a definition of life, that is, a world that uses several definitions of what life means. These definitions arise through their relation to specific contexts as we processually interact with, and work through, new technologies that enable the creation of organic living systems through inorganic means.[23]

In academic discourse, the plurality of the notion of life is heavily moderated and modified through our consideration of biotechnological advances via a variety of disciplinary lenses: philosophical, scientific, anthropological, etc. Today, new exciting methods of interdisciplinary work between art, design and synthetic biology are emerging as synthetic biology finds new ways to invent living systems, which are not yet well understood. There is

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[22] This statement was inspired by the ideas of PhD candidate (in the Communication and Culture program at York University/Ryerson University) David Coangelo, who gave a talk on the state of being Post-Internet at the Duration Conference held at OCAD University in August 2011.

[23] Malaterre, Christophe. 2009. Biological Theory. 4(4): 357-367.

thus a shift in the mode of knowledge production within each field, which brings with it a shift in the politics of the performance of disciplinary knowledge. Dramatic collaborative changes in the way that experts work together and in each other's fields requires an investigation of how their work affects the world through an ever-shifting set of new practices that change at the speed our technologies do.

As I have noted, in this thesis I am investigating the cultural implications of contemporary art and design practices in synthetic biology. In the creative interdisciplinary fragments of synthetic biology, there is a strong working culture of artists and designers in collaboration with synthetic biologists, but there remains a paucity of academic work focused on the cultural, political and aesthetic implications of this flourishing site of interdisciplinary practice. One of my goals here is to make a contribution towards our understanding of the increasingly common interdisciplinary collaborations that are occurring in synthetic biology. I am therefore investigating the initiatives of artists, designers and other non-expert scientists such as DIY (do-it-yourself) biologists or "citizen scientists" in synthetic biology who explore a non-traditional approach to biotechnology. Their DIY ethic is helping to generate a new science that justifies itself based on curiosity and the need for increased accessibility to knowledge that breaks the hermetic seal of the laboratory and opens its resources to different publics. In addition, I investigate the potential their work creates for aesthetic, ethical and political shifts in contemporary biotechnological thought, practice and culture.

In my own art practice I am interested in building an understanding of how textile art and DIY crafting can be used to interrogate, complicate and reflect upon contemporary discourses of life, its definition, and its synthetic creation. I attempt this through the rearrangement of physical materials in the art installation setting and participatory activities of crafting with a wide ranging public. Through these interwoven theoretical and practical connections of crafting synthetic life, both in literal (biological) and metaphorical (artistic) contexts, I therefore ask how artists can use textiles, DIY craft and participatory research-creation to reveal and entangle several competing discourses from an interdisciplinary perspective.

Such an investigation is not geared toward specific instrumental demands, nor is it hoping to unify the legacies of craft with synthetic biology. Instead, I seek to extend and question the possible approaches to artistic practice in synthetic biology by drawing out some of the conceptual relations between crafting and biotech, particularly through DIY and non-specialist approaches to *making* (making knowledge, making bodies, making life).

Theoretical framework and methodology

I am largely reading my research through the philosopher Isabelle Stengers's concept of the "Ecology of Practices", which is a non-neutral tool for thinking about what is happening in practices. That is, thinking through and with what is happening in what we think of as fields, disciplines, and their associated "attachments" that help us identify their actions as practice(s). Stengers developed the Ecology of Practices as a way to resist the "demolishing force" of capitalism in conceptualizing practices, seeing that capitalism creates difficulty for any practice in its reach that does not align with its capital-generating intentions.[24] For Stengers, the Ecology of Practices are sites of attachment and force that enable creative engagement for thinking and acting in resistance to the destruction of capitalism, while imagining the potential and possibility for new politics, creativity and force

[24] Stengers explains that capitalism does not provide any space for other generative modes or ideals to exist because of its inherent comepetitiveness and eternal strive to eliminate alternatives. The logic of capitalism relies on its ability to infiltrate and take-over at the same time as reduce the possibility to "live well" or functionally operate if an entity decides to not join in its choir. It strangles market places and ideologies.

within the practice considered through concepts of dynamic resistance. It focuses on what practices could be, rather than what they are recognized as in this moment, through realistic sites of attachment.

> "Ecology of practices has not for its ambition to describe practices 'as they are', resisting the masterword of a progress which would justify their destruction. It aims at the construction of a new "practical identities" or practices, that is new possibilities for them to be present, that is to connect. It thus does not approach practices as they are … but as they may become." [25]

To elaborate further, the Ecology of Practices is a way of thinking about how to foster the potential creative force of a practice, as well as explore the experimental togetherness among practices in order to gain what practices need in order to answer challenges and enable changes in a society dominated by capitalism. It is thus a social technology that "any diplomatic practice demands and depends on."[18] The Ecology of Practices asks how politics operate at the level of the sensible, intelligible, and the possible, and thus it lends itself well to the consideration of how the coming together of divergent disciplines can "make strange" the normative conception of a practice. I use Stengers' concept as a lens through which to interpret the value and action of non-scientific "attachments" in synthetic biology, those being the activities of artists, designers and citizen scientists that I am considering in this thesis.

I argue that their attachment to synthetic biology renders the practices of relevant artists, designers and citizen scientists as creative dynamic forces in contemporary biotechnology. Their work not only affects the evolution of discourse in synthetic biology from what it might be had there never been non-scientific agents engaging in the field, but it also creates a complex, dynamic, interdisciplinary "Ecology of Practices". When brought

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[25] Stengers, Isabelle. 2005. Introductory notes on an ecology of practices. Cultural Studies Review. 11 (1): 183-196, p 185.

together, their interrelational dynamics combine to suggest particular resistances to the inevitable attempt of authorities, bureaucrats, and business leaders to co-opt synthetic biology's technological capacities for anything other than capitalist, military, or government-sanctioned control.

Having said that however, my argument needs to be nuanced somewhat. I am not suggesting that just because someone is an artist, designer or DIY biologist working at the edges of knowledge in synthetic biology that they are necessarily critical in their contributions to art/design/knowledge. Nor are they necessarily resistive forces in the face of capitalist control of biotechnology as Stengers's seems to search for. Rather, in this thesis I discuss the work of specific individuals and organizations whose work circulates in synthetic biology to varying degrees of dissensual force amidst more normative institutionalized biotech. Each person or agential "attachment" to the science intra-acts with the field in specific ways that establishes them responsible for a particular aspect of the discourse around synthetic biology, but they are not inherently critical/resistive in the way that Stengers' concept of the Ecology of Practices seems to read. Saying so in the context of synthetic biology would be writing too much to an agenda on the transformative power of art. The fact is that it is still very early days in synthetic biology to be able to fully assess the cultural implications of the diverse art, design and DIY science in the field, but I start the conversation here in light of the conceptual and political potential of the Ecology of Practices for further debate.

As I will demonstrate, synthetic biology is a field of extreme interest to capitalism since it creates an entirely new platform for the fabrication of products at the cellular level. It is also widely practiced in arenas that are heavily controlled by government bodies and institutions, and is therefore subject to the cultural implications of the forces of political engagement that are always bound within such systems. Consequently, the Ecology of Practices helps in the articulation of the political possibilities that are enabled by the interdisciplinary interactions occurring in synthetic biology, developing a deeper understanding of the overall function of art, media and design in scientific areas. In this sense, I am interested in the politics and performance of interdisciplinarity and use this interest as a lens through which I read and interpret this little-known field.

I develop a foundation for the Ecology of Practices in synthetic biology alongside my personal artistic practice through a non-representationalist approach to my thesis project. In doing so, I have attempted to take on philosopher Karen Barad's challenge to performatively understand, rather than merely represent, knowledge. Barad explains the performative understanding of knowledge as an attempt to bring critical discourse back to focusing on the materiality of things rather than symbols. Barad writes in direct opposition to lineages of intellectual thought that emphasize the power of semiotics over the material world concerning how we use language to say things about the world through symbolic representation of phenomena. In this vein, Barad argues for a performative understanding of discursive practices.[26] Such a performative understanding goes beyond language and other forms of representation; her point being that representational media do not necessarily infer knowledge about preexisting things in the world. Instead, she insists on understanding, thinking, observing and theorizing as practices of engagement with, and as part of, the world we live in. Inspired by Barad's notion of performative understanding, the combination of my written thesis and creative practice are an attempt to escape the trappings of representationalism by embodying my research as a processual theoretical and creative

[26] Barad, Karen. 2003. Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter. Signs. 28(3): 801-831.

performance that come together in the realization of praxis - the fusion of theory and practice.

Situating myself in my methods

I was trained as a biologist during my undergraduate program and obtained an honours degree in the subject. During this time I hosted a science radio show on our campus/community radio station that I prioritized while I let the lab reports I was supposed to write up slip to the bottom of my to-do list. Outside of school I always found myself socially embedded and employed in art/design communities rather than the scientific ones my biology peers enjoyed themselves in. As such, the seed for my strong interest in interdisciplinarity between the arts and sciences was planted some years ago, and so before I had even applied to pursue my Master's at OCAD University, I had caught wind of the recent interdisciplinary developments in synthetic biology that I am researching now through my casual and constant search for artscience curiosities. I mainly tracked the progression of this discourse through artist websites and DIY biology forums. Before thinking about institutionalizing this interest of mine through a Master's project, I had in particular cultivated quite a collection of knowledge about its functioning by keeping tabs on the websites, blogs and Twitter feeds of a handful of scientists, artists, designers and citizen scientists concerned with synthetic biology. The interdisciplinary crossover in the field has matured much since then, yet my online research methods, which were spurred from my curiosity about the potential value of these types of collaborations, remains useful as a method of research that I use to gather relevant information about its evolutionary events in order to articulate the field to others.

Moreover, in the summer of 2011 I travelled to Portland, Oregon to work as an editorial assistant on a documentary about synthetic biology. George Costakis and Sam Gaty, the co-directors of the film and founders of the production company Field Test Independent Film Corps have been travelling for the last three years to document the advances and attitudes of the prominent characters in the synthetic biology world.[27] Working with them dramatically re-shaped my understanding of synthetic biology and its internal functioning, predominantly from a practical perspective. My project is, in some significant ways, indebted to them and the knowledge I absorbed by immersing myself in their film project. Although my experience working on the documentary did not explicitly shape my thesis in a particular way that I can account for, it implicitly informs the degree of clarity with which I can discuss the major players and competing discourses, knowledge-distinctions, and scientific practices that currently constitute the field.

Moving from my focus on mapping and interpreting the current trends in interdisciplinary synthetic biology and into its relationship with my own artistic practice, I have developed the foundations for an understanding of the role of physical *formal rearrangement* in synthetic biology as well as craft. I define formal rearrangement as the changing juxtaposition of independent fragments of a whole (for ex: the corporeal components of a body) to make a reconstructed whole. I consider it a binary-blurring tool that functions across divisions of the natural and the artificial in synthetic biology and institutional/citizen discourse of synthetic biology though craft.

I investigate how biological remix, or the *rearrangement* of biological parts, operates in the genomic environment of synthetic biology. Here, fragments of "biological media" (genes sequences) are carefully chosen, synthesized and assembled in novel living organisms to create life from the remixing and reinventing of naturally occurring genetic parts that get artificially arranged. In my own textile art practice, I have created an interactive exhibition of

[27] Field Test Film Corps, *A Natural History of Synthetic Biology*. www.fieldtest.us

modular components of metaphoric synthetic bodies. More specifically, I have created sewing patterns for a variety of possible human, animal, plant and microbiological "body" parts that can be bioengineered and reconstructed synthetically. The sewing patterns serve as blueprints to make art from, and are a cheeky reference to DNA, which in its general acceptance is referred to as the "genetic blueprint" of life.

From the sewing patterns the body parts get made into textile art works that are hung in the gallery setting. As well, the public can download these patterns to make their own synthetic body parts and add them to the exhibition if they please upon their next visit to the gallery space (The Ontario Science Centre). Most importantly though, each visitor who encounters the installation gets to *rearrange* the body parts, combining them in strange and surprising configurations. Each time the parts get rearranged, a new narrative of what possibilities a synthetic body holds gets expressed and shared, which others can work from. As such, I will explore the connection between formal biological rearrangement in synthetic biology and tactile rearrangement of fabric parts to engage people in questioning expressing and what is happening in the synthetic creation of organisms, *which have bodies* that we don't often acknowledge.

Synthetic biology in its contemporary form is still in its infancy and most of its cultural currency is at present bound in the ways scientists, artists, designers and journalists imagine the future based on its uses. In my research and art practice I position my installation as a participatory means through which to also contribute to the foresighting and imagining of this emerging interdisciplinary field.

Rationale

Synthetic biology meets the requirements that Thomas Kuhn set out for a scientific practice to be considered a scientific revolution, which enables a true paradigm shift in the way that science is practiced. Specifically, it does this by pulling adherents away from more traditional practices within its field of genetic engineering, thus classifying a transformation of paradigm[20]. Kuhn offers valuable insight when he advises:

> "We must recognize how very limited in both scope and precision a paradigm can be at the time of its first appearance. Paradigms gain their status because they are more successful than their competitors in solving a few problems that the group of practitioners has come to recognize as acute. To be more successful is not, however, to be either completely successful with a single problem or notably successful with any large number."[28]

Synthetic biology may succeed in some of its long-term goals of creating cheap and efficient solutions for some of our greatest societal problems, but there are also many potential risks associated with this revolution that deserve investigation, which the "Ecology of Practices" can help reveal a creative force for "thinking (these) practices" with.

As a new paradigm of scientific practice, humanity may not actually have all the knowledge it requires to accomplish the unwieldy and ambitious goals of synthetic biology in its attempt to create a biology that irrefutably corresponds with engineering principles.[29] At its core is the notion of designing nature, but this means designing something that humanity can't claim to yet entirely understand in its unmediated state. Each day, entire fields of specialists in "traditional" biology labs spend their days decoding nature and its complex behaviours in hopes of better understanding how it functions, as well as our place in relation to it. Meanwhile, synthetic biologists are already using nature to design novel life forms from it at a level of whole systems that the genetic engineering that came before did not attempt to

[28] Kuhn, Thomas. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press, 1967, p 12.

[29] Benner, Steven A., Zunyi Yang, and Fei Chen. 2011. Synthetic biology, tinkering biology, and artificial biology. What are we learning? Comptes Rendus - Chimie 14 (4) (201104): 372-87.

do. The question then begs itself: what is at stake when we create new systems of life modeled from preceding systems of life that we lack a complete understanding of? Most likely we will never be able to understand nature to such a level of wholeness, but the gap between our understanding of nature, and synthetic biology's creation of "a new nature" leaves an empty niche for the production of knowledge that should be occupied with critical questions in order to gain any ground of understanding therein.

I have surveyed recent institutional regulations in the governance of synthetic biology practices, and noticed some interesting developments that raise difficult questions about the politics of synthetic biology's function in society. An extreme but true example of this comes from DARPA. The Defense Advanced Research Projects Agency is a research division within the Pentagon that invents technologies for the US military. In its budget for 2011, DARPA allocated $137 million to its Material and Biological Technology Research Unit, $6 million of which will directly fund the inauguration of a project called BioDesign, which is explicitly focused on the use of synthetic biology for militaristic potential. In the budget DARPA describes BioDesign as

> "…a new intellectual approach to biological functionality. The intrinsic concept is that by using gained knowledge of biological processes in combination with biotechnology and synthetic chemical technology, humans can employ system-engineering methods to originate novel beneficial processes. BioDesign eliminates the randomness of natural evolutionary advancement primarily by advanced genetic engineering and molecular biology technologies to produce intended biological effect."[30]

DARPA is therefore developing a research initiative based on synthetic biology practices to build synthetic organisms that will not be subject to the pressures of Darwinian evolution, but rather human-driven evolution. Darwinian evolution, understood as the force

[30] DARPA. 2010. Department of defense fiscal year (FY) 2011 president's budget. Washington: 1, p 10.

of genetic change based on competition for fitness between individuals in a population, and among entire populations of different species, is drowned by such biotechnology that focuses on the synthetic assemblage of particular metabolic processes for specific, intended biological effects.

