EVOLUTION OF THE SUBJECT

SYNTHETIC BIOLOGY

IN

FINE ART PRACTICE

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EVOLUTION OF THE SUBJECT SYNTHETIC BIOLOGY IN FINE ART PRACTICE

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ABSTRACT

Acknowledging a rise in the use of synthetic biology in art practice, this doctoral project draws from vital materialist discourse on biotechnology and biological materials in the works of Donna Haraway, Jane Bennett, Rosi Braidotti and Marietta Radomska to consider the liveliness of molecular biological material through art research and practice. In doing so, it reframes DNA and the micro-organism through anthropomorphic performative practice that draws on myth and metaphor to allow readings of material that account for liveliness rather than use as resource. As such it contributes to environmental and ecological art practices that question our cultural entanglement with material and performative art practice that considers the nonhuman by artists such as Eduardo Kac, Oron Catts and Ionat Zurr, Špela Petrič and Maja Smrekar.

The thesis does not recount a bioart practice, but a fine art practice that uses performative strategies to *think with* the act of using life as material. Amid the highly technical, accelerated pace of synthetic biology, the research slowly reconsiders methods and materials over an extended timeframe where liveliness, rather than use of the organism, takes precedent. By specifically acting as performative vector situated within synthetic biology practice, the relationship between meaning and materiality is brought under close scrutiny in attempts to infectiously transmit knowledge rather than generate lively commodities. As such, the thesis questions existing histories of scientific knowledge and proposes alternative stories that reframe aspects of laboratory practice through an aesthetics of care.

The core of the research resides in artistic practice situated within the Institute of Genetic Medicine at Newcastle University, where I store my thought physically within the body of the living organism, *Escherichia coli.* The work follows a close reading of scientific protocols whilst exploring the affect of working with laboratory life as medium. This leads to the development of anthropomorphic performative works and sculptural works that draw on myth and ritual to reframe genetic material as lively material. Further, practice-based aspects of the research sit within and contribute to the expanded field of sound and sonic art, including artists such as Alvin Lucier and Chris Watson, to develop technologically embodied approaches for listening to laboratory life (audification of Atomic Force Microscopy data, sonification of DNA through synthetic speech neural networks) and for experiencing life at the nano-scale within the context of immersive audio-visual installations.

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This thesis is dedicated to my mother with her love of art, my father with his love of science and to Damian, Lewis, Oscar, Benedict and Joseph, whose lively materiality inspires me daily.

DECLARATION:

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others. The work was undertaken in collaboration with Professor Volker Straub and the Muscle Team at the Institute of Genetic Medicine, Newcastle University.

Ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Faculty Ethics Committee on 15 February 2016 and a further amendment sought and granted on 13 October 2016.

I declare that the word count of this thesis is 40 935 words.

0 WHAT WILL HAPPEN IF I STORE THIS THOUGHT SAFE WITHIN YOU?

Start with the circle, a flexible zero. Ouroboros. A plasmid loop of DNA. What will happen if I store this thought safe within you? Is this the start, or is start just an idea that someone once had?

Let's start again.

1 Introduction

Taking as a starting point the concept of life as subject[1], this practice-based PhD project explores the agency of the organism in reference to the growing body of artwork that either sits within, or comments upon, synthetic biology and genetic engineering. Drawing from post-structuralist discourse on language and the animal[2], post-humanist literature on the human in relation to other species[3], and new materialist discourse on the post- and nonhuman[4], I suggest that life is deconstructed within synthetic biology, in effect dividing and at the same time multiplying our temporal and spatial understanding of living material. These thoughts shape a practice rooted in a vital materialist approach to understanding living material, that encompasses thought and matter as inseparable intra-action[5].

The question that frames the doctoral project is,

In what ways can art practice situated within synthetic biology expand understanding of our relationship with microbial life as material?

The research arises from art practice based both outside and inside the laboratory[6], where, drawing source material from synthetic biology, feminist science studies and art practices that employ synthetic biology techniques, I undertake a slow performative practice that attempts to relate to genetic material and micro-organisms through varied readings of technology. The core of the doctoral project revolves around the act of placing my thought within synthetic DNA and then physically inserting this DNA into the body of the common laboratory micro-organism, *Escherichia coli* (*E. coli*).

1.1 Now I Know What I Don't Know

> 'I get this strong feeling that previously I was ignorant of my own ignorance, and now I understand my ignorance. It's slightly depressing as you realize how ignorant you are. But this is progress.' (Ewan Birney interviewed by Hall, 2012)

In conversation with the artist, Oron Catts, he told me that when running bioart workshops, his parting gift to participants would be a graduation certificate with the words, 'Now you know what you don't know'[7]. Cambridge-based bioinformaticist Ewan Birney echoes these words during a 2012 interview with Stephen Hall on unraveling the complexities of the non-coding elements of the human genome. If I have learned anything from my experience in the laboratory, it is that the facts of science are embedded in a narrative that is continually being rewritten.

Embarking upon an exploration of life as material meant first learning the basics of genetics and molecular biology[8]. I coupled my practical training with scientific and historical reading around DNA, plasmids, viruses, the genetic code and the common laboratory organism, *E. coli*. The combination of practical application with historical context enabled me to critically engage with the subject matter in unexpected ways. I found myself unable to believe faithfully in the scientific facts, tinged as they were with shades of ambition. In the following chapters, I present my own cross-readings of the tiniest motes of life. These are the details as I have interpreted them - one reading among many possible – and they have shaped my thinking as the project progressed.

DNA and language are intertwined. Both reside within us and inherently frame our being in the world. DNA is often referred to as code and indeed synthetic biology makes extensive use of this analogy through formulating methods by which the 'code of life' can be syntactically broken down and rebuilt. However, as this thesis will argue, the semantically complex relationship between DNA and language is often reduced to a denotative tale by science, one that belies the richness of lively expression. As feminist science theorist, Donna Haraway has noted, '[t]he story of DNA has been an archetypical tale of blinding modern enlightenment and untrammelled, disembodied, autochthonous origins' (Haraway, 1992, p. 331). Through performative engagement with DNA and microbial life, I attempt to retrace the story with mythical readings that offer a means to reconsider biological material from a relational perspective.

Cultural theorist, Timothy Morton, invoking philosopher Jacques Derrida's concept of deconstruction and Julia Kristeva's genotext, compares the deconstruction of text to molecular biology and DNA. Morton suggests that, just as 'no text is totally authentic', neither is any particular life form (Morton, 2010a, pp. 1–17). Derrida's post-structuralist approach to language draws attention to both what is present and absent in language, which is perhaps most accessibly read through Derrida's concept of différance, or trace (Derrida, 1979), the presence of space or absence given as a result of a mark made (often discussed as, but not limited to, writing) that holds within it the capability to call forth what is absent - the producer, the meaning, and the receiver. Thus for Derrida, through the trace (or what the mark is not), meaning is never fixed and thus defined iteratively. Morton's supposition is that an author commits words to a page, but those words are never entirely original, they have come from somewhere before, in another context, and they will be interpreted in many new contexts after being committed to the page. DNA, by the same argument has existed before and will again in other forms. By way of example, Morton explains that bacterial DNA can create plastics in one scenario instead of the usual proteins in another. As artist and philosopher Manuel DeLanda explains when talking of spider goats, the existence of DNA in a particular form is contingent, not necessary (DeLanda, 2011b).

It is possible therefore to agree with Morton that neither DNA nor text is authentic. The subtle, but key, difference I address is one of liveliness, which I read through Jacques Derrida's definition of *l'avenir* (Dick and Ziering Kofman, 2002). The deferral of knowledge implied in *l'avenir* - a future to come that we cannot know in the present - can equally be applied to biological material in evolutionary terms. The meaning of a text varies according to our interpretation of it, we may not know its future iterations but they exist right alongside us as 'strange strangers', to appropriate Morton's terminology (Morton, 2010b, p. 15). With biotechnological appropriations of DNA however, there is a strang*er* stranger. It is possible to rearrange DNA just as one might with text, but there is in DNA a form of agency several layers removed from our cultural agency and as such, futures may arise that have nothing to do with the stories that we wish to tell[9].

DNA can be rearranged to form new proteins, which combine to form novel organisms. But the organism's form is only a part of a narrative, with many possible interpretations. This form is also impacted by epigenetic factors as well as the structure of the DNA itself. Thus it is the interconnectedness of the DNA to the body of the cell and the nutrients, viruses,

antibodies and other entities that relate to it (and this relationship across evolutionary time also) that determine how it comes to be. Haraway suggests that '[o]rganisms emerge from a discursive process. Biology is a discourse, not the living world itself.' (Haraway, 1992, pp. 296–298) and in this idea, the walls of scientific nomenclature begin to tumble, with the foundational stone, 'nature' pulled away first. Thus by acknowledging the specific, situated circumstances in which DNA and the organism are used in the laboratory, I aim to broaden their narrative, through a 'material-semiotic' feminist reading (Haraway, 1991, pp. 195–201).