Freeman Dyson, the theoretical physicist and mathematician well known for his musings on biotechnology has said that Darwinian evolution is not only grossly misunderstood as the sole force driving biological evolution today, but that it is over.[31] To wit, Dyson points out that it died out about 10 000 years ago when *Homo sapiens* began to manipulate the biosphere through human-directed modes of evolution like breeding, an engine of genetic change that runs thousands of times faster than Darwinian evolution.

Synthetic biology and the technological aspirations of DARPA dramatically advance human-driven evolutionary processes through things like synthetic chromosome construction. These organisms would be designed specifically to carry out the particular desires of biological function for use in the innovation and advancement of military intelligence. DARPA's outline of their next-step strategies for the project in the 2011 Base Plans include the following tasks:

> " - Identify and initiate strategies that would enable a new generation of regenerative cells that could ultimately be programmed to live indefinitely until needed for an injury repair or therapeutic application.
> - Develop genetically encoded locks to create "tamper proof" DNA and protect commercial applications.
> - Permanently append a synthetic organism's genome and prevent foul play by tracking organism use and history, similar to a traceable serial number on a handgun."[32]

The budget makes DARPA's intentions to create biological weapons using synthetic

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[31] Dyson, Freeman. 2011. LIFE: WHAT A CONCEPT! An *Edge* special event at Eastover Farm, www.edge.org.

[32] DARPA. *Department of defense fiscal year (FY) 2011 president's budget*, p 248.

biology techniques that they claim the need for from the perspective of US national security well understood. Whether or not they will be able to accomplish such technodystopian projects cannot yet be determined. We are still in very early days of innovation with synthetic biology; the reality of biological complexity that synthetic biologists must work in does not render projects that reduce organismal complexity to a system of computable substrates easily feasible. The computational metaphor that is riddled throughout synthetic biology discourse would work nicely in a Cartesian environment, but the biological is not such a milieu and it would be naïve to say that all we need to do is arrange the right co-ordinates of the genome - and voila! Regardless of my distrust of this project's possibility anytime soon, DARPA's intentions to execute such a project are no less important if they don't accomplish it than if they do, since their budget has imagined a future that now can be worked towards through their research, thus informing the discourse on how humans relate to synthetic life, and how humans should be able to interact with nature.

In *War in the Age of Intelligent Machines*, Manuel De Landa argues that new technologies follow a standard method wherein they are first inserted into social practices in order for them to be proven effective. However, once the technology has demonstrated its usefulness past a certain threshold, the state adopts the technology for its own uses. Consequently, the state transforms the technology into a type of "war machine." An example he gives is electronic calculators, which were first presented as a common processing tool for mathematic functions, but were then co-opted in World War II to control the deployment of weapons.[33]

In following this formula, we see that President Obama's administration has created a multi-million dollar research budget for DARPA to kick start its practical foresighting of

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[33] De Landa, Manuel. 1991. *War in the age of intelligent machines.* New York: Zone Books, p 157.

how to best use synthetic biology for the military-industrial complex. Not coincidentally, this connection to military use percolated right when synthetic biology became widely recognized in its ability to change human modes of biological production, (particularly since Craig Venter's successful creation of an entirely synthetic bacterial genome in May 2010, which I will discuss in chapter two).

Synthetic biology's first public value was social; it promised to invent effective toxin-biosensors, cheap vaccines and highly controlled bacterial metabolic functions to clean up environmental disaster zones. These developments in turn affect the quality of the lives and sociality of people living in parts of the world that benefit from such remedies. Now, as demonstrated by recent cultural advancements such as those found in DARPA's budget, it has already entered a process of co-option into the sector of state-control designated for war machinery, just as De Landa predicted.

Félix Guattari was not hopeful that a biotechnological revolution like synthetic biology would promote critical thinking in the public realm, but rather that like the scientific revolutions that came before it, he feared it would eliminate judgment from the masses and enter a homogenized forum of political consensus, particularly as it gets co-opted into a state - sanctioned area of control.

> "Why have the immense processual potentials brought forth by the revolutions in information processing, telematics, robotics, office automation, biotechnology and so on up to now led only to a monstrous reinforcement of earlier systems of alienation, an oppressive mass-media culture and an infantilizing politics of consensus?"[34]

Guattari identifies the general lack of critical thinking put forth by society in its encounters with new technologies that embody the force and potential to change how we go about our

[34] Guattari, Félix. Soft Subversions. MIT Press: Cambridge. 1996, p 103.

lives. He believes in the revolutionary power of each technology brought forth, that is, its ability to be used for revolutionary or democratic purposes, but that this potential can and will only be realized through the people who consciously use its tools for resistance. In this sense, a technology is always a non-neutral tool that we perceive as an active force through its use as an apparatus in a specific social context. I agree with Guattari when he says that the normative mode through which we relate to technology is not to question its variety of uses, but accept the social context through which it has been presented to us. As such, the "infantilizing politics of consensus" results from not questioning the force of the technology to do things other than what we know the technology to do already.

Eugene Thacker takes up this question in *The Global Genome,* where he suggests that one way we might get beyond the "infantilizing politics of consensus" when relating to an evolving technological revolution is to embrace what Guattari called the "post-media era". The "post-media era", although never explicitly defined, is provided as an outline of "new ways of thinking and acting in the world that are predicated on finding new ways of thinking about technology in relation to the 'subject'."[35] According to Thacker, doing this creates the conditions for new territories that allow for thinking about experience, existence and selfhood in relation to science and technology. These are each always-present possibilities that reside at the nexus of where humanity and technology meet. When the possibility is ignored, the reduction of technology to pathways of power (such as the state) or pathways of knowledge (such as science) is facilitated.

> "Guattari poses the possibility of a "post-media era" as one alternative. As its name indicates, the post-media era would be one that both incorporates media (that is, it is not anti-technology), but also transforms media such that they are no longer assumed to be separate from the subject (that is, they are no longer an object, a commodity, a tool, or

[35] Thacker, Eugene. 2005.*The Global Genome: Biotechnology, Politics, and Culture.* Cambridge: MIT Press, p. 307.

something opposed to the subject). Guattari does not define what this post-media politics would be, but he suggests that one route is to move from "consensual media" (media homogenization standardization, and corporate ownership) to "dissensual post-media" (bottom up media that emphasize polyvocality, that are critical)."[36]

In further unpacking this passage, Thacker considers Guattari's suggestion for a "dissensual post-media" that are critical through the lens of bioart. Bioart is the creative artistic practice where artists use biology as either a subject matter, or a medium with which to make their art. That is to say that the art work deals with biotechnology as a central idea to the piece, or actually uses biotechnological instruments like pipettes, instead of traditionally artistic ones like paintbrushes, to create the work. Often bioartists work in interdisciplinary collaborations with scientists in order to obtain lab equipment or access specimens that they may need for their projects, as well as gain the knowledge they need in order to partake in such technologically-disciplined actions. A commonly used biotechnology in bioart is the bioreactor for tissue culturing, which is obviously much more difficult for an artist to access and know how to use than the more traditional paintbrush or sculptor's clay.

In effect, Thacker spends time considering the "media" produced by bioartists. These include wet media or biological media, as well as media-art that transgress the boundaries of art and science. These media are interpreted as critical territories that harness resistive dissensual forces. They create room for debate within the realm of an "infantilizing politics of consensus" about our technology, human subjectivity, and the meaning of their overlap in the larger social sphere.

Artistic practice as social research, social insurrection, critical pedagogy, tactical transformation, and other such revolutionary activities is often discussed as a "way out" of our political, capitalist, and environmentally-doomed trappings. In the case of bioart, which Thacker posits as a non-neutral tool for creating alternative ways to relate to technological

[36] Ibid.

revolution (such as the current revolution in genetic engineering, computer science and mechanical engineering that together make synthetic biology), Thacker suggests we "might do better and ask how cultural research dealing with biotechnology can take seriously its interdisciplinary nature."[37] It is precisely this question of interdiscipinarity that interests me in the relationship between art, design, and synthetic biology as it relates to transformative politics and critical assemblages. I suggest that this interdisciplinarity has the potential to be extended through the "Ecology of Practices" to include not only synthetic biology and art, but design, cultural studies, and DIY or citizen science (which I will elaborate upon shortly).

Artscience collaborations are sites of exploration for finding new ways to reveal and transform the politics embedded within the specific artistic and scientific practices that the collaborations might incorporate. They are capable of this because the interdisciplinarity disrupts the perspective that scientists grow comfortable with when they adopt a professional and perhaps inevitably normative gaze at their subjects in work-a-day science. Similarly, they challenge artists to consider their work through different paradigms, that include quantitative, empirical and scientifically scrutinizing investigations of their work. This schism in practice introduces an alternative possibility for labour practices in art and science, opening up a new political dimension that regards how work ought to be done. Over time, art-science collaborations demonstrate supplemental possibilities for performing and producing knowledge that extend and experiment beyond the limits of disciplinary thinking. I consider this to be a political gesture towards the generation of unorthodox but potentially valuable labour models for artists, scientists, and other relevant interdisciplinary parties.

These types of interdisciplinary collaborations have also moved beyond the settings of the laboratory or the studio to interact with "complex social, political, economic and

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[37] Ibid.

environmental contexts, thereby addressing the extended fields in which sciences circulate, and indicating how the laboratory is never hermetically sealed."[38] As such, synthetic biology serves as a fertile site to map in terms of its forces, attachments, and interdisciplinary players that not only contribute to the growing discourse on the value and potential of artscience collaborations, but also extend beyond the thrust for the unification of art and science and consider the entire strange milieu in which science evolves: culture.

Synthetic biology is an evolving atmosphere that is affecting the arts, sciences, design, DIY culture, social sciences and beyond. In this way, it is an exciting technological environment to investigate that can teach us not only about the potential of artscience collaborations, but also allows us to ask questions about the process of becoming, in a whole culture, which includes participants from more sectors than just the arts, or sciences. Synthetic biology is a cultural phenomenon that is politically, ethically, and technologically intriguing, of which art and science are just a part.

Bruno Latour has argued that "we have never been modern" and has shown that we instead engage with modernist activities through processes of "enframing" the world that close us off from the potentials it holds for us, since alternatives always exist.[39] Instead, when we lack criticality, we too often pre-determine the results of our initiatives in the human and material world, closing off vast possibilities that we could otherwise enlarge and arguably enlighten the world with. For Latour, these constructed modernist trappings often come back to haunt us in the form of ecological crises. Two centuries of industrialization resulting in our current climate change crisis is the most obvious example of such a haunting return.

Synthetic biology is still emerging in its contemporary form. While evolving, it is

[38] Gabrys, Jennifer and Yusoff, Kathryn. 2011. Arts, Sciences and Climate Change: Practices and Politics at the Threshold. *Science as Culture.* 1: 1-24, p. 12.

[39] Latour, Bruno. Politics of nature: how to bring the sciences into democracy. Harvard University Press: Cambridge.

also positioning itself as a revolutionary force in the way that science and industry interact as we annihilate the factory and replace it with the meticulously designed synthetic cell. Such transformative political potential is a target of concern for thinkers like Guattari, Thacker and Latour. Although finding a solution for how to best avoid the modernist trappings of the looming synthetic era is beyond the scope of my investigation, I am arguing that the Ecology of Practices is a useful conceptual apparatus through which to enter the digestion process. Consequently, in the second chapter I will build a detailed mapping of the interdisciplinary actors whose work affects the developing discourse of synthetic biology in order to identify how their integration can be interpreted in an Ecology of Practices.

Both Latour and Stengers suggest that an integral component to exploring alternative functionalities of being and thinking in the Modernist world start with slowing down the speed at which we think.[40] This is done in order to alter our perspective on issues of progress by shifting the automatic associations they carry which bind speed to concepts like efficiency, innovation and growth. In my research I build up the notion of *formal rearrangement* as a material tool of production that is found in both synthetic biology and art practices, which transforms into a conceptual tool when we consider what it can teach us about processes of making. As I will demonstrate, the rearrangement of genetic devices in synthetic biology to create new biologicals, which have well characterized codes that are shared openly through online platforms, shares many similarities to the function of *formal rearrangement* in my art practice as a textile crafter. It functions as a tool for thinking in synthetic biology and craft alike because it allows a moment of pause, reflection, and careful choosing of how to construct the biological or artistic body in question. Slowing down to

[40] Stengers, I. The cosmopolitical proposal, in: B. Latour and P. Weibel (Eds) Making Things Public: Atmospheres of Democracy, pp. 994–1003. MIT Press: Cambridge. 2005.

become aware of the rearrangements one makes in the genetic code or participatory art installation can therefore create a contemplative and intentional relationship between the maker and synthesized object, which I argue we might learn something valuable from.

Rearranging parts of anything focuses on the recombination of chosen parts to constitute a new whole, and instills an ethos of invention. In my research project I question the notion of progress and novelty inherent to rearrangement for reconstruction. I consider what these notions have to offer us in terms of their meditative potential for thinking through how we ought to rewrite, reprogram, redesign and recombine parts to make a *different* whole. The process of rearrangement requires thought, curation, decision-making, and an iterative design process. In its ability to make us re-think and not merely re-invent, it creates an opportunity to slow down, critique, and think about invention before rushing into another high-modernist adventure.

It is in this sense that I am following the line of thought from Stengers to Latour that questions how to bring science into democracy. In order to do so I am exploring the significance of the formal rearrangement of genetic parts alongside crafted textile parts as an entry point for my own artistic practice, which contributes to a *performative understanding of knowledge* in synthetic biology. I do this as well to offer a personal artistic and theoretical contribution to the Ecology of Practices, rather than a unifying declaration of how synthetic biology ought to unfold in an interdisciplinary milieu.

Chapter 2: Literature review

Synthetic biology in the 21st century

Synthetic biology is not a new term for specific scientific practices that seek to remodel and reconstruct life in its mechanic structure and behaviour, however the term has new meaning in the 21st century. One main difference in its contemporary use is that synthetic biology aims to create *organic* life through *inorganic* means, whereas earlier forms of synthetic biology created inorganic life-like systems that advanced knowledge of *artificial* life.[32] The contemporary use of the term brings with it new ways to warp the boundary of territorialization between natural and synthetic worlds.

Evelyn Fox-Keller explains that synthetic biology was first coined as a term in scientific practice in 1905 by French biologist Stéphane Leduc in *La Biologie Synthetique*, a work in which he sought to understand the chemical and physical mechanisms of life through their reconstruction in the lab using simple chemical systems that lacked DNA, like metals and inks.[41] These substances, when combined under certain conditions, grew into complex structures capable of structural change that mimicked the growth of organisms. This property, now understood to have been driven by osmotic pressure, first seemed like the spawning of a type of synthetic life since its motility and growth gives the impression that the systems have an evolving ecology of their own, rendering them life-like if not a curious version of life itself.

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[41] Fox Keller, Evelyn. 2002. Making sense of life: explaining biological development with models. Cambridge: Harvard University Press.

Today however, we are engaged in a different type of synthetic biology. The contemporary notion of synthetic biology is explained well by a synthetic biology research group at Harvard University when they say

> "Synthetic biology extends the spirit of genetic engineering to focus on whole systems of genes and gene products. The focus on systems as opposed to individual genes or pathways is shared by the contemporaneous discipline of systems biology, which analyzes biological organisms in their entirety. Synthetic biologists design and construct complex artificial biological systems using many insights discovered by systems biologists and share their holistic perspective."[42]

Synthetic biology is often surrounded by confusion as a term that has cropped up in recent years against the backdrop of the genetic engineering we have become accustomed to since the 1970s. As indicated in the quotation above, the synthetic biology paradigm brings with it a goal of understanding and engineering the genetic constituents of organisms in order to create artificial genetic systems with particular focus on considering their interrelation and holistic connectedness. Consequently, synthetic biology is sometimes referred to as "Genetic Engineering 2.0" whereas the now traditional genetic engineering of the past focuses much more on single gene manipulation using recombinant DNA and cloning technology. This older type of genetic engineering leaves DNA sequences directly modified but not necessarily significant amounts of the genomic milieu in which the engineered system in situated.