1.2 Glossary

Certain key terms recur throughout this thesis. My specific use of these terms is defined below.

1.2.1 Laboratory Life

The phrase 'laboratory life' has become synonymous with the work of Bruno Latour and his anthropology of the laboratory environment (Latour and Woolgar, 1979). I extract Latour's phrase and transform it within the context of an auto-ethnographic laboratory art practice, where it becomes a referent to the diverse array of organisms that exist only within the confines of the laboratory.

1.2.2 Lively Material

I define the term *lively material* in reference to political theorist and philosopher, Jane Bennett's 'vital materiality' or 'vibrant matter' (Bennett, 2010, p. 117) and within this, I seek to define a specific, but not limited, range of elements identified through their relation to living material. Lively material is an extension of 'living material' (described below, see Section 1.2.2.3) to include the molecular biological material that is inherently vital to the processes of life but that does not fall under any commonly accepted definition of life[10]. I derive this term from my experiences embedded in the laboratory, where plasmids, viruses and DNA are not considered as life, yet when contained within the body of an organism, they act within the body and are thus lively. 'Living material' concerns a boundary shaped by

commonly held beliefs within the life sciences as to what constitutes life. ‘Lively material’ extends beyond the boundary to include elements that possess a capacity to act. It is possible, following Bennett’s account of assemblages (Bennett, 2010, pp. 20–23), to extend this term to the lively molecules of carbon, hydrogen and oxygen (and thus by extension, silicon, or other molecules that may constitute other forms of life), therefore relating to vibrant matter all the way down. Indeed I intend for this continuum to be considered through use of the term, but the term is defined within this doctoral project in reference to the specific lively materials that I have encountered: DNA, viruses and plasmids. ‘Lively material’ also aligns with other terms arising out of bioart practice and bio-philosophy, such as ‘semi-living’ (Catts and Zurr, 2002), which refers to tissue culture grown within the laboratory and ‘non/living’ (Radomska, 2016, pp. 32–26), which seeks to problematize the distinction of the concepts of life and death by proposing a continuum of life that is unbounded. ‘Lively material’ concurs with Radomska’s notion of a continuum in that I seek to erase the distinction between life and non-life in current scientific definitions, but differs by approaching the continuum through a molecular gaze that retains some concept of physical matter as bounded object.

Forms of lively material reconsidered in this thesis:

1.2.2.1 DNA, Viruses and Plasmids

DNA, although inert, has what philosopher Manuel DeLanda (referencing Deleuze, Spinoza and Leibniz) describes as ‘capacity’ (DeLanda, 2011b); that is, there is a capacity to act, and this capacity is always in relation to something. In the case of DNA there is the capacity to generate and express within a living body. Thus I argue that DNA is lively material, and in holding a capacity to act, DNA demonstrates an agency that is articulated through its relations within the body of the organism and as such, I suggest such lively material requires consideration through a nonhuman ethics.

Within this thesis, the plasmid, virus and bacteriophage (often simply, ‘phage’ - a bacterial virus that transfers (genetic) information by infecting its host) become *lively material*. They are considered inactive without a host body, but are essentially lively forms of DNA. Within cell bodies they have the capacity to act, to pass on their genetic information. They communicate. Despite detailed understanding of the molecules that comprise DNA and of the mechanisms by which plasmids, viruses and phages act, even despite a newfound ability led

by synthetic biology mogul, Craig Venter to create entirely synthetic genomes within cells (Gibson *et al.*, 2010), as yet there is no definitive understanding of how matter and meaning combine to generate life (Villareal, 2008; Kaebnick, 2010), although the role of viruses has long been implicated (Forterre and Krupovic, 2012, pp. 43–60).