In the 21st century, synthetic biology employs intradisciplinary[43] methods that incorporate biology, computer science, chemical, electrical and/or materials engineering to

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[42] Andrianantoandro, Ernesto, Subhayu Basu, David K. Karig, and Ron Weiss. 2006. Synthetic biology: New engineering rules for an emerging discipline. Molecular Systems Biology 2 28 (10): 1038-1049, p. 1038.

[43] I use the term intradisciplinary to refer to the multiple aspects of synthetic biology that are influenced from different fields like computer science, engineering, and biotechnology. This term is used differently than the term interdisciplinary, which I employ in this paper to

differing degrees in working towards its research goals. Synthetic biology today is considered a high profile field of biotechnology within which O'Malley et al. have distinguished three different approaches, schools, or "knowledge distinctions": DNA-based device construction, genome-driven cell engineering and protocell creation.[44]

A) DNA-based device construction

DNA-based device construction can be understood as the design and creation of genetic circuits or pathways that allow for customizable metabolic function of simple organisms based on the interrelation of well characterized and functional genetic parts. Devices, things we can put together to build a circuit, is a concept borrowed directly from engineering principles where devices are used to build machines from several interrelated parts that come together to perform predictable functions guided by human intention. This entails a similar design process to how we build cars or computers from several smaller, standardized, functioning constituents. A major goal of synthetic biology and genetic device construction in particular is to develop a deeper understanding of biological design from the bottom up instead of the top down. This implies knowing how to construct living systems by adding parts together rather than starting with an organic life-form and taking parts away in order to understand its make-up. This is currently being explored most successfully through the creation of genetic circuits and studying their behaviour in cells.[45] DNA-based device construction is therefore characterized by focusing on biological effects over

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describe the multiple aspects of my project that span across art and science and include synthetic biology, art, design, DIY science and cultural studies.

[44] O'Malley, Maureen, Alexander Powell, Jonathan Davies, and Jane Calvert. 2007. Knowledge-making distinctions in synthetic biology. BioEssays 30 (1): 57-65.

[45] Nandagopal, Nagarajan, and Michael Elowitz. 2011. Synthetic biology: Integrated gene circuits. 2011 333 (6047): 1244-8.

biological essence and employs a logic that emphasizes application and functionality over definition, as a living organism, of a specific kind.

The Registry of Standard Biological Parts has become a major player in popularizing the invention and use of genetic devices in evolving synthetic biology research. The Registry is closely affiliated with iGEM, the International Genetically Engineered Machines Competition. iGEM is a worldwide synthetic biology competition aimed at undergraduate students that started at MIT in 2004 where teams try to invent the most useful or innovative genetic devices to control small organisms with, like bacteria, yeast and worms.[46] In the competition's inaugural year, 5 teams competed in an interuniversity arena. This number grew to 190 teams in 2010, a number which has now outgrown MIT's hosting capacity and thus the competition took place as 3 separate regional competitions in various international locations in 2011. The winners from the 3 regional competitions then compete with one another to crown the global winning team.

More than just a student competition, iGEM is, for nearly the entire synthetic biology community, an annual reunion that houses panel discussions, workshops and poster sessions for the people involved in defining what synthetic biology means today. This group includes not only senior scientists of synthetic biology, but citizen scientists, artists, designers, the FBI and the coordinators of the Registry of Standard Biological Parts, who freely provides the competing teams with the genetic constructs they need to build their genetic devices.

iGEM is largely responsible for recruiting a new generation of synthetic biologists to bring the field into the future and establish the industrial and economic foundations for its

[46] I was fortunate to have had the financial support of OCAD University's Office of Graduate Studies to attend iGEM 2010 at MIT in Cambridge, Massachusetts. The experience proved very helpful to my initial research process that sought to simply comprehend the network of contemporary synthetic biology practices.

widespread use in society.[47] The biological materials these young synthetic biologists use to create their projects come directly from the Registry. From its website, The Registry of Standardized Biological Parts is self-described as

> "a continuously growing collection of genetic parts that can be mixed and matched to build synthetic biology devices and systems…The Registry is based on the principle of 'get some, give some'. Registry users benefit from using the parts and information available from the Registry in designing their engineered biological systems. In exchange, the expectation is that Registry users will, in turn, contribute back information and data on existing parts and new parts that they make to grow and improve this community resource."[48]

In 2003, computer scientists Tom Knight, Randy Rettburg and chemical engineer Drew Endy founded the Registry for Standard Biological Parts at MIT, as well as the trademark name for the parts themselves: Bio Bricks™. In essence Bio Bricks refer to a specific "brand" of open-source genetic parts as defined by a Bio Bricks technical standards setting process. They are DNA sequences (a double stranded functional set of nucleotide bases coding for a particular gene) of defined structure and function that share a common interface or "sticky end". A "sticky end" refers to the nucleotide molecules (G for guanine, A for adenine, T for thymine and C for cytosine) at the end of a strand of DNA, and they are important in molecular biology because they define the next strand of DNA that can be joined to it (such as is often done in cloning when a genetic sequence is cut in order to insert a vector sequence of DNA into the original strand at the cut site, the ends of which must be properly joined together in order to thus modify the genome). Any two complimentary strand ends (A always binds to T and C always binds to G in creating the "zipper" that connects two strands of DNA) can anneal (or join securely) to one another, even if the

[47] Field Test Film Corps. 2012. *A Natural History of Synthetic Biology*. It was through my experience working on this film as editorial assistant that I understand the internal practical and political functioning of synthetic biology in relation to iGEM to be as such.

[48] http://partsregistry.org/Main_Page

strands come from two different organisms. The "sticky end" is a particular type of end fragment of DNA that has an overhang of extra nucleotides on one of the two DNA strands so that there is room for a second unequal strand of DNA to anneal to it (i.e. a strand with a complimentary "sticky end").

Bio Bricks are unique in that they are coding sequences of DNA that have standardized "sticky ends", meaning that all Bio Bricks are compatible with other Bio Bricks, creating a common interface for their connection. One can think of it much like a standardized cable such as a USB that allows certain electronics to speak to one another, but not those that only take firewire, for example. As a result, the Bio Bricks standard has created a new paradigm of engineering practice within synthetic biology. They are most commonly composed together in a series to create a chain of Bio Bricks that then constitute an engineered genetic device that gets inserted into a genome when put in combination with other genetic factors. Synthetic biologists then insert the engineered genome into a simple organism, such as a bacterium that has been emptied of its native genome in order to activate the Bio Bricks in vivo. This is done to achieve biological function and hopefully a useful product of some sort. Common applications constructed using Bio Bricks include biosensors, new modes of cellular communication between cells, cell regulators, protein generators, or even cell-killing devices.[49]

Let me be clear in stating that not all synthetic biologists whose endeavors include creating novel biological parts, devices or circuits are necessarily involved with iGEM or the Registry. In fact some, like Steven Benner, outright do not accept the iGEM/Bio Bricks/Registry of Standardized Biological Parts way of doing things in synthetic biology. As Benner argues, this so-called paradigm shift does not stand to add any value or help define the field from the bioengineering that came before.

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[49] http://partsregistry.org/Featured_Parts

> "I am repeatedly asked by science reporters about the emerging use of "synthetic biology" in the engineering sense: "What's the fuss? Isn't synthetic biology just more 'Flavr Savr'® tomatoes?" The question is raised in analogous form by molecular biologists who see in synthetic biology "contests", which attract student participation worldwide, nothing more (and nothing less) than the cloning that has been done since the 1970's. At worst, it illustrates the aphorism that "the difference between men and boys is the price of their toys."[50]

Without casting Benner's critique aside, it is important to note that the aforementioned organizational bodies are extremely prominent forces in contemporary discourse around the evolving 21st century synthetic biology paradigm. They are of particular interest to me because they most heavily target and successfully reach a large youth population through events like iGEM. These competitive young scientists constitute a generation of emerging synthetic biologists who are imagining the future they want to live in, and are working towards in their research. As such, I will later return to examine the aspects of synthetic biology that work alongside current trends in youth culture, which include the belief in free access to information via open source systems, an example of which being the Registry. Consequently, I will not examine genetic device construction practices that fall outside of the iGEM-Registry community in the interests of not allowing the focus of this paper to become too unwieldy.

B) Genome-Driven Cell Engineering

Genome-driven cell engineering is the second knowledge distinction in synthetic biology I mentioned that must be explained. It employs both top-down (starting with the natural genome and then stripping away information) as well as bottom-up (starting with

[50] Benner, Steven A., Zunyi Yang, and Fei Chen. 2011. Synthetic biology, tinkering biology, and artificial biology. What are we learning? Comptes Rendus - Chimie 14 (4) (201104): 372-87, p. 373.

nucleotides) approaches to working with the whole genome. These approaches are used in genome-driven cell engineering to find the minimal genome (smallest genome required to run a living cell), transplant modified genomes into cells, and completely synthesize whole genomes from scratch.[51] These divergent practices all consider the genome as the causal engine of the cell, thus providing a rationale for their grouping.

The search for the minimal genome requires reducing an organism to its most basic biological components. This is done by stripping away any molecular constituents of cells that do not aid in the performance of vital life functions until the cell dances with the possibility of its own biological incapacity to live but remains genetically robust enough to stay on the positive side of the threshold. The non-coding genetic material in a naturally occurring genome can make up the majority of the genetic data bound within it. This implies that building organisms without non-coding data eradicates a lot of "filler" DNA, simplifying the process of working within the genome when one wants to insert bioengineered parts or circuits into it. By stripping life down to its bare minimum, scientists hope to bypass many of the roadblocks they normally encounter in bioengineering, the most daunting of which being that genetic data can be too numerous to properly navigate entire biological systems with precision and functional accuracy.[52]

In finding the smallest possible genome that can "run" a cell, synthetic biologists are working with basic genetic frames that organisms can then be built from. These frames are

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[51] O'Malley, Maureen, Alexander Powell, Jonathan Davies, and Jane Calvert. 2007. Knowledge-making distinctions in synthetic biology. BioEssays 30 (1): 57-65, p. 59.

[52] Schmidt, Markus. 2009. Chapter 6 Do I understand what I can create? Biosafety issues in synthetic biology. . *In Synthetic biology : The technoscience and its societal consequences.,* ed. Schmidt Markus,Kelle, Alexander,Ganguli-Mitra,Agomoni, 1-189. Netherlands: Springer.

referred to as a "chassis".[53] "Chassis" is the word used to describe the basic frame of a car before specific parts like a steering wheel and hubcaps are added to it in its becoming of a specific model of automobile. In much the same way, different genetic extensions can then be added to the biological chassis to give rise to synthetic organisms that have been carefully designed from well-characterized genetic parts. This makes creating life similar to manufacturing items along an assembly line, whereby objects are standardized and connected to other objects via a chassis body in a manner that saves time, money, and materials since the constituent objects don't need to be worked on individually to fit together (remember the sticky ends).

In synthesizing entire genomes from scratch, an entirely bottom-up design faction of genome-driven cell engineering, the organism's genome first gets designed in a software that acts much like a word processor and strings together a specific sequence of A's, G's, C's and T's. This is done according to the desired coding sequences that the synthetic biologist has in mind for specific protein production. The written sequence then gets sent to a machine called a DNA synthesizer, which holds adenine, guanine, cytosine and thymine in bottles (like ink cartridges) and dispenses them according to the information held in the computer-generated design it works from. The DNA synthesizer literally prints the genome in short sequences, called oligonucleotides. The oligonucleotides then need to be annealed together to concretize the genome. Oligonucleotide synthesis is achieved by a stepwise addition of nucleotide residues to the terminus of a growing chain of nucleotides until the desired sequence is assembled. The process includes several other technical steps such as de-blocking, coupling, capping, and oxidation, but I will not probe deeper into their specificities here.

[53] Heinemann, Matthias, and Sven Panke. 2006. Synthetic biology - putting engineering into biology . Bioinformatics 22 (22): 2790-9.

Craig Venter, a controversial synthetic biologist, published research on his creation of what some call the first organism without a genetic ancestor on May 20, 2010. It is also known as the first living creature to have a computer for a parent. It was alive in as much as it grew, reproduced and had functional activity. Via whole-genome engineering, he and his research team first designed a relatively simple genome of a bacterium modeled after common parasitic bacteria found in ruminants (cattle and goats) that causes lung disease. The bacteria is known as *Mycoplasma mycoides*, and it has a genome of 200 000 nucleotide base pairs arranged in a plasmid (a circular genome that bacteria possess). The entire synthetic genome was successfully reproduced using DNA synthesis, and was then inserted into a naturally occurring *Mycoplasma capricolum*. *Mycoplasma capricolum* is another common bacterial pathogen of ruminants, which had had its original genome removed and was thus essentially genetically empty at the time when the synthetic plasmid was inserted. The successful genome transfer and subsequent viability of the bacteria with a synthetic genome (it's ability to replicate itself billions of times) created the world's first organism with an entirely synthetic genome. Officially named *Mycoplasma laboratorium*, the creation has been popularly nicknamed "Synthia". [54] The project is rumored to have taken over 10 years to accomplish while being worked on by 20 scientists, costing more than US$40 million to complete.

C) Protocell creation

The third approach I will touch on is the creation of protocells, an intensely bottom-up perspective in synthetic biology that attempts to build a wide variety of cell types from scratch. Protocells are often difficult to classify as living, non-living or semi-living since they

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[54] Venter, Craig; Gibson, D; Glass, John; Lartigue, Carole; Noskov, Vladimir; Chuang, Ray-Yuan; Mikkel, A. 2010. Creation of a bacterial cell controlled by a chemically synthesized genome. Science Express 10 (1126): 1-12.

usually lack DNA but grow and seem life-like in their mechanical essence.[55] Protocell science as a knowledge distinction in synthetic biology is considered more widely divergent from the first two types of synthetic biology I've mentioned than they are from one another because protocells are often created in order to know more about how biology works rather than redesign biology to serve human needs.[16] There is an exception however in the particular case of contemporary architecture that is utilizing protocell science to design materials and structures that can adapt to their surroundings in ways that living systems do, which I will unpack in more detail later in this paper.

In general, protocell creation is more of a science (which seeks to understand) than an engineering practice (which seeks to build). As Steven Benner explains, he and his colleagues who work in protocell creation "use synthesis to develop a better understanding of the concept of 'life'."[56] Protocell scientists are interested in questions that build upon early investigations into the mechanical and chemical structures needed to support life as was undertaken by Stéphane Leduc in 1905, and the search for the inorganic compounds which may have spurred the first forms of life, conducted by Miller in 1953.[57] It relies heavily on theoretical modeling (used to grasp relationships in molecular biology), cellular self-assembly, and intra-cellular dynamics that allow living systems to thrive and evolve. The protocells are built as reconstructions of the above-mentioned relationships and their surrounding biological milieu in the form of chemical models. These chemical models are constructed in

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[55] Armstrong, Rachel. 2011. How protocells can make 'Stuff' much more interesting. Architectural Design 81 (2): 68-77.

[56] Benner, Steven A., Zunyi Yang, and Fei Chen. 2011. Synthetic biology, tinkering biology, and artificial biology. What are we learning? Comptes Rendus - Chimie 14 (4) (201104): 372-87, p. 387.

[57] Luisi PL. 2006. The emergence of life: from chemical origins to synthetic biology. Cambridge: Cambridge University Press.

the lab and are intended to carry out the same cellular processes as naturally occurring cellular systems for the purpose of further study.

Protocells usually start out by having the molecular components needed for basic metabolic processes synthesized, which are then inserted into cellular compartments like vesicles, or are developed in vitro. Liposomes are a particular type of vesicle often used in protocell creation, whereby genes and enzymes are inserted into them to produce "semi-artificial" cells.[58] The focus of protocell science is about getting to the root of what makes metabolism, genome replication, cell division and evolution tick by making theoretical models for these processes and then attempting to create them in the lab in relatively simple forms. It is also interested in improving upon theoretical models of biological phenomena, and revealing the chemical and mechanical constituents that drive their function.