1.2.2.2 Bioassemblage

The term *bioassemblage* arose from my work to assemble a thought within synthetic plasmid DNA. I define the bioassemblage as a culturally specific form of lively material. Bioassemblage describes the assembled biological object in the context of biotechnology. It may be a virus, a plasmid or a genetically modified organism. It is a constructed object that comprises lively materials assembled as component parts. It is therefore a naturecultural object (Haraway, 2003, p. 1). The term assemblage deliberately combines the engineering metaphor with an art historical use of assemblage and also the Deleuzian/Guattarian machinic concept of assemblage[11] thus describing a multiplicity of parts that act together but can equally be replaced or substituted for other parts. Added to this is the prefix -bio thus denoting that the machinic assemblage is lively and therefore unpredictable. The bioassemblage thus pays homage to Donna Haraway's cyborg, 'a condensed image of both imagination and material reality' (Haraway, 1991, p. 150). It alludes to humanity's use of DNA as tool and specifically to the information-processing model of the genetic code. The bioassemblage contains material that can be read by the biological cell or by the human mind but the meaning derived therein can never be fully comprehended by either.

1.2.2.3 Organism / Living Material

Within the context of synthetic and genetic biology practice, I experience the microbial organism as *living material*: material that has the properties pertinent to life and that is used as resource. In my practice within the laboratory, I specifically use the term *organism* to refer to the living body of the microbial cell (most often *Escherichia coli (E. coli)*, a common resource within synthetic biology) thus foregrounding life rather than material. The term organism and living material are used interchangeably throughout the thesis to refer to an expanded sense of the living cell as a form constantly in motion. I begin by using the term organism to refer to the living body of the cell. As the thesis continues, this definition evolves to take on a broader subject position. The organism is a bounded notion of lively material with a generative force:

it grows and multiplies. Thus inherent in my use of the terms organism and living (as opposed to lively) material are the simultaneous properties of boundedness, a means of differentiating forms and generation, a means of repeating forms. The organism then can be seen as a field of individuation, Deleuze's 'vital egg' (Deleuze and Patton, 2004, p. 250).

The question of the organism is central to this thesis. As with philosopher, Jacques Derrida's question of the animal (Derrida and Wills, 2002), I begin to form a situated response to my position within the laboratory, through questioning whether an organism is a life and in doing so, begin to tease out a personal ethics for my laboratory practice[12].

1.2.3 Alchemical Sensing

I introduce the term *alchemical sensing* to describe my experience of relating to lively material through technologically embodied perception. Attempts to reveal lively material, through increasingly complex layers of technology are considered as alchemical in reference to the ancient Greek and Egyptian origins of the tradition. Not alchemical in the sense of seeking immortality or turning metal into gold, but alchemical in the *anima mundi* sense of seeking out the essence of matter[13]. In attempting to define lively material through layers of technological apparatus, configurations narrow our focus to a specific location and time. Multiple configurations through layered technological apparatus therefore simultaneously extend and cloud our reading of material.

1.2.4 Genophone

Genophone has emerged through a contortion of material and language within this doctoral project. The prefix *geno-* co-opted within science to refer to hereditary material, has origins in family, birth and race. The suffix, *-phone* denotes speech sounds. Thus with *Genophone*, I develop an abstract reading of genetic material as language and its evolution as a means of communication. The *Genophone* exists physically as both art object and resource [14] (Mackenzie and de Crécy, 2016). The term arose from my attempts to exhibit a process of translation as a sculptural object. Technically, the *Genophone* translates text into phonemes into DNA, algorithmically evolves the DNA-as-code and then translates the evolved DNA into audible speech. Conceptually, *Genophone* acts as a translation device, from the genetic code to

the spoken word, enabling a form of communication with the organism. It becomes a performative tool, providing an imaginative means to interact with material that cannot be seen or experienced directly.

1.2.5 Psychotransgenics

I arrived at the term *psychotransgenics* latterly as a means to describe the activities that I have undertaken in the laboratory and that begin to unfold during the workshops, *Transformation* (Mackenzie, 2017e) that explore the affect of generating transgenic life. *Psychotransgenics* borrows from Guy Debord's 'psychogeography' (Debord, 1956) a sense of slowing down to observe personal responses to a situation. It takes into account not only the physical act of generating a transgenic organism, but the performative, experiential and philosophical act of doing so: a thinking through making. The use of the term also references a psychological approach to relating to the organism through metaphor and anthropomorphism, which I trace back to alchemical ideas of a world soul that align with vital materialist readings of matter (Bennett, 2010, pp. 116–120). Through a slow, anthropomorphic reading, psychotransgenics attempts to broaden the tasks undertaken as mundane laboratory practice into a richer enquiry of the multi-relational affect of working in this way.

1.2.6 Scientific Terms

A glossary of scientific terms used in the thesis is included in Appendix I.