One related example is a study that was conducted to find out if heterotrophy (the biological state of needing to acquire nutrients) or autotrophy (the biological state of making one's own nutrients) evolved first in living systems based on experimental evidence. The question tested was "which biological system is simpler and thus more likely to have been the first to appear?" Protocells of both systems were built in the lab in order to identify the system with the simplest assemblage of building blocks, from which the conclusion was drawn that life had a heterotrophic beginning.[59]

Protocell science is as diverse in its factions as is synthetic biology as a whole. Biologists working in this area are trying to understand how life may have first evolved by implementing and building chemical protocellular environments, or to determine if artificial

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[58] Luisi PL, Ferri F, Stano P. 2006. Approaches to semi-synthetic minimal cells: a review. Naturwissenschaften 93:1 – 13.

[59] Mansy, Sheref S.2011. Experimental Model Protocells Support a Heterotrophic Origin of Life. Orig Life Evol Biosph 42: 394-397.

synthetic genetic systems support Darwinian evolution. They are also researched to discover simple life-like chemical systems that are structurally similar to living cells, but lack DNA in order to help a variety of structural applications grow as formations that are capable of evolving with their ever-changing surroundings like living organisms. This is particularly being investigated in architecture to create "living buildings."

As an evolving and esoteric area of synthetic biology research, protocell creation is becoming very fruitful as a site for interdisciplinary practice. Designers like Neri Oxman at the MIT Media Labs is working towards a new type of "Mediated Matter" wherein the materials that designers use for fabrication processes embody the same evolutionary capabilities of those found in nature. Oxman's work considers the protocell as a jumping-off point for creation.[60] Additionally, Rachel Armstrong, an interdisciplinary researcher at The Bartlett School of Architecture, University of London is creating life-like protocellular systems in order to build "architecture that repairs itself".[61]

Protocell science however is not unique in having experts from non-scientific domains trespass its disciplinary boundaries in order to create new integrative collaborations across the arts and sciences in synthetic biology. In fact, artists and designers are working particularly heavily in the school of synthetic biology already discussed known as DNA-based device construction. It is interesting to note though that in my research I have not come across one artist or designer who is working with synthetic biologists that are contributing to whole-genome engineering practices. This is likely due to the immense cost of synthesizing all of the oligonucleotides that are required to build a complete functional genome from scratch, among other practical factors.

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[60] Oxman, Neri. 2011. Proto-Design: Architecture's primordial soup and the quest for units of synthetic life. *Architectural Design* 81 (2): 100-105.

[61] http://www.ted.com/talks/rachel_armstrong_architecture_that_repairs_itself.html

Although I am reading this research through the apparatus of the Ecology of Practices that resists capitalism as the sole driving force for the generation of product, knowledge, or art, I acknowledge that capitalism as such does of course still manage the interdisciplinary processes I am interested in. This becomes clear when we see that artists, designers, and other extra-artistic non-scientists can mobilize more freely in certain domains of synthetic biology than others when the cost of participation is a concern. Consequently I will draw upon contemporary art and design practices that are involved with the schools of synthetic biology that explore DNA-based device construction and protocell creation, but not genome-driven cell engineering.

Interdisciplinary Trends in Synthetic Biology: Art, Design, DIY

Although synthetic biology has been a term used since at least as early as 1905, new uses for the term have arisen in recent years through the three aforementioned schools of practice. However, the change in synthetic biology which I would like to focus on is how people outside of the expert discipline, namely artists, designers and DIY or "citizen" scientists are getting involved in (and inevitably changing) the evolving discourse of this re-emerging biotech. Synthetic biology works within a realm that has dense theoretical implications concerning design. These include the quest to successfully and valuably re-design living systems and thus the very set of notions that correspond to the meaning of what constitutes life. Rather appropriately then, several artists and designers who are trained in design from a more traditional creative disciplinary background that focuses on aesthetics, criticism and the phenomenological experience of design have entered the debate on how we might go about the design of living microbiological bodies, and life itself.

Sociologist of synthetic biology Jane Calvert has argued that as biology becomes a product of design choices rather than evolutionary pressures, and because synthetic biologists and designers are both interested in creating new things for the world, their overlap in collaborative projects might be able to shed valuable light on "how to design life well". By exposing synthetic biology to broader discussions about the human factor integral to designing new life, such as considering and questioning the values and politics that are inherently communicated in synthetic biology practices, Calvert posits that interdisciplinarity in synthetic biology has enormous potential to generate valuable approaches to working in the field.[62]

Calvert goes further to consider what happens when synthetic biology, art and design come into contact with Science and Technology Studies. Science and Technology Studies is an academic field that draws out the effects of science on society but also the cultural contexts within which scientific decisions are made to reveal how science could always have been other than it is because it is manifestly a human construction. When art/design, synthetic biology and Science and Technology Studies intersect, Calvert says we end up with a triad of intellectual and practical forces that generate new ways of thinking and promote critical reflection on all sides of the collaborating disciplines. I agree with her assessment and believe that interdisciplinary discourse around such potentially powerful and world-changing scientific paradigms is a necessary and fruitful cog in the wheel of a democratic society (or a hope for one). I take inspiration from Bruno Latour, who deserves being quoted at length when he says

> "If science is left to its own devices to define by itself – without further scrutiny or court of appeal – what the body is made up of, as if it pertained to the realm of primary qualities, it will be impossible for other versions of what a body is to be sustained… if one agrees to give science the imperial right of defining all by itself the entire realm of primary

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[62] Calvert, Jane. 2010. New forms of collaboration? Synthetic biology, social science, art and design. Paper presented at Synbio in society: Toward new forms of collaboration? Washington, DC.

> qualities, while militancy limits itself to the residual province of subjective feelings. Biopower should have a bio-counterpower. Without it, 'body talk' will never be any more effective than the songs of slaves longing for freedom."[63]

There is an obvious social concern inherent in looking at science with only one disciplinary critique or technique. As Latour warns, if science is left to its own devices to define for itself what it is, society is left faced with a homogenous hegemonic framing of the world through science, which will always overlook the multiplicity of voices the world is truly constituted by. We live in a time and place when society grants significant power and legitimacy to the advances and opinions of science, while it deprives the same authority to other disciplines of expertise. This is a trickle-down effect found in Western culture that has historically valued rational, empirical disciplines over "softer" areas of research, such as art or the humanities.[64] At the societal level we must be aware of how much authority we grant any one homogenous disciplinary perspective, and I argue that one way to work towards a heterogeneous awareness of the world is through practice that employs interdisciplinary modes of thinking and acting in order to acknowledge the polyvalent practices, ideologies and approaches to life that always exist in any society. I invest in the concept of *play* to realize critique in my research, and I advocate on the behalf of it as a methodology for wide ranging interdisciplinary projects. Play allows experts from different fields to come together in collaboration (ex: scientists, artists, hackers) and question one another. It creates a space in which to perform knowledge differently, with humour, and to open up new threads of

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[63]Latour, Bruno. "How to talk about the body? The normative dimension of science studies", in special issue edited by Madeleine Akrich and Marc Berg, 'Bodies on Trial' Marc Berg and Madeleine Akrich, special issue of Body and Society Vol . 10, number 2/3 pp. 205-229 (2004), p 224.

[64] Beaulieu, Anne. 2002. Images are not the (only) truth: Brain mapping, visual knowledge and iconoclasm. Science, Technology and Human Values 27 (1): 53-86.

discourse in the face of little questioned epistemologies such as those found in science.

DIY ("do it yourself") science, also known as citizen science, amateur science or enthusiasts' science is a growing cultural movement that works to increase the accessibility of biotechnology for the everyday hobbyist. DIY biologists use the tools of open-source information sharing and networking to build community laboratory spaces that are dedicated to democratic scientific activities that allow non-specialists to explore their scientific interests outside of the usual academic or industrial settings. The DIY science movement is most significantly enabled through the Internet, where discourse around it evolves on dedicated websites and online forums.

In synthetic biology, DIY practices have been popularized through the creation of DIYbio in 2008 (profiled in more detail below). Since DIYbio's inception, several other hobbyist websites, amateur synthetic biology groups, and even certified public lab spaces such as GenSpace in New York City[65] have cropped up in the name of learning about and practicing synthetic biology regardless of one's disciplinary training. Their work, although heavily debated as to whether or not it should be called "real science", opens up interesting questions in the conversation about democracy, society and biotechnology, which are widely explored in scientific, academic, hacker, and art/design communities.[66] Diverse groups of researchers are working to assess and prepare for the broad range of potential risks associated with this movement, which include issues of biosecurity, bioterrorism and biowarfare. Presently, interested researchers range from the FBI[67] to anthropologists.[68]

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[65] Kean, Sam. 2011. A lab of their own. Science. 333 (6047): 1240-1.

[66] Wright, Alex. 2008. Managing scientific inquiry in a laboratory the size of the web. The New York Times, December 28, 2010, 2008, sec Science.

[67] Kelty, C.M. 2010. Outlaw, hackers, victorian amateurs: diagnosing public participation in the life sciences today. Journal of Communication. 09 (01): C03.

It is not only citizen scientists who have subverted the normative practices of the institutionalized synthetic biology lab, but increasingly artists and designers as well. In each their own way, these groups have entered the synthetic biology laboratory as non-experts, exposing scientists to their own disciplinary modes of thinking and making. Together in labored union, their interdisciplinary work establishes a polyphony.[69] This polyphony (or chorus of distinct voices) inevitably informs the still-evolving paradigm of contemporary synthetic biology in ways that diversify and complicate our understanding of it through a merely scientific framing. I use the term here to explain my hope for a continuing direction of polyphonic work across the arts and sciences in today's Western secular society that often looks to science as an all-knowing deity. Science is always in part a human construction and the promise of multiple voices from different backgrounds contributing to its creation is a hopeful one.

Synthetic biology expects itself to fundamentally change the way we do things at the industrial, medical, scientific, and economic level. Its creation of new knowledge and founding of its own position in today's world must only be established through polyphonic methods. Accomplishing this involves including the work and voices of interested and

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[68] Gaymon Bennet, Nils Gilman, Anthony Stavrianakis, and Paul Rabinow. 2009. From synthetic biology to biohacking: Are we prepared? Nature Biotechnology 27 (1): 1109-11.

[69] Literary critic Mikhail Bakhtin developed a theory of polyphony to describe Dosteovsky's tendency to write novels wherein his characters would each speak for themselves and not act in service of any other character's will. This creates an unfinalizability of individuals, meaning a collection of many voices with each their own distinctiveness (a true polyphony). When matters of science and society are taken into consideration, polyphony should be aspired to so that discourse evolves according to the input from many voices without any one voice acting in the service of another. I justify this based on the argument that every voice always has something at stake in a changing society, regardless if it belongs to scientists, artists, designers, or everyday non-professional citizens.

Bakhtin, Mikhail, and Caryl Emerson. 1984. Problems of Dostoevsky's poetics. Minneapolis: U of Minnesota Press.

relevant non-scientists, such as artists, designers and perhaps to a lesser extent, but no less valid, DIY biology groups. I say lesser not because of institutional hierarchy, but because they often explicitly only want to "tinker" with biology rather than design it, and thus have less at stake since they are not usually focused on generating new knowledge for the creation of synthetic biology applications.[28] A dynamic and diverse collection of individuals and working groups within each of these categories has already caught wind of this necessity (or opportunity) and are profiled in fuller detail below.

It is worth explaining that there are particular activities in the extra-scientific practices of the field (that is the non-scientific work occurring around and within synthetic biology) that ally more closely to one knowledge-distinction category of synthetic biology than any other. This trend is different for social scientists of an anthropological or Science and Technology Studies tradition whose job it is to perform critical analyses of the scientific practices, discourses, and practitioners pushing the science forward despite the various school of synthetic biology they are studying. I explain this to highlight that differences can be found among the three types of contemporary synthetic biology schools with respect to how easily non-scientists can enter their arenas. The approaches to synthetic biology practice therefore vary in degree of accessibility for artists, designers, DIY biologists, hacker-types and social scientists.

To remind you, the knowledge-distinction categories are DNA-based device construction, whole genome engineering and protocell creation. DNA-based device construction can be understood as the design and creation of genetic circuits or pathways that allow for customizable metabolic function of simple organisms based on the interrelation of well characterized and functional genetic parts. This school of synthetic biology is often explained using the metaphor that likens it to the snapping together of interchangeable standardized Lego bricks to create a functional whole. It seems to be the most accessible school of synthetic biology for artists, designers and hackers to enter, which I will demonstrate may be because of its focus on open-source biology and heavy recruitment of young science students to comprise the next generation of synthetic biologists. The best example of this can be found at MIT's iGEM, the International Competition for Genetically Engineered Machines.

There are many sound reasons as to why DNA-device construction and its close affiliation with iGEM and Biobricks has been a more accessible route into the synthetic biology community for non-scientists. A key event in the crossover between art, design and synthetic biology happened between 2007 and 2009, when artist-designer Alexandra Daisy Ginsberg was doing her MA at the Royal College of Art in London. Her program, Design Interactions, stresses the philosophy of their Graduate Program Director Anthony Dunne and his notion of Critical Design, which he established in the book Design Noir.[70] Critical Design emphasizes a belief that design can function as more than mere aesthetic fascination or functional ability in the object-subject, and that like art it too can promote critical thinking about the broader functioning of politics and technology in contemporary culture. As such, the Design Interactions course brings graduate design students into close contact with emerging technologies in order to explore and question the designed object's critical potential to communicate possible futures that may one day come to fruition.

It was in this course that Alexandra Daisy Ginsberg started working with the subject of synthetic biology in her work, and other British designers soon became involved such as James King. Through my personal conversations with both of these designers at conferences

[70] Design Noir was co-written with Fiona Raby, another design professor at the Royal College of Art in London. Dunne, Anthony, and Fiona Raby. 2001. *Design noir: The secret life of electronic objects*. Basel: Birkhäuser.

like iGEM, I understand that their school was well positioned to pair them up with British synthetic biologists at Imperial College London who were preparing for competition at iGEM. They also went on to work with the iGEM team at Cambridge University. Through these collaborations, the designers were able to work with undergraduate synthetic biologists and their senior advisors in helping to shape the design of their iGEM projects, one of which went on to win first place at the competition in 2010 (*E. chromi,* Cambridge University). With the success of *E. chromi*, designers became a visible part of the synthetic biology community at the iGEM competition, the most important event in the world of DNA-based device construction using Biobricks. Alexandra Daisy Ginsberg in particular has become very successful as an artist-designer exploring the "Biotech Revolution" in her work. She has had her work relating to synthetic biology featured in the MoMA among several other renowned art institutions, and she holds several research positions as Design Fellow in the synthetic biology community. The presence of Alexandra Daisy Ginsberg and James King at iGEM has contributed to the welcoming of other non-scientists at the competition, who have become more populous in the field since 2010 and will be profiled in more detail below.

The second school of synthetic biology, genome-driven cell engineering, employs both top-down (starting with the natural genome and then stripping information away) as well as bottom-up (starting with nucleotides) approaches to working with the whole genome in order to create entirely new genetic libraries for organisms. I have not come across any art or design projects in my research that deal with this school of synthetic biology, which is not surprising considering that the majority of synthetic biologists are not concerned with this faction of the field, not to mention how expensive it is to write entire genomes from scratch.

Genome-driven cell engineering is an extremely expensive area of scientific research and its main stakeholder is the JCVI (J. Craig Venter Institute) in La Jolla, California (where the first strain of bacteria to have an entirely synthetic genome was created). Craig Venter speaks openly about his interest to patent his synthetic inventions; he is half-businessman, half-scientist, and already had enormous clout in the scientific community as the person who completed the Human Genome Project in collaboration with researchers from the American National Institute of Health (NIH).