1.3 Summary of Chapters

In Chapter 2, I set the context for the project by situating within a framework of synthetic biology and bioart practices that engage with living material. I reconsider existing bioart practice through the lens of vital materialist readings of matter (Latour, 1993; Bennett, 2010; Braidotti, 2013; Radomska, 2016) and related art historical and curatorial practice (Mitchell, 2010; Silvestrin, 2012; Hauser and Martin, 2015). I draw upon theorist, Robert Mitchell's definition of vitalist bioart to describe the specific practices that engage with living and lively material in the context of biotechnology and suggest that aesthetic tension evidenced in such

works, whilst necessary, is potentially problematic in perpetuating a division between scientific and cultural knowledge production. Exploring existing practices that engage with biotechnology I ask, *How does art practice rooted in biotechnology shape our relation to living material*? In doing so, I develop an approach to the exhibition of bioart projects which I describe as 'on a pedestal' and 'behind glass'.

In Chapter 3, I build the framework for my engagement with the laboratory, locating my research through the question, *How can performative engagement with synthetic biology expand ways of knowing in the laboratory?* I re-engage my interest in the life sciences and begin by learning the basics of genetic and molecular biology both practically and theoretically through diffracted readings of scientific texts. In the context of studio practice, I explore the concept of evolution, drawing upon experimental strategies employed by Alvin Lucier (Lucier, 2014), William Burroughs and Brion Gysin (Burroughs, 1999)[15] in order to develop text- and drawing-based works that combine language systems with chance events. This leads to a performative exercise where I enter into speculative dialogue with the laboratory organism, asking a series of questions for which I have no means of receiving an answer. This exercise marks an origin that I return to later in the project to shape the core of the practice-led activity in the laboratory.

In Chapter 4, I explore various strategies for relating to the organism through technology. Having previously observed micro-organisms under the microscope and experienced an overwhelming sense of distance from them, I explore sound as an additional means to develop a closer relation to the organism, asking *Can technology be used to develop an embodied experience of the organism?* In doing so, I experience a specific and narrowly focused sense of the organism that can only be accessed through complex layers of technology, which I define as 'looking without seeing' and 'listening without hearing'. I suggest that the combination of phenomenological encounter and intuitive decision-making employed through performance by artists Alvin Lucier and John Cage (Lucier, 1965) offers a richly expanded reading that acknowledges technological layering and simultaneously clouds perception in what I describe as 'alchemical sensing'. This technological layering is then situated in the context of language as technology. In searching for a way to experience evolution, I ask, *How does translation of the genetic code in novel ways open up possibilities for extending our experience of genetic material?* I draw upon existing research within science and art practice that compares biological material to language (Davis, 1996; Kac, 1999; Ailenberg and Rotstein, 2009; Goldman *et al.*, 2013; Bök, 2015) to devise a method for encoding subjective

thought in the form of DNA for insertion within a living organism, where the capacity for agency arises. Thus I ask the organism, *'What will happen if I store this thought safe within you?'* - the consequences of which are explored in Chapter 5.

Chapter 5 forms the core of my practical research, where my engagement within the laboratory at the Institute of Genetic Medicine pivots around the question, *If working with living bodies in the laboratory is abstract, how can this body relate to it?* Referencing a technique pioneered in an art context by artist Joe Davis (Davis, 1996, pp. 70–74), I use the tools and techniques of synthetic biology to encode a message within a synthetic DNA plasmid. The message is a question to the living organism that will eventually embody the synthetic DNA that I create. The creation of the plasmid and subsequent insertion within *E. coli* becomes a pivotal moment in the research, where the living organism replicates my subjective thought and I experience DNA as having the capacity to act within the body of the organism. The experience of assembling a question as plasmid DNA and inserting this within *E. coli* in the laboratory is recorded in a video and photographic diary. Through these actions I develop a sense of the genetic material that I am working with as inherently *lively material*. The organism is genetically modified by the insertion of the plasmid and I am overwhelmed by a sense of responsibility for this organism that is made not born, which I grow continually within the laboratory. I explore the possibility that the organism might act on the information I have placed within it, thus changing both the organism and my thought in some way. I investigate this through sequencing the DNA of the organism, which involves continually growing and killing the organisms in what I describe as a paradoxical process of *nurtorture*. My specifically gendered experience of genetically modifying the organism with my thought in the laboratory is manifest in the short documentary, *Untourage #3*, where I present my actions to scientist colleagues and their reactions lead to a dialogue around care rather than use in the context of the laboratory. This leads to a series of experimental *Works of Kinship* that are described in Chapter 6.