Through my time working on the documentary about synthetic biology with Field Test Independent Film Corps, I learned (from watching the 40+ interviews with major figures in the synthetic biology community) that Craig Venter holds prominent power in the community, but nearly completely isolates himself from the wider discourse and its practitioners. Venter and his employees are not present at most synthetic biology conferences and they do not sit on the board of any of the major governing councils in synthetic biology, such as SynBERC, the Synthetic Biology Engineering Research Center. SynBERC is funded by the National Science Foundation and is "a multi-institution research effort to lay the foundation for the emerging field of synthetic biology." Moreover, it is associated with most major synthetic biology projects and research groups in the United States.[71] Whole-genome engineering is a flavor of synthetic biology that is difficult for outsiders to get a taste of, meaning that there is particular difficulty for artists, designers or other non-scientists to enter its laboratories and help shape its discourse since even other synthetic biologists are seldom let in. It is also enormously expensive in comparison to other approaches given the cost of oligonucleotide synthesis, which creates another barrier for non-scientists to work with its practitioners. The amount of oligonucleotides required to synthesize an entire genome from scratch far outnumbers the genetic production costs of any other synthetic biology practices.

Protocell creation is the third school of synthetic biology that I consider - the attempt

[71] http://www.synberc.org/

to build a wide variety of different cell types from scratch. These cells are often created to gain a deeper understanding about how life functions rather than to create functional organisms for the fabrication of a new material. They can be so diverse that some lack DNA and are thus considered "semi-living". I have found that designers and architects are the extra-scientific agents most interested in this faction of synthetic biology, with little discourse about how DIY and biohacking fits into its paradigm. All of these relationships will be explained in full detail below.

Rachel Armstrong and Neri Oxman are two major designer/architects who have been contributing to the discourse around protocell creation in synthetic biology. This discourse is entirely separate from that of DNA-device construction; their work is not found at international competitions like iGEM, and they are not found collaborating with synthetic biologists associated with that strain of research. Instead, both of these researchers are also architects and their interests lie in creating architecture and design methodologies that enable materials and structures to co-evolve with their surrounding environments. Their work challenges the design efforts of biomimicry to truly embody the functionality of organic life rather than merely mimic. Where they use protocell science to design architectural systems that can change in real time according to environmental pressures, biomimetic objects are static.[72] Protocell creation has become of interest to both these designers in their pursuit to advance biomimetic design because of its focus on building life from the bottom up. Both Armstong and Oxman are inventing new systems of fabrication for architecture and design that are inspired by nature and hope to encapsulate life-like properties in the materials they design so that they can respond to the environment the way that organisms do.

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[72] Armstrong, Rachel. 2011. How protocells can make 'Stuff' much more interesting. Architectural Design 81 (2): 68-77; Oxman, Neri. 2011. Proto-Design: Architecture's primordial soup and the quest for units of synthetic life. Architectural Design 81 (2): 100-5.

By pursuing research in protocell science, Oxman and Armstrong bypass much of the unwieldy biological complexity found in other domains of synthetic biology. They manage to do this because protocell creation is looking to understand and replicate the most basic of chemical configurations and components necessary to create life-like behaviour in cellular environments. The differences in their work and approach to protocell creation will be parsed and explained below in the following detailed account of the most-often present and/or prominent non-expert biologists involved in synthetic biology today.

Synthetic Aesthetics

Synthetic Aesthetics is a collaborative research-creation project between Stanford University and the University of Edinburgh that was launched in 2010.[73] It has created six paired residencies, which are each comprised of one artist or designer and one synthetic biologist. In a residency each team spends half of their time in the studio of the artist or designer, and the other half in the laboratory of the scientist. The residencies are taking place all over the world and are often divided half and half between two continents. Each interdisciplinary team is working together to create new knowledge for both members' respective disciplinary fields around how art/design thinking may contribute to their science, or how science may contribute to their art/design practices.

The project is particularly interested in how synthetic biology, as a field that is so deeply ingrained with the concept of "designing life" could benefit from integrative research that brings those who are adept at designing things and experiences (artists and designers) into its practices. In a climate of controversy concerning the principles of synthetic biology as a technoscientific practice, Synthetic Aesthetics can be described as a strategic foresight and innovation research-creation project concerned with advancing knowledge for

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[73] www.syntheticaesthetics.org

practitioners and the public about synthetic biology through untraditional means. Residents invest their efforts in experimental laboratory practices that creatively explore how we might want to use the new technologies offered by synthetic biology before homogenous scientific practices determine their use for us.

Jane Calvert, a sociologist at the University of Edinburgh, Alistair Elfick, a mechanical engineer at Durham University and Drew Endy, a biochemical engineer and synthetic biologist at Stanford University who founded the BioBricks Foundation and iGEM are Synthetic Aesthetic's principal investigators. The overseeing team also includes Pablo Schyfter, a postdoctoral scholar from Stanford University working on the philosophies of technology and synthetic biology, and Alexandra Daisy Ginsberg, the artist and designer whose work focuses on how synthetic biology can be imagined and created in new ways through the lens of art and design. Her work is a prominent inspiration to all art, design and synthetic biology crossover as she is arguably the pioneer of this interdisciplinary work across the involved fields.

The residents themselves are Christina Agapakis (synthetic biologist) and Sissel Tolaas (smell artist) working on symbiosis and smell; Hideo Iwasaka (synthetic biologist) and Oron Catts (bioartist and co-founder of the Tissue Culture and Arts Project) working on tissue culture; Fernan Federici (synthetic biologist) and David Benjamin (architect) working on plants and modularity in architecture; Mariana Leguia (synthetic biologist) and Chris Chafe (composer) working on micro fluidics and sound; Sheref Mansy (synthetic biologist) and Sascha Pohflepp (designer) working on protocells and critical design; and Wendell Lim (synthetic biologist) and Will Carey (interaction and industrial designer) working on communication and tangibles.

Super Cell

Design students at the Bauhaus University in Weimar and molecular biology, philosophy, and psychology students from the Ruprecht-Karls University in Heidelberg, Germany collaborated to create Super Cell. Super Cell is an online supermarket of the future that sells household and personal products hypothetically created using synthetic biology, and range from neuronal networks that allow one to use their brain while they sleep to filtration systems that turn animal waste into drinkable milk for humans.[74] It uses humour and satire in its approach to critical design that attempts to engage "shoppers" to think about the potential biotechnological future that lies ahead through the pretend marketing of synthetically created biological goods for the home.

DIY Bio

DIY Bio is an organization that is dedicated to creating opportunities, spaces and tools for amateur biologists to engage in citizen science through practicing biology outside of the institutions and companies that normally make it inaccessible to the everyday enthusiast.[75] It is a growing community of citizen scientists who are increasingly becoming expert in many biological practices and are quite well equipped to carry out their experiments with the gamut of low-cost laboratory devices that many DIY biologists have been inventing. They've worked to develop a code of ethics, responsible oversight, and leadership in biology that happens outside of traditional professional spaces in order to increase the public's confidence in what they do. It has local chapters set up all over the world where DIY

[74] www.super-cell.org

[75] www.diybio.org

communities come together to exchange knowledge and carry out experiments. DIY Bio's co-founders are Mac Cowell, a biohacking hobbyist with undergraduate training in biology who also works at iGEM is particularly interested in synthetic biology, and Jason Bobe, who worked on the Personal Genome Project at Harvard University with the renowned synthetic biologist, George Church.

DIY Bio has also created the FutureLabCamp, an event that has so far taken place in Boston and New York City that brings artists, designers, hackers and DIY biologists together for sleep-over research summits. The summits are designed to allow the participants to work collaboratively as they prototype imaginative devices and experiments that use any combination of their talents in the pursuit of new ideas and tools in synthetic biology.[76]

Hackteria

Hackteria is a self-described resource for open source biological art, DIY biology and generic lab equipment. It operates mainly as an online collection of projects and was founded in 2009 by Andy Gracie, Marc Dusseiller and Yashas Shetty, artists who began working together when they met during the Interactivos?09 Garage Science conference at the Medialab Prado in Madrid. It aims to provide rich resources for anyone who looking to get involved in DIY bioart, open source software and electronic experimentation.[77] It is closely associated with ArtScience Bangalore, the only team comprised entirely of art students that compete regularly at the iGEM (International Competition for Genetically Engineered Machines) conference at MIT.

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[76] http://futurelabcamp.com/

[77] www.hackteria.org

BioCurious

Biocurious has many of the same operating goals and activities as DIY bio in as much as it fosters community for amateur biologists also known as citizen scientists. BioCurious is different from DIYbio in that it has founded a collaborative laboratory space in the Bay Area of San Francisco dedicated to non-institutional biology. The idea for BioCurious arose in 2009 from a conversation between its co-founders Eri Gentry and Melanie Swan (founder of diygenomics.org), after which Tito Jankowski, Josh Perfetto, Joseph Jackson, Kristina Hathaway and Raymond McCauley joined the directing team to bring BioCurious to life. It is a major player in the evolving network of DIY science and amateur synthetic biology.[78]

Rachel Armstrong

Rachel Armstrong is the co-director of AVATAR (the Advanced Virtual and Technological Architecture Research Group), in Architecture and Synthetic Biology, at the Bartlett School of Architecture, UK. In her current work she argues that it is possible for buildings to share some of the properties of living systems such as real-time responsiveness with the changing environment, which she is supporting through research with protocell creation. She defines protocells as "being primordial molecular globules, situated in the environment through the laws of physics and connected through the language of chemistry…."[79] She is an advocate of the protocell's potential to change the future as a technology native to the 21st century, and has co-authored The Protocell Manifesto to

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[78] www.biocurious.org

[79] Spiller, Neil; Armstrong, Rachel. 2011. Introduction. Architectural Design 81 (2): 14-23.

support it.[80] Her work with architect Neil Spiller challenges the biological formalism that surrounds most synthetic biology research, which I will revisit.

Neri Oxman

Neri Oxman is a professor and director of the Mediated Matter group at MIT, a research-creation computational design lab situated in the MIT Media Labs. Her group invents new fabrication technologies that mediate between matter and the environment to transform the design and construction of objects, buildings and systems. In her PhD dissertation she developed the theory and practice of material-based design computation, which focuses on using heterogenous materials that dictate the form and function of the object based on their interaction with the environment. This radically transforms the age-old design mantra, which states that function dictates form, which contingently dictates the material for fabrication. Her creations are life-like in their composition and are capable of changing according to environmental pressures that affect the materials of the object, such as density, temperature, weight, or tension, much like an organism would respond morphologically to these same stressors.

In a recently published article, Neri Oxman explains that her research and design method, Material Based Computation, operates in parallel to protocell creation's bottom up approach to designing living and life-like systems. Rachel Armstrong argues in the same journal that Neri Oxman has established the protocell as an agent of synthetic ecologies with architectural purpose, demonstrating their sociality, since they work collectively to grow and move. This challenges the singularity of the origins of life and suggests that life may have first evolved from collective living systems instead. The Mediated Matter group is now

[80] Spiller, Neil; Armstrong, Rachel. 2011. A manifesto for protocell architecture: against biological formalism. Architectural Design 81 (2): 24-25.

seeking synthetic biologists to join its team of experts, which already include engineers and architects[81] suggesting that she will be someone to watch in the near future for new explorations in the applications of synthetic biology as it relates to design.

Expanded thinking in synthetic biology

The descriptions you've just read about the prominent non-disciplinary players in the synthetic biology community portray some of the breadth of perspectives that are currently influencing the evolving synthetic biology discourse aside from traditional laboratory culture. Through their interconnectedness in various residencies, research summits, competitions, community lab programs and institutional settings, the artists, designers, social scientists and DIY biologists are rubbing shoulders several times a year and exposing one another to their work and thoughts on how the synthetic future should or could unfold. Of course, the field is still nascent, and so the methods of interdisciplinary collaboration among all the players involved are not yet developed as something concrete. Instead, what one finds in the interdisciplinary community around synthetic biology is a dynamic force of enthusiastic people with a wide variety of backgrounds and talents who have established potentially novel value for the practice of a science that polyphonically considers the wider societal context in which it is functioning.

These groups and individuals are developing new paths through which to enter and inform the evolving discourse of this high-profile scientific revolution. In a few years some of their projects may come to fruition and help change the way that synthetic biology considers things like: its ethical responsibilities, culturally encoded modes of doing lab work, considerations for future generations of life in a synthetic world, understanding of "good design" for organism-generated products, or sophisticated aesthetic interventions of their

[81] http://www.media.mit.edu/research/groups/mediated-matter

biological creations, to name a few. Therefore, the current interdisciplinary activity found in synthetic biology could become a foundational example of the value of interdisciplinarity that practices of the future may look to, and build off of, in establishing their own best practices for a technologically mediated world that can't yet be predicted.

An asset of this interdisciplinarity that we already find in synthetic biology is the ability of the non-scientists to articulate a critique of the assumptions made by synthetic biologists in their work in an effort that generates alternative perspectives on how work ought to be done. Such alternatives could enrich, politically inform, or disrupt the field, but more likely so, the public conversation around it.

Rachel Armstrong would likely be written off as a soft scientist by most traditional synthetic biologists who follow any type of engineer's thinking in creating new life. In *The Protocell Manifesto* which she co-authored with Niels Spiller, they go so far as to say that biological formalism is meaningless; void of truth entirely. Biological formalism, the belief in a biological milieu that arises solely from the genetic determinism of DNA has always reigned in scientific definitions of life is an absolute requirement for engineering practices. Without biological formalism, engineers and synthetic biologists alike would not have a framework in which they could work to recreate any variety of minimal or primordial cell in their quest to generate protocells. If there is no truth to biological formalism, there would be no understanding of what parts must be added together, or what parts must be stripped away in order to test functional cellular entities.

For Armstrong "the implications of protocell technology are far reaching. This beginning may be as profound as a second biogenesis for biology and the origins of life sciences, which promises much more than a brand new day and opens up a whole new world."[82] Based on a Dadaist text, the Protocell Manifesto for architecture that she co-wrote with Niels Spiller reads

> "What we call protocell architecture is, at root, a piece of Surrealist research, in which all the lofty questions have become involved…it is an alien to the natural world, yet speaks the same fundamental languages of chemistry and physics. The results of these conversations and interactions constitute a parallel biology and second biogenesis whose aesthetics are described by Surrealist agendas."[83]

Now, taking her seriously, what could it mean for a synthetic biologist to realize and benefit from this "second biogenesis" and adopt a Surrealist agenda in similar ways that these protocell architects do? Their practical attachments that make them experts in their fields are incongruent barriers that do not coalesce with the musings of Armstrong who ultimately denounces the dogma that enables their field to practice. However the clash between their systems of thinking does not mean that Armstrong is wrong, or that her point or perspective is not important for science beyond the realm of architecture; it is simply *different*.

It is exactly this difference that fuels the Ecology of Practices so that we can, as Stengers advises, not talk about practices as they are but how they could be. This is always the value of the artist, the progressive thinker, the outside-the-box actor. Instead of reducing complexity in order to control a system through scientific knowledge and intervention, such people in synthetic biology can turn our assumptions on their head, enlarge our frameworks of conceptualization, and ask pressing questions of any science that is too self-certain. In this way, Armstrong may be a "biosensor" herself, implanted in an environment of diverse cultural discourse in order to warn experts that they've put too much faith in any one

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[82] Spiller, Neil; Armstrong, Rachel. 2011. Introduction. Architectural Design 81 (2): 14-23, p 22.

[83] Spiller, Neil; Armstrong, Rachel. 2011. A manifesto for protocell architecture: against biological formalism. Architectural Design 81 (2): 24-25, p 24.

paradigm of "life" when her personal critical threshold starts to clip. Outsider attitudes like hers might be an apt way to communicate how scientific practices risk endangering all of us from reaching a premature concensus. A useful reminder that Pickering, Kuhn, Guattari and Thacker each offer us is that interdisciplinary perspectives, which Armstrong contributes to, are needed to resist the modernist trappings of scientific revolutions.

Going back now to the modes through which synthetic biology has become popularized in recent years, iGEM returns as the major channel through which young synthetic biologists are provoked to learn how to engineer "synthetic machines" while creating new knowledge for the field. iGEM is the most obvious example where blooming scientists are invited to craft the myth that the rational design of life is possible, before it actually exists. Artist-designer Alexandra Daisy Ginsberg points out that it isn't only iGEM, but The International Rational Genome-Design Contest, GenoCon, and CAGEN (Critical Assessment of Genetically Engineered Networks) that are fueling the recruitment of new myths in an attempt to sustain the field's futurity through the *competition* model. Ginsberg asks "but why are there so many competitions?...If science is about closing down variables to find the truth, the role of fiction and narrative is to create many versions of the truth, to open up space to find new questions and ideas."[84]

In her own attempt to challenge the scientific myth in synthetic biology that life can be rationally and predictively engineered, Ginsberg created *The Irrational Genome Design Competition*. The public relations material for the competition reads

> "Synthetic biology aims to strip out everything we don't need, want or understand so we can design elegantly engineered, reductionist living machines. But when was life ever like that? Proposing an alternative vision for synthetic biology, The Irrational Genome Competition celebrates unintentional design and the wider ecosystem, encouraging nature to better

[84] Ginsberg, Alexandra Daisy. 2010. The Irrational Genome Design Contest. Future Thresholds. (38) 1: 6-9, p 6.

design itself. Entries need not be functional, but could they still be useful? These biological artifacts could help us examine synthetic biology, and life itself. Could they help show us what part of our irrationally designed selves we fear synthetic biology may compromise?"[85]

With the Irrational Genome Competition Ginsberg is speaking directly to the synthetic biology community, promoting her alternative competition alongside the now canonical competitive events in an MIT publication that her colleagues will be exposed to. She is using her privileged position as a Design Fellow in the synthetic biology community to turn the rhetoric of synthetic biology inside out, and ask the scientists and young synthetic biologists directly *why* we would ever want to speak about life and the concept of rationality in the same sentence. It's one of those great questions that you feel preposterous for not having asked yourself if you've gone along with the language of synthetic biology all along.

Artists have been particularly successful in pointing out the mythologies woven into synthetic biology discourse that promote an understanding of biology as something reducible, controllable, and predictable. Instead they remind us of the inherent unwieldy complexity that all biological systems have and work interdependently within to survive. In discussing the "engineering mindset", artists Oron Catts and Ionat Zurr of the bioart research-creation laboratory SymbioticA and in Oron's case, Synthetic Aesthetics, have written

> "Engineers are interested in synthetic biology [or in biology in general] because the living world provides a seemingly rich yet largely unexplored medium for controlling and processing information, materials, and energy… what might an artistic mindset achieve? Can it be a counter-balance or an attempt to artistically engage with an engineering future doomed to be perceived as reactionary in one way or another?"[86]

[85] Ibid., p 7.

[86] Catts, Oron and Zurr, Ionat. 2010.The Illusions of Control, Radical Engineers and Reactionary Artists. Future Thresholds. (38) 1: 26-30, p 30.

Catts and Zurr, are well known for their critical artworks that question the subjectivity and materiality of biotechnology. In this case they are working to generate discussion that does not alienate the synthetic biology community, but asks them to realistically consider how their respective disciplinary perspectives can merge to create a tertiary category of knowledge, that although always possible, is not often explored. Their questions help us realize the potential force of interdisciplinary activity, and challenge us to articulate realistic possibilities that can arise by the merging of art and science. These possibilities are often touted as admirable efforts, but seldom discussed in terms of the new directions they create. It is here that non-scientists can become a vector for change and new imaginings of the world as we know it. The Ecology of Practices, the interdisciplinary matrix, the artscience community, and the hope for democratic interactions between distinct fields are all things that we edge towards when we ask these types of questions of ourselves, and even more arduously, challenge one another to come up with plausible solutions to.

Merging the arts and sciences raises the potential for the political subversion of normative practices, though as I have discussed at the beginning of this thesis, it is not inherently so. Instead, I argue that interdisciplinarity across art, design and science becomes interesting when it is executed critically with the hope of challenging the accepted expert voice of science and emancipating yet unnoticed areas of expertise and experimental practice in different cultural contexts in order to make practices *better* (ethically, aesthetically). Returning to Stengers:

> "Making arts and sciences political is not about staging an unsavory confrontation between these avowedly separate terms. Instead, it is about exploring the interconnected creation of worlds: the possibilities of facts coming into being and being taken seriously; the registers of representation (and power) that make these worlds viable; and the possibilities unfolded through this more deliberate meeting with politics."[87]

[87] Stengers, Isabelle. The Invention of Modern Science, translated by D. W. Smith University

The aspect of interconnectedness that Stengers highlights is the principal focus of all interdisciplinarity. In the next chapter I will introduce my own artistic practice in its relation to my research on synthetic biology. I will develop an argument for the inherent relatedness between synthetic biology and DIY craft based on the notion of formal rearrangement in biological and art materials, and will connect my own art practice to the theory found therein. In my attempt to personally contribute to an Ecology of Practices for synthetic biology, relationality is the binding force that brings interdisciplinarity, my research of synthetic biology, the particular material properties of my chosen craft, and the political relevance of non-experts' involvement in synthetic biology discourse together in the next chapter of my thesis.

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of Minnesota Press: Minneapolis. 2000 (1993), p 86.

Chapter 3: My Approach and Results

Subjectivity in Synthetic Biology

In this chapter I would like to discuss issues that situate my own art practice as a DIY craft artist within the Ecology of Practices related to synthetic biology. Firstly, I will explore the notion of the synthetic from a philosophical perspective to relate its definition as a human-made, but not artificial, nor natural entity to the creative synthesis of art making. In particular I will investigate the relationship between democratic modes of fabrication and synthesis made from the purposeful arrangement of artistic and biological forms across the axes of non-expert science in synthetic biology (nourished from art, design and citizen science participation) and non-expert making in craft, as explored through the DIY craft phenomenon. I will use this as a conceptual tool to demonstrate the unification of material practices in synthetic biology and my textile craftwork.

The synthetic has long been explained in terms of the dialectic: thesis + antithesis = synthesis. A synthetic substance is always the result of the combination of two or more parts to make a new whole. The term has a human-made connotation, bringing with it a sense of the artificial as opposed to the natural. The synthetic however, is not artificial, nor natural, but something different entirely. As it straddles the binary between these two entities and forces a tertiary hybrid space between them into existence, the synthetic challenges any language or paradigm that works with a binary logic. Mihair Nadin, a prolific scholar in the areas of aesthetics, computer science, electrical engineering and post-industrial society has said that there is a crucial differentiation between the synthetic and the artificial that even well-educated researchers in the area do not find significant, but must be accounted for. Where "artificial life is a top-down approach of the nature of applied analysis, "synthetic life is understood as "combining pre-existent entities with the aim of making something new...a process of uniting opposites."[88]

In synthetic biology, synthetic organisms are indeed made through the unification of opposites. Craig Venter had to use a natural living bacterium that he removed the genome from (let's call it the *thesis)* in order to insert into it a non-living, artificial genome that he constructed using bioinformatic technology and a DNA printing machine (*antithesis*) to create the first synthetic bacteria (*synthesis*).

In highlighting an important difference between the thesis and antithesis, or living and physical components of the synthetic cell, Nadin uses the theory of anticipatory systems. Living systems like you and I are referred to as "anticipatory models". This means that we think in real time or in advance about how to best relate to our environment and are not entirely dominated by it. We are capable of anticipating the world due to our biological complexity and evolutionary potential. An example that he gives of an anticipatory scenario is the urge you would have to prevent yourself from falling off of a cliff if someone were to try and push you from the ledge of one. You would abruptly try to turn around, side-step to safety, or collapse to your hands and knees to grab something that might save you from descent. A rock on the other hand, is what is known as a "reactive system". If you were to throw the rock off of a cliff, it would fall at a velocity that exactly accords to its own weight. It merely reacts to the environment that acts upon it, and cannot anticipate alternative outcomes. The reason Nadin gives for this is that it exists below a certain threshold of complexity and is not capable of evolving.[89]

The significance here is that the anticipatory/reactive model and natural/artificial binaries get utterly confused when we talk about the synthetic. With the rise of synthetic

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[88] Nadin, Mihail. 2009. Anticipation and the artificial: aesthetics, ethics, and synthetic life. *Artificial Intelligence and Society.* 10(1): 1-16, p 3.

[89] Ibid., p 6.

systems we see the combination of artificial or physical components that can *evolve.* As we've seen, Craig Venter's bacterial strain is viable and can replicate itself billions of times. It can literally accumulate genetic mutations and change over generations into an evolved version of itself through the processes of natural selection. No rock can do that. Consequently, the synthetic organism, capable of evolving, though made artificially (i.e. is not found naturally in the world) is neither artificial/not living (a completely reactive system) nor natural/alive (a completely anticipatory system). It is some amalgamation of the two, which we do not yet know entirely how to classify. In order to address this complication, Nadin suggests that we need to revisit the distinction between the "natural sciences vs. the sciences of the artificial" and connect them "to the very generous thought regarding the symbolic, i.e. how we perceive the world and share this perception with others."[90] I believe that we can use art as a research-creation tool with which we can share our own perceptions and engage people to share theirs. It is particularly collaborative and participatory art projects that bring such dynamic relationships between multiple people and their diverse perceptions to fruition. Before I explain and situate my own art practice within this perceptive framework, it is first important to look at other forms of representation, namely language, that shape our perception of paradigms such as the natural, artificial, and synthetic.

Constructivist and computational rhetoric in synthetic biology

While some synthetic biologists have talked of reducing biological complexity in order to engineer biological systems from the bottom up, synthetic biologist Dr. George Church of the Department of Genetics at the Harvard Medical School said once in an interview

[90] Ibid., p 2.

> "As opposed to reductionism, synthetic biologists take a view of learning as a constructivism…Synthetic biology is about systems-level planning and testing. It is akin to systems engineering from bottom up as opposed to reduction from top down. We design and construct high order biological devices out of the biological building parts."[91]

George Church is the head of the Personal Genome Project and one of the most-cited synthetic biologists in the field. Considering that he uses the language of a biological constructivist philosophy, it is then interesting to look at the rhetoric for understanding synthetic life he is promoting.

Art history tells us that for the Futurists, the principles of engineering and formalism were applied to art making in *constructing* works that celebrated and tried to harness the revolutionary capacities of the machine and the new machine-centred society. Today we see a similar application of machine-centred analogies onto living systems in synthetic biology as we aim to invent future life. When George Church talks about the tacit approaches to engineering life in synthetic biology he speaks of "biological devices out of biological building parts."[86] The metaphors are industrial, not sensual, as living things are. If someone didn't know that synthetic biology was about constructing *living organisms* it would be hard to recognize from his quotation that he is not a mechanical engineer.

Similarly, iGEM is the most obvious example of synthetic biology rhetoric embracing the industrial, and rejecting the sentient or sensual. It does this as it strips all biological or organic language from its name and describes the simple organisms that the students invent and modify as "genetically engineered machines." By reducing the biological to the machine, iGEM implies that we can understand living organisms to such a detailed

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[91] Marusina, Kate. 2011. Synthetic Bio Builds from the Bottom Up. *Genetic Engineering and Biotechnology News.* 31(10): May 15.

degree that they become computable, predictable, and standardized creations limited only by the human imagination for good design.

Richard Doyle has mapped the rhetorical use of machine and computational metaphors in microbiology to demonstrate how science, in an age of molecular importance, uses rhetoric to mask its own questionability and create its authoritative role in defining notions of the living and its ability to discover truths. Doyle argues that science largely uses the rhetoric of microbiological software to define life, where living organisms can be modified through the "cutting", "pasting", and "deleting" of genetic material, for example. Such language renders the status of living creatures "readily alterable", just as we alter the status of software by manipulating its code through rhetorically identical actions, when in fact the biological processes are not identical to the computational ones.[92] For Doyle, using such recognizable language works with the human conscious in ways that cause us to accept the validity of what is being said since it plays on reductionist notions of control and certainty in human knowledge that we are so familiar with from our achievements in computer science. In this vein then, where rhetoric of molecular software is used in biology, science is allowed to forget the human-driven, historically specific conditions that enabled its knowledge to arise in the first place.

To further flesh out the implications of such rhetoric, I'd like to mention the work of Nikolas Rose on the contemporaneous state of biopolitics. Rose's work brings the Foucaultian notion of biopolitics (or in other words, the understanding of how power is administered across citizen biological bodies by institutional bodies through technologies of governance) into the 21st century. In his analysis of how the politics of life functions in advanced liberal democracies today, Rose explains that we now have increased emphasis on the responsibility of individuals to manage their own medicalized affairs. He notes also that

92 Doyle, Richard. 1996. *On Beyond Living.* Stanford University Press.

we have largely shifted biopower from the government to quasi-autonomous regulatory bodies, like bioethics commissions and private corporations. In his reading of such a politics, he goes on to say

> "Over and above these shifts, perhaps, the novelty of contemporary biopolitics arises from the perception that we have experienced a "stepchange," a qualitative increase in our capacities to engineer our vitality, our development, our metabolism, our organs, and our brains… It is now at the molecular level that human life is understood, at the molecular level that its processes can be anatomized, and at the molecular level that life can now be engineered. At this level, it seems, there is nothing mystical or incomprehensible about our vitality—anything and everything appears, in principle, to be intelligible, and hence to be open to calculated interventions in the service of our desires about the kinds of people we want ourselves and our children to be… and the stake in a molecular vital politics."[93]

Reading Doyle through Rose then, it becomes clear that the rhetoric used in high-profile emerging biotechnologies that operate at the molecular level, such as synthetic biology, is crucial to understanding the power relations embedded therein. A critical reading of scientific rhetoric is important not only because rhetoric dictates how science sees itself and functions, but because rhetoric itself takes part in administering an entirely new politic of life that is based upon a "molecular vital politics." When molecular software becomes a discourse used to describe the relations between molecular components, scientific practices and real biological bodies in an age of molecular vital politics, we cannot afford to let science define all of the semantic and technical parameters for itself.

Scientists are generally not trained to be reflexive, nor are they asked to question the rhetoric they are trapped by, and advance through, their use of it in their work. Instead, it is the non-expert scientists, outsiders, or interdisciplinary actors that complicate such processes and reveal new understandings of power and the factors that go into shaping it. Science and Technology Studies scholars have been particularly successful in making clear

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[93] Rose, Nikolas. 2006. *The Politics of Life Itself*. Princeton University Press, p 4.

such critical crevices in our culture, but it is also artists, designers and citizen scientists who can inform our thinking about institutional science through fresh eyes. Their work contributes to an Ecology of Practices, as has my own, which I explicitly situate as an interdisciplinary investigation of synthetic biology and citizen science through craft and cultural studies.

Before I elaborate on my own artwork, I would like to revisit the precipice of societal change on which we presently sit. We are moving past the modern industrial era, which rampantly exploits the world's natural resources, into a digital, networked and bioindustrial era that promises renewable modes of production for the future. This shift brings with it a novel distributed bioeconomy where more people can participate than ever before, making interdisciplinary work like that of Synthetic Aesthetics becomes increasingly possible.[94] The evolution of unprecedented cultural movements, like citizen science, is likely to affect real change in a networked and distributed era where cultural capital is built from the ground up and circulated online. Can these changes however also open up new modes of production for the non-biological artist? Absolutely.

Technological change in biology will always create new modes of production for all artists, designers, and creators of any non-biological denomination because between each actor and the technology an ecology (or culture) exists. The processual advancements of technology never happen in isolation from the culture in which they are framed. This culture also always frames other technologies and their users, who are influenced by the same reverberations that affected the original technological development. Any artist can contribute to the interconnected ecology through vastly diverse modes of attachment, contributing to the very Ecology of Practices that I am so interested in in this thesis.

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[94] Rifkin, Jeremy. 2011. *The Third Industrial Revolution.* Palgrave Macmillan.

Particularly, artists who work with visual imagery have considerable influence in an Ecology of Practices, and can challenge how we think we ought to practice our practices. Art historian WJT Mitchell takes up this question in his book *What do Pictures Want?* when he explains

> "It is not so much that we evaluate images but that they introduce new forms of value into the world, contesting our criteria, forcing us to change our minds… Images are not just passive entities that co-exist with their human hosts. They change the way we think and see and dream. They re-function our memories and imaginations, bringing new criteria and new desires into the world."[95]

The artist who works in images has a considerable amount of influence in an Ecology of Practices because they diversify the portrayal of society in the public eye, as well as visual concepts of practices themselves. Images have always held potent political force. Without this power, marketing and advertising would not function as successfully as it does in a capitalist economy that uses the society of the spectacle to implant messages into the minds of prospective customers. Similarly, war-time propaganda posters would not have been so successful in recruiting new troops without their graphic elements. It should not come as a surprise that artists who wish to involve themselves in an emerging political discourse around the future of technology might choose to do so through imagery that pays particular attention to formalism in order to communicate a particular set of expressions. In my own work I have chosen to use a distinctively "amateur" visual process and form to communicate a particular set of expressions relating to my research. I will now explain why the aesthetic afforded by textiles and DIY craft in particular enable a useful complication between synthetic biology, citizen science and DIY craft; a complication that invites us to learn and think about new relationships and possibilities for a future full of biotechnological advances.