In Chapter 6, I document the process of bringing subjective experience out of the laboratory and into public contexts, addressing the question: *How does the experience of synthetic biology in the laboratory translate into an experience in the context of the gallery?* At each stage of the project, I explore experimental approaches to exhibiting my research; approaches that are bound by the specific parameters of UK legislation on the exhibition of genetically modified organisms and by my reluctance to impose further upon the organisms in my care. Initially I consider how my thought might change over time within the organism and,

using evolution-modeling tools, I create a speculative evolution of my thought within the body of the *E. coli* as a sound work. This sound work is presented with a single spot-lit unfired clay vessel, impregnated with the DNA plasmid that contains my thought, in the installation, Pithos. Through this installation I begin to develop a critique of gendered biotechnological language, specifically the definition of the organism within synthetic biology as 'chassis' (Frow and Calvert, 2013, p. 47), through evoking the myth of Pandora to reframe the body of the organism as unpredictable vessel. The speculative evolution of my thought is further developed in collaboration with Étienne de Crécy of Edinburgh University into a web-based, neural-network speech synthesis tool, Genophone. Initially, *Genophone* is used to generate the audio component of the sculptural installation, -*Phage*[16], which begins to address my fascination with the bacteriophage as imposing, parasitic agent and my instinctive experience of the heavily layered technology required to translate genetic information. Both works become the basis for the exhibitions, *Viral Experiments*[17] and *Genocentric*[18], where I attempt to bring together experiences of technological layering, a sense of the liveliness of material and the power structures inherent in working with living material. *Genocentric* was a part of Edinburgh International Science Festival where I also conducted artist-led genetic modification workshops, *Transformation*[19], shaped by my situated experience of working with living material. In foregrounding my thought-as-DNA, as BioAssemblage #1[20], I ask, *Can art practice that works with living (and lively) material reconsider material not as living commodity, but as infectious idea?* During these workshops, my thought as a DNA *bioassemblage* is inserted within *E. coli* and participants are invited to metaphorically place themselves under the microscope and be interviewed by a sentient community-being of bioassemblages.

In conclusion, I summarise the areas of new knowledge identified within the thesis and highlight post-doctoral research that has arisen from my initial question.

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[1] I begin with the term 'life as subject', in reference to the 'personal appearance' of delphiniums exhibited by Edward Steichen at the Museum of Modern Art, New York in 1936 (Museum Of Modern Art, 1936).

[2] The writing of Jacques Derrida continues to inspire my practice and I have also drawn from Michel Serres, Jean Baudrillard and Michel Foucault (Derrida, 1967, 1979, 1988, 2000; Baudrillard, 1994; Derrida and Wills, 2002; Foucault, 2005; Serres, 2007).

[3] For further reading, the Posthumanities series published by University of Minnesota Press has an extensive collection on the subject, for example Donna Haraway's, *When Species Meet* (Haraway, 2008); *The Nonhuman Turn* edited by Richard Grusin (Various, 2015); and *Zoontologies: The Question Of The Animal* edited by Cary Wolfe (Wolfe, 2003).