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[95] W.J.T. Mitchell, "The Surplus Value of Images," in What do Pictures Want? : the Lives and Loves of Images. Chicago: University of Chicago Press, 2005, p 101.

DIY – from science to craft

As I explained earlier, DIYbio was created in 2008 with the aim of turning biotech into an accessible hobby for the everyday biotech enthusiast. Tinkering away in community labs with hacked or donated lab equipment, DIY biologists are part of a larger citizen science movement wherein people are inventing open-source tools that may eventually make experimenting with synthetic life possible in your own home. Extending far beyond the laboratory however, do-it-yourself is an approach to labour that has been widely celebrated in craft. Textiles in particular are a popular area of crafting where amateur fabric artists such as myself often label their works as DIY projects.

But what exactly is DIY craft? Well, it's a difficult thing to pin down because so many people practice it in so many disparate ways (which makes sense since the DIY ethic is supposedly about "democratic" modes of labour), but I will endeavor to describe it here. I consider DIY craft as the process of engaging in the creation of a hand-made object that specialized skills are not required for. In this sense, it is inherently an accessible craft since mostly anyone should be able join-in in the creative process regardless of their inevitably varying experiences with the materials and processes of making. However, in an attempt to execute a more qualitative definition of DIY craft, researcher Sally Fort conducted a study for the Arts Council of England that describes it as follows

. "DIY culture refers to a wide range of grassroots political activism… the commitment to the non-commodification of art, the appropriation of digital and communication technologies for free community purposes, and the commitment to alternative technologies... This creative handiwork is often nostalgically ironic, concerned with style, irony and occasionally kitsch; often contains wit and humour; it is about choice. It does not seek validation within traditional art methodology rather it is motivated by a desire for creative and economic freedom."

And funnily enough, she adds

> "These new crafters are mostly young women, in their 20's and 30's, who delight in combining retro images with traditional craft techniques to produce practical items with an off-kilter, humorous streak. There is no right or wrong. If anything the movement is defined by its eclecticism." [96]

Well yes, that DIY demographic sounds awfully familiar to me!

In her descriptions, Fort highlights the non-conformist attitude of the DIY craft world that operates to offer alternative modes of object production amidst a capitalist industrial society. Whereas capitalism operates on notions of invention, property and exchange, the DIY world deliberately creates different circumstances for itself where the sharing of ideas, techniques, and materials is promoted. With the rise of the digital era, DIY communities have been able to reach out to each other on the Internet, not only to admire each other's creations, but to share tips and instructions that further democratize the practice. Popular crafting websites like Craftster[97] (where tips are exchanged) and Etsy[98] (where DIY crafts are sold) have garnered the attention of a new generation of crafters who both make, and sell, their DIY works. It's easy bait for people to get involved who generate a sense of pride in making things themselves, since the material costs for DIY crafters are often very inexpensive, and the activities devoid of any need for hyper-specialized equipment. Let's not forget that part of the identity of the DIY craft activity is that it is also considered a fun thing to do at home.

Moreover, art historians have mapped the relationship between DIY crafting and several subcultural movements that have arisen since the 1970s that embraced crafting which spoke out against the mainstream through humorous, kitschy or activist craft works. Specifically the Riot Grrrl movement of the 1990s has been credited with fueling today's

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[96] Fort, Sally. 2007. *UK DIY craft research report.* UK: Arts Council of England, 1, p 3.

[97] www.craftster.org

[98] www.etsy.com

DIY craft culture, which is often also qualified as "indie", or, independent. The Riot Grrrl movement was an avant-garde, punk-infused, anarchofeminist music movement and social scene that originated in the northeastern United States. It largely created and influenced zine-making as well as DIY crafting for activist outcomes, or, *craftivism.* In their independence from the societal norms of the establishment, Riot Grrrls reclaimed women's domesticity in handmade objects and made it their own political canvas to communicate feminist sentiments, both through zine-making and more traditional crafts, like textiles[87].

Today the activist potential of DIY craft is enhanced by a succession of new Internet technologies that connect "craftivists" in disparate locations through mutual creativity. "Craft blogging offers crafters a forum for collaborative or replicable projects that can raise awareness about a cause or invoke action to end unjust practices…which channels ideas about sustainable living, anticonsumerism…"[99] Although many DIY crafters carry out their work for their own enjoyment rather than to communicate an overt political sentiment that perhaps fuels their engagement with the work, it must be acknowledged that the DIY ethic is inherently political. DIY naturally belies the hegemony of industrial production and invites all to take part, stripping authority away from the notion of "how to do it right", or achieve professional execution through exclusive fabrication platforms that capitalism requires to sustain the merit of the goods it creates. DIY is therefore anti-establishment and anti-institutional. This is the binding seam between the DIY activities of crafters and scientists alike, who both exert efforts to create alternative models of labour, and spaces for production that defy how society originally defined how they ought to practice. Separately, though in solidarity, they are changing the face of how things are made from the sewing

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[99] Dearie Clegg, Bridget. 2010. Craftivista: Craft blogging as a platform for activism. Honors Program., Miami University.

factory floor to the university lab bench.

No research has yet been conducted on the "coolness" of DIY biology, nor any investigation of the social capital it raises for its practitioners, as has been done with DIY craft.

> "Craft has become the new cool, the new collectible: a rebellion against high-street branding and mall sameness alike, against the globalization of labor exploitation and consumer indifference. In contemporary art, handmade, tailor-made, personalized marks of individual expression and personal statement collide in an excited array of "crafted" and narrative-rich works with a fleshy affection for utopian ideals."[100]

From my experience however, it would not be surprising if it soon becomes appropriate to assess its trendiness since most of the DIY biologists I have met share a similarity with DIY crafters: they are also in their 20s and 30s, urban-dwellers and enthusiastic about new ways to disrupt economic and industrial models.[101] Although DIY biologists claim to be rooted in an anti-institutional perspective that promotes open access and knowledge sharing in biotech, their actions complicate the truth of this. Several DIY groups participate in large institutionalized synthetic biology gatherings such as MIT's iGEM, and sell their own "open" branded lab equipment for the amateur scientist online. In this sense, I'd like to call for a recognition of their redefinition of how to practice, produce, and sell biotech, while pointing out that they are not necessarily anti-capitalist, nor entirely anti-institutional, as it often sweepingly remarked. Indeed it is early days still for the DIYbio movement and its popularity

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[100] Jefferies, Janice. 2010. Loving attention: An outburst of craft in contemporary art. In *Extra/ordinary: Craft culture and contemporary art.*, ed. Maria Buszek, 222-237 Duke University Press.

[101] I was fortunate to meet several DIY biologists throughout my course of study for this project. This happened first when I attended iGEM at MIT in 2010, and secondly when I was working on the documentary film in Portland. With the film company I travelled the Synthetic Biology 5.0 conference at Stanford University where we were able to meet up with the founders of DIY Bio Boston, BioCurious in San Francisco, and GenSpace in NYC.

is slowly rising; the DIY identity in science is far from being a closed and understood system.

In my own work I have engaged with DIY craft not for its coolness nor for its overt reclamation of women's domestic handiwork in contemporary culture, but because of its obvious reference to DIY biology and its qualities that make it a disruptive technology. In my work I aim to provide information and ask questions about what synthetic technologies offer the future. I hope to do this in an interdisciplinary way that explores emerging biotech not only from a scientific perspective, but a humorous and critical one that determinedly embeds the questions I raise in a wider cultural context.

In my particular case, I face challenges in getting my message across since the fields I am investigating are still so little known. Synthetic biology is only a household name for a select few communities in the world, as is DIY biology, and therefore most of the parties I've gone to in the last two years have been chalk-full of dreaded thesis-talk where I end up boring people to death when they ask me what I do. The problem is, I have to explain to them in some detail all the different parameters around which I am researching to do it any justice, which includes a lot of unknown names. Trying to create a narrative out of science can be a challenging thing, particularly among non-scientific audiences who don't take a natural interest in the subject. Having learned from my social experiences of dealing with my research topic among peers, which often end with the sense that I was too academic, dense, scientific or otherwise inaccessible in my explanation, I decided to embrace an expressive, open-ended, child-like and humorous approach to my art-making on this subject, leading me to DIY craft. Not only does DIY craft disrupt the thick academic, scientific or policy laden approaches through which synthetic biology often gets explored, but it references the contemporary state of emerging disruptive technologies that are changing the face of the institutionalized, industrialized world as we know it. As we grow increasingly connected in the digital age, and access to free information becomes regarded as a human right, it is the DIY and community-led projects that are shaping the future of work. I believe we are moving into a networked age of collaboration and participation based on an emerging distributed economy, which informs the thinking behind my work in the DIY Body Project.

The DIY Body Project

The DIY Body Project is an interactive textile art installation inspired by DIY approaches to biology and crafting that takes place online at www.diybody.org as well as in the *Spark!* Exhibition in the !dea Gallery at the Ontario Science Centre. The !dea Gallery is a space dedicated exclusively to the intersection of art and science, and it specifically promotes the work of emerging Canadian artists. *Spark!* will be open to the public from March to August, 2012.

I have been working with two institutions in the preparation of the exhibit, namely the Ontario Science Centre and University of Toronto. The relationship to these institutions came about when my Principal Advisor, Dr. David Cecchetto put me in touch with Rebecca Michaels, one of the curators of the show who was seeking artworks from artists that work from biomedical inspiration. Rebecca is currently pursuing a Master's of Museum Studies at U of T and as a fulfillment for one of her seminars she is curating the *Spark!* exhibition, along with some other colleagues from her graduate program. Together they are working in collaboration with the OSC !dea Gallery's principal curator, Ana Klasnja, with whom I have also been working closely throughout the months leading up to, and during exhibition.

The work itself is rooted largely in the spirit of open-source resource sharing. This ethic is found in biotechnology where genetic constructs are shared freely on the internet in genetic databases, in citizen science forums where people collaborate to invent open-source biotech equipment, and in crafting where DIY communities share tips and techniques online about how to make high-quality, economically autonomous objects. In the DIY Body Project, I have generated a set of free downloadable sewing patterns that enable one to sew a diverse array of stuffed imaginary synthetic body parts, which are representative of human, animal, plant, microbiological and fictional corporeal components. These sewing patterns, a metaphor for the "genetic blueprint" or DNA of an organism are packaged in a kit I've made that includes educational material about synthetic biology and the DIY biology movement (which are mainly re-

Figure 1: Select sewing patterns that are included in the downloadable kit.

formulated excerpts from this thesis). It is made free to the public at www.diybody.org and I have created a short video about the project to send to different blogs to promote people downloading it.

From these patterns, participants are invited to make their own body parts out of materials they may have at home like fabric, plastic and polyester stuffing (or anything else handy), as well as to alter the patterns to include their own imaginative visualizations. For example, they might decide to use the stomach pattern, but find that it would be better to make it half-stomach, half-ear so that the creation can hear its own stomach grumbling if they fancy that sort of thing. I have put the sewing patterns under a Creative Commons Share-Alike license and am therefore inviting everyone to remix the sewing patterns into new configurations and imaginations of synthetic body parts, corporeal amalgamations, hybrids, absurd organs, and the like. I also encourage people to make their own sewing patterns from scratch. Once new sewing patterns have been generated, there is the option to upload their own remixed, or all together new sewing patterns to the website so that a catalogue of diverse, DIY, community-generated body parts are archived and shared in an evolving online platform.

Figure 2: The cut out sewing patterns once printed from the downloadable kits.

Figure 3: Process documentation of sewing a stuffed stomach.

Personally I have made over 55 stuffed body parts from my DIY patterns, which I am installing in the gallery alongside 25 additional parts that have been made by participants in DIY Body Project workshops that I've facilitated. I have held two fabrication workshops, one at U of T as part of Subtle Technologies ArtScienceCamp, and the other with a grade 11/12 art class at Don Mills Collegiate Institute. The number of body parts in the installation made by people other than myself may increase over time as more workshops are carried out, or individuals craft parts themselves once they've downloaded the "genetic blueprints" from www.diybodyorg.

The parts are suspended from the ceiling of the gallery on several strings of fishing line that fall down from a ceiling grid, skimming the floor, almost like tentacles. On each of the strings there are several sewn body parts tethered together, with extra line attached to them that can be grabbed and pulled across to connect with other body parts on other strands. In this way the installation becomes interactive and the public is invited to examine, touch and move the body parts in the installation. They can remix the arrangement of parts and hook them together in new configurations that create an assemblage of a "synthetic body" in flux. The parts however have had to be permanently tethered to some degree in their place so that rambunctious visitors do not take the sewn pieces home with them, as is apparently a common problem at the Science Centre (and has been happening regardless).

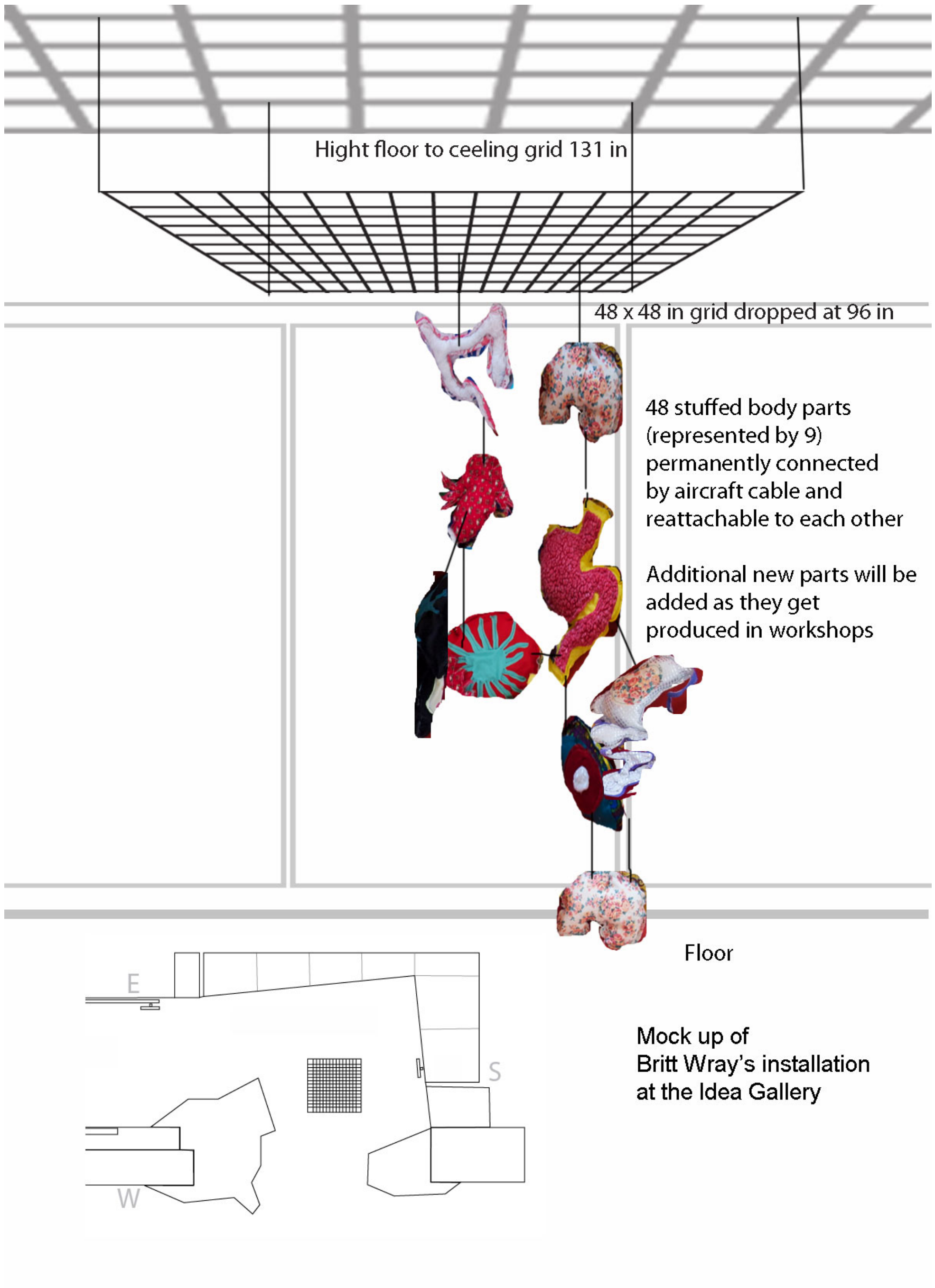

Figure 4: Early mock up of the installation in the !dea Gallery, courtesy of Ana Klasnja.

Figure 5: A sample of DIY body parts connected by aircraft cable (later changed for fishing line).

Figure 6: Close ups of sewn body parts: large intestine, eukaryotic cell, kidney.

If participating Toronto-based online DIY crafters (who will hopefully catch wind of the project by way of craft blogs and Toronto event calendars) go so far as to sew the stuffed body parts from the patterns I provide, or their own newly generated patterns, they can then bring in the pieces that they make to the !dea Gallery and add them to the exhibition. The hope is that during the duration of the show, The DIY Body Project will grow and change on a daily basis as people rearrange the configuration of parts in the installation, and also add new ones to it. Much like a real organism that evolves with its surrounding environmental pressures, gallery visitors can interact with and manipulate the textile body parts in the show, bringing the "synthetic body" to life as imagined through an always changing, collective effort.

Additionally, Karen Hager, who is in charge of public scientific programming at the OSC has hired me to give workshops once a month from August to March 2012 as part of her "Creative Sundays" program that brings artists to the OSC to explore scientific topics through hands-on making with the visitors. In the workshops we will be fabricating DIY textile body parts while talking about synthetic biology and citizen science, which might also generate more parts to be added to the installation during the last couple of months that the exhibition is up.

I am provoking the public to participate by asking them questions about how they imagine synthetic biology should and should not be used in the realm of the future biological body. I am interested to pose these questions at a time when the boundaries between categories, whether they are species or disciplines, are increasingly blurred. I am particularly interested in targeting youth (aged approximately 8 to 18) to contemplate the ramifications of this technology through crafting. I find this a conceptually relevant target since they are the first generation that will fully come to see and understand the material effects of synthetic biology and citizen science in the world. From the writing on www.diybody.org and the didactic panels in the gallery space, I ask them to consider the following:

> "There is an increasingly prolific list of synthetic bodies entering the biosphere from laboratories all over the world each year, and we have no reason to think that this human-driven genetic evolution will lose momentum anytime soon. In fact, the amount of money, energy and intellectual resource invested in the synthetic future is only increasing. At the same time, having influence over the synthetic future is becoming increasingly possible for everyday people as artists, designers, and citizen scientists suggest alternative ways to approach it. **What do you want it to look like?**
>
> The DIY Body Project invites you to share your own visualization of the future synthetic body, while building off the creation of others. **What types of synthetic organisms excite or concern you? What do their**

> **bodies look like and how do they function? Are they made from real or imagined human, animal, plant, and bacterial parts?** Show your idea off by adding to the online collection of textile DNA (sewing patterns), and adding your pieces to the DIY Body Project exhibit at the Ontario Science Centre this year from March through August."

The invitation to participate is very open-ended. I am excited to see what additional parts people will create with this project in mind and hope that the outcomes will be playful or borderline absurd. It is important that participants make their body parts by hand, and hopefully stray from the original sewing patterns in order to insert themselves into the project. Just as it is crucial in DIY crafting to create an object that embodies the imperfections created by human touch, it is also important in the DIY Body Project to break rules, make mistakes, and utterly confuse the notion of biological formalism that we have become so accustomed to in representations of the biomedical body.

Figure 7: The DIY Body Project installed at the Ontario Science Centre (far left).

Figure 8: The DIY Body Project, from inside the !dea Gallery.

Disrupting the biomedical gaze – the importance of size and arrangement

For my installation I've sewn pink fuzzy neurons the size of my leg and eyeballs the size of my hand. Though no piece is utterly gigantic, they each betray their true biological size (particularly the microbiological representations) and are made large enough to hold, squeeze and connect to one another. I've used all recycled fabrics, meaning that the materials they are made of are vastly diverse and create a sense of "hodge-podgeness" in the exhibition. The body parts thus range between the shiny, scratchy, leathery, see-through, colourful, furry, fuzzy, and otherwise outlandishly *non-biological.* Their material properties of texture, colour and size therefore combine to create an utterly theatrical portrayal of the organs that constitute human, animal, plant, microbiological and fictional synthetic bodies. This is an intentional aesthetic effect that invites visitors to play with parts and engage in a fun-loving relationship with not only the physical attributes of the work, but their own thoughts about what a synthetic body could represent, and mean for them.

Of course it is important to acknowledge that synthetic biology in its literal practice is only just starting to design new bodily functions in simple mammalian systems, which it otherwise does exclusively in viruses, bacteria and worms. However, with the freedom inherent to artistic exploration I am taking advantage of the room afforded to non-scientists to push the boundaries of scientific truth, and create narratives instead. Through the utterly nonliteral representations of the synthetic body that I am creating in the DIY Body Project, I am culling and supporting thoughts that stretch beyond the literal and into the speculative, where any future is possible.

As I discussed earlier, Richard Doyle has shown us how the pervasive rhetoric of microbiological software in biotechnology today allows science to forget the conditions that allow its knowledge to rise, creating an effect of impenetrable scientific authority. In my installation, the microbiological software and machine rhetoric of synthetic biology is left behind and gets swallowed by a visual language that promotes a hyperphenotypic understanding of plants, animals, humans, etc. in an imaginative and playful light. The visual and tactile language employed in the DIY Body Project resists the visual rhetoric of the biomedical gaze, where organs always have their correct material appearance, colour, size, and arrangement in the body. By asking visitors to make their own sense amidst the chaos of suspended colours and fibre flesh, an alternative lens for *looking at* science, bodies, and the synthetic is created. It generates a space and time where we, as synthesizers of information, are not forced to equate life with software or machines.

During a studio critique in which my advisory committee members plus one other critic commented on The DIY Body Project, Professor Luke Painter mentioned that it reminded him of an anti-Body Worlds exhibit. Body Worlds – the renowned international exhibition of plastinates (corpses preserved through plastics) that has been travelling since the 1990s – displays an "ambiguous form of post-mortem existence" of the corporeal vessels of body donors whose anatomical attributes have been preserved, sometimes manipulated, and exhibited.[102] In his essay on Body Worlds, Stefan Hirschauer states that the plastinate's meaning comes from "the extent to which an anatomy exhibition can impose a 'medical gaze' over a non-professional way of perception, which would stubbornly associate bodies with persons."[103] Similarly, the DIY Body Project finds meaning in the space between the normalized medical gaze that falls upon most representations of bodies (which are, I agree, too often stubbornly associated with *human* bodies), and the visitor's perception of the body parts as toys, stuffed animals, or aesthetic absurdities. In returning to Painter's comment however, the DIY Body Project does act as an anti-Body Worlds exhibit in that it preserves nothing, manipulates everything, and invites visitors to touch, squeeze and rearrange "the biologicals"; nothing is sacred. Body Worlds on the other hand commands the visitor to observe at a distance, never touch, and find awe in the biomedical gaze that so meticulously unfolds the body's sacred layers before their eyes, which other than in medical textbooks, always remain unseen.

In further disrupting the biomedical gaze in my project, I have played with the scale of the body parts in addition to their texture, colour, and spatial relationship to one another. The DIY Body Project employs no rules of scale or veritable reference to the actual size of a body part and a proportional relationality in sewn form. Instead, all true size is lost and body parts take on a randomized proportion in relation to one another. Arms and legs look

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[102] Hirschauer, Stefan. 2006. Animated corpses: Communicating with post mortals in an anatomical exhibition. *Body and Society* 12 (4): 24-52, p 24.

[103] Ibid.

shrunken or emaciated, a salivary gland is the size of a watermelon and a stem cell is comparable in size to a vinyl record.[104]

Susan Stewart wrote *On Longing,* a seminal work on the importance and affective qualities of size in art making. In it she discusses the difference between the miniature and gigantic, and notes "while the miniature represents a mental world of proportion, control, and balance, the gigantic presents a physical world of disorder and disproportion."[105] Although the body parts in my installation are not large enough to be gigantic compared to the bodies of the human spectators who will interact with them since they do not totally overpower nor envelop their bodily presence in the gallery space, they are indeed gigantic in comparison to their true size in real biological form. The shift in size of the body parts to absurd analogs of their true biological selves is obviously purposeful to the viewer and creates a sense of playfulness. This loss of "proportion, control, and balance" indeed gives way to "disorder and disproportion", qualities that then invite the spectator to create new narratives of how a body looks and must function.

By creating an alternate and disproportional corporeal space, my hope is that spectators will feel free to imagine wide-ranging possibilities of potential body paradigms that interrogate and disrupt our normative reliance on biological formalism as a guiding light to understanding life. Synthetic biology conjures myth cloaked in rhetoric as it makes increasingly literal comparisons between bodies and rationally engineered machines. As a way

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[104] The disruption of an authoritative scientific framing of the body in the DIY Body Project is reached through a playful methodology. By using mismatched fabrics and sizes, both of which are utterly non-life like in their materiality, the very basis of what a body is made of is performed differently, with a nod towards the absurd. I did not engage in the usual aesthetics of bioart in this project that use laboratory machinery and biological specimens to materialize the artwork. Instead, the juvenile aesthetics and domestic materials shy away from the cold, controlled aesthetics of the laboratory to open up a purposefully messy, humorous and perhaps more approachable performance of biology for a general, intergenerational audience.

[105] Stewart, Susan. 1993. *On Longing.* Duke University Press, p 74.

of talking back to synthetic biology's belief in a biological formalism so rigid it renders life predictable, controllable, and computable, the betrayal of true biological size in The DIY Body Project generates an alternative perspective through which to view the changing status of the synthetic body.

Chapter 4: Conclusions

DIY - The importance of inserting *yourself*

In this thesis I have made a contribution towards understanding contemporary interdisciplinary theory and practice in art, design, citizen science and synthetic biology. In my investigation I have identified the potential for the control of synthetic biological technologies by institutional powers that are beginning to co-opt them for things like military use and space colonization. I have built upon the thought of critical theorists like Stengers, Barad, Pickering, Guattari, Latour, Thacker and Rose among others in order to identify what is at stake therein.

I have also investigated several extended social concerns around this emerging science, which range from conservation and biosecurity issues to biopolitical struggle. While doing so I mapped sites of interdisciplinarity in the field to locate possible alternative explorations of the role of the synthetic in an increasingly designed world. At the same time I have questioned what we understand synthetic to mean amidst an understanding of life that has historically been divided between natural and artificial forms.

In order to illustrate a holistic understanding of synthetic biology and its interdisciplinary attachments for an art and design readership, I summarized the field through a tracing of its history in North America and Western Europe. I traced its lineage from its original inception in the early 1900s through to the 1970s when genetic engineering was discovered, and into the present as we build genetic devices, design entire genomes in computers to print from synthesizers, and create semi-living protocells in today's synthetic biology. I also parsed the differences between the three main knowledge distinctions of synthetic biology (DNA based device construction, genome driven cell engineering and protocell creation), and explained how the science of each functions for a non-scientific audience.

I identified the prominent interdisciplinary artists, designers, and citizen scientists who are setting precedents of interdisciplinary collaboration in synthetic biology and emerging biotech in general. My survey of these individuals and organizations locates them in the Ecology of Practices in synthetic biology that I have contributed to through my own writing and practice. I gave a detailed account of the values and differences between the aforementioned interdisciplinary activities, and further discussed how the work of creative individuals like Rachel Armstrong, Neri Oxman, Alexandra Daisy Ginsberg and Oron Catts specifically challenge and critique the narratives that dominate synthetic biology rhetoric.

Through my field research on the synthetic biology documentary with Field Test Independent Film Corps, and participation in the bioart residency at Banff (summer 2011) I came to understand the importance of interdisciplinarity and citizen involvement to critical education around emerging biotechnology. I consider this involvement a necessary component for any healthy society that faces a paradigm shift in our relation to technology, as we have today. I use this belief to fuel my own practice as an interdisciplinary researcher and maker who straddles the fields of biology, cultural studies, art, and media production.

Additionally I have positioned myself artistically within the Ecology of Practices around synthetic biology as a DIY textile crafter. I embraced the DIY approach not only because of its obvious allusion to the DIY biology movement that informs part of this thesis, but because of the political relevance of the history of DIY crafting as a resistive force to institutionalized sites of power. I explored this history through its relationship to citizen science and their shared potential for disrupting the reductive rhetorics of scientific hierarchy and institutionalized practice. I argue that through such disruption, more public approaches to knowledge production (in terms of their accessibility and relevance to the individual) are created. I then connected this potential to my own art practice that relates to my Master's research.

In my installation the DIY Body Project, I have made a space for the public to generate its own evolving narrative of what a synthetic body can mean, look like and function as through collaborative methods of resource sharing and playful making. Without promoting a specific rhetoric of the body as human, the synthetic as machine, or the biological as computable as is often seen in biotechnology, I take an open-ended approach to what it might mean to make formal decisions about constructing bodies through the arrangement of crafted body parts, as is literally done in lab of the synthetic era. The installation, which takes place in the Ontario Science Centre as well as online at wwww.diybody.org explores how knowledge is shaped through participatory methods both in the gallery setting, and in the home.

Throughout my degree at OCAD University I have come to understand the value of the research-creation process as an engagement with knowledge and knowledge production that is driven by the flux between theory and artistic practice. More importantly, I have realized the consequence of my own identity within the research-creation process, and recognize that the relationship between maker and made is always situated as a result of contingent events and does not arise devoid of any particular history or biographical context. In my own work, I am driven to investigate synthetic biology in an interdisciplinary institutional setting that affords me access to creative minds and artistic tools because of my background as a misfit biologist. The Interdisciplinary Master's in Art, Media and Design has fueled my interest in my (somewhat obscure) chosen fields and given me confidence that new knowledge can be generated in their overlap. This program has certainly motivated me to continue researching, making and educating within the increasingly interconnected areas of art, design, media and biology.

Similarly to what Eugene Thacker advised when he wrote about the "post-media era", I believe that cultural producers interested in technology must discover "new ways of thinking and acting in the world that are predicated on finding new ways of thinking about technology in relation to the 'subject'."[26] Just as good storytellers must do, artists and cultural critics should locate their narrative in relatable, personal and subjective affective strategies and scenarios rather than impersonalized, broad experiences. I have tried to do this by investigating interdisciplinarity across fields that are most closely related to my own personal work history and educational interests, as well as by generating an experience for individuals to personally connect with my artistic narrative through immersive, hands-on methods. I will continue in this vein of production in my future work as a researcher and media practitioner (returning to my interests in audio and video production) interested in the overlaps of emerging biotechnologies, criticism, and art production, likely through a PhD in the near future. It is not merely a thematic coincidence that my project revolves largely around DIY approaches to emerging biotechnology and art making. Rather, the aspect of doing something *yourself* is integral to my research which aims to cultivate meaningful affective speculations about contemporary and futuristic science as shaped through play and craft in a subject area normally dominated by epistomoligical certainty. This remains a gesture towards what may be shaping up to be our notably boundary-blurring and difference-embracing future, in an artistic, social and scientific sense.

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Appendix A

The following accompanying material is available upon request from the Ontario College of Art and Design Library:

CD Rom with installation and DIY Body Project workshop images, as well as the slides used during the defense of this thesis.

Anyone requesting the material may view it in the OCAD Library or pay to have it copied for personal use.