[4] Alongside several works by Donna Haraway (Haraway, 1988, 1991, 1992, 1997, 2003, 2004, 2008, 2016) and a brief foray into the writing of Karen Barad (Barad, 2003, 2007, 2014), neither of which strictly sit within vital materialism, the following works have been influential throughout the doctoral project (Latour, 1993; Braidotti, 2005, 2013; Bennett, 2010; DeLanda, 2011a, 2011b).
[5] I align with feminist science theorist, Karen Barad's concept of intra-action as denoting the 'mutual constitution of entangled agencies' (Barad, 2007, p. 33).
[6] The majority of the doctoral project is conducted at the Institute of Genetic Medicine, Newcastle University, UK, with elements of research being undertaken in collaborations with Lancaster University, UK; Erasmus MC Viroscience, Rotterdam, The Netherlands; Department of Materials Chemistry, Durham University, UK; ASCUS Art & Science, Edinburgh, UK, the Centre for Speech Technology Research, Edinburgh University, UK and the Departments of Computing Science, Design, and the Faculty of Health & Life Sciences at Northumbria University, UK.
[7] Skype interview with Oron Catts, 24.05.17.
[8] There is not the capacity to elaborate on the detail within the thesis, suffice to say that I found the MOOC, *Useful Genetics Part 1 and 2* from the University of British Columbia a very good introductory source (Redfield, 2012) and would point interested parties towards Lyn Margulis' *Five Kingdoms*, Evelyn Fox Keller's *A Feeling for the Organism* and Jermijenko's *BiotechHobbyist* for a refreshing mix of history and education (Keller, 1983; Margulis and Schwartz, 1998; Jeremijenko, 2004) and to the texts, *Molecular Cell Biology* and the *Gene Synthesis Handbook* for a diffracted take on the practicalities (Lodish *et al.*, 2000; GenScript, 2014). This coupled with the patience and advice of Dr Stephen Laval, my mentor for the first year of my research went a long way to helping me come to terms with a field that I had not engaged with since my final years of high school.
[9] A 'stranger stranger' of course runs the risk of becoming circular, or perhaps spiraling out of control, but that is, in part, the point here.
[10] There is no singularly accepted definition of life, there are historical definitions that offer a 'working' agreement of the key principles, but these are revised and contested in both science and philosophy as molecular biology and consciousness studies begin to converge around drives, energy and the physical properties of the mind.
[11] Philosopher Thomas Nail notes that the Deleuzian/Guattarian term assemblage is the English translation of the French, *agencement*, which translates as, 'a construction, an arrangement, a layout', which differs from the French, assemblage, which means, 'a joining or union… a bringing together' (Nail, 2017).
[12] This began, through discussion with my collaborators as the question, *Is a microbe a life, and if so, how can I relate to it?* By Chapter 5, the question had formed a specific shape as I began to engage in laboratory practice, becoming, *If working with living bodies in the laboratory is abstract, how can this body relate to it?*
[13] I refer (loosely) to Plato's view of the world soul but instead suggest a reconsideration of the patriarchal ordering of organic matter in a 'great chain of being' (McDonough, 2017) to a feminist reading that permits chaotic leakage and blending of organic matter.
[14] *Genophone* exists in new media form as a speech synthesis system that is capable of translating DNA into phonemes or phonemes into DNA. The system can also predict how the DNA/phonemes will mutate according to an evolution model algorithm
[15] Such experimental approaches can be traced to Dada in the 1920s, Neo-Dada and the Fluxus art movement of the 1960s and 1970s. Musique Concrète similarly expanded this experimental approach into sound-based practices.
[16] https://www.loumackenzie.com/phage
[17] https://www.loumackenzie.com/viral-experiments
[18] https://www.loumackenzie.com/genocentric
[19] https://www.cnos.org.uk/transformation
[20] http://www.viralexperiments.co/bioassemblage-1

2 SHIFTING BOUNDARIES

Technology and life as one and the same is a reality that humanity begins to come to terms with in the biotechnological era, where the production of living organisms is commonplace. Designers and engineers are today as willing to fabricate from living tissue, micro-organisms and DNA as from stone, metal and clay. As living material becomes increasingly commoditised, I began by asking, *How does art practice rooted in biotechnology shape our relation to living material*?

2.1 Reading Life as Material through Art Practice

> 'Genres are for bins. "What bin should we put you in, so that we can sell what you do?" Ignore the bins. Ignoring the bins helped me a lot, because nobody really asked me what I wanted to do – and I never decided.' (Anderson, 2017)

Capitalist society wants to make synthetic biology a bin, a multi-disciplinary bin that people can be put in, people who make things from living material. Let's all be synthetic biologists and grow the economy. It is a rapidly expanding academic and commercial sector with (and surely this is the true test of becoming a bin) its own conferences and symposia[21]. Through finding novel ways to use life as material, synthetic biology offers such alchemical promises as eternal youth (Finkel and Holbrook, 2000, pp. 246–247) and turning base elements into gold (Brown, 2012). This relationship to alchemy has been explored explicitly by Georgiana Kirkham, particularly in relation to the social and cultural attitudes to alchemy and synthetic biology (Kirkham, 2009, pp. 70–80). The significant potential in genetically altering existing microbial organisms, for use as energy and within healthcare and medical treatment, has generated a lucrative industry with both private- and public-sector investment growing and a number of funded research opportunities within the technology and defence sectors[22]. In tandem with this investment is a growing interest in the social, political, economic and ethical implications of synthetic biology[23]. Yet despite the financial investment in applications of synthetic biology, the extent of public knowledge of this emerging field is still limited[24].

As cross-disciplinary architect and synthetic biology practitioner, Martyn Dade-Robertson has said, synthetic biology is, 'not an, "it" but a collection of disciplines gathered around a funding source'[25]. The ability to manipulate genetic material is no longer the reserve of the genetic specialist. Through the internet and open source software that encourages the simplification and mechanization of biological processes (see for example, OpenWetWare, 2009), it has become theoretically possible to extract DNA, sequence and synthesise genetic information from a classroom or art studio almost as readily as within a laboratory. This 'creative commons' approach to life as medium has enabled disciplines both within and outside of the life sciences to actively engage with the subject, with perhaps the most notable example being the International Genetically Engineered Machine competition (iGEM, 2017). This competition encourages high school and university students across disciplines to think of innovative ways to re-arrange the genetic components within a living organism, for the betterment of humanity: new medicine, greener fuel and so forth.

The ability to manipulate life via synthetic biology has been of significant interest to the art and design communities also. Since the inception of iGEM, other more creatively focused competitions have also become established, such as the Netherlands-based, Bio Art & Design Awards (ZonMW *et al.*, 2017) and in the USA, Biodesign Challenge (Art Works and National Endowment for the Arts, 2017). Whilst few artists explore the phenomenon that is synthetic biology directly - artist Howard Boland, in his PhD thesis, *Art from Synthetic Biology* (Boland, 2013) engages practically with material whilst artist, Joey Holder's work *Ophiux* (Holder, 2016b) engages conceptually with the subject - there are considerably more who have dipped their hands in the bin to work with synthetic biology methods. Chicago based 'transgenic' artist[26] Eduardo Kac has explored synthetic biology from a methodological and ethical perspective, with the works *Genesis* (Kac, 1999), *Eighth Day* (Kac, 2001), *GFP Bunny* (Kac, 2003) and *Natural History of the Enigma* (Kac, 2009). Artist Joe Davis, often termed the grandfather of Bio Art, similarly used synthetic biology techniques to develop the work, *MicroVenus* (Davis, 1996) and poet, Christian Bök is working on a long term project to synthetically engineer a poem into the extremophile bacteria *Deinococcus radiodurans* in his work *Xenotext* (Bök, 2015).

Contingent in using life as material, particularly genetically modified life and especially in the context of its public exhibition, is that the material is generally considered to have agency. It might move, leak, smell, or worse, *react*. This has led to location specific

approaches to working with life, driven by health & safety and/or ethical legislation. Artist Sneha Solanki has worked with genetically modified *E. coli* and, as an alternative to the 'personal appearance'[27] of the work, not permitted outside specially licensed premises in the UK, Solanki produced a video- and sculpture-based installation. Others outside the UK have pushed the boundaries further with The Tissue Culture and Art Project (Oron Catts and Ionat Zurr) not only exhibiting 'live' work but also enabling the audience to participate in the 'death' of the work[28]. This is a mode of engagement that I too have explored in my performance, *The Creators* as a part of the exhibition, *Oltramarino* (Mackenzie, 2013b), exploring life and death in the hands of the scientist and artist, albeit not with genetically modified organisms but with live cyanobacteria.

This tension brought about by public proximity to the vibrancy of living matter has led theorist, Robert Mitchell to define what he describes as 'vitalist bioart' (Mitchell, 2010, pp. 16–34). Specifically referring to the necessary boundaries (often including the use of lab materials) created by the vitality of the materials within bioart, Mitchell suggests that vitalist bioartists use scientific framing successfully in generating affects that 'oscillat[e] between a sense of agency and a sense of passivity' (Mitchell, 2010, p. 13) and in doing so establish an infectious 'vector-frame' (Mitchell, 2010, p. 89) that draws the spectator closer to the work. Mitchell delineates between vitalist bioart and what he refers to as prophylactic bioart (that which critiques through other mediums such as painting or photography and therefore does not directly engage with vital material).

Whilst I agree with Mitchell's analysis, I also find it problematic. He does not distinguish between practices that engage with materiality as primary function (for example, design and architecture practices) and practices that are primarily conceptual. Thus Mitchell's definition of vitalist bioart specifically points to a paradox that I face in working with living material: Mitchell, citing Matthew Fuller, suggests that 'media can bring something new into existence' and 'art can establish new uses for "standard objects" precisely because art "insist[s] on the possibility of the entirety or any part of life being always reinvented"' (Mitchell, 2010, p. 109). In my practice, I choose to work with material as signifier[29] but in doing so, my work exists in the paradox of attempting to explore the use of new media authentically without bringing 'something new into existence'. Not in the sense that I avoid engaging with the media, but in the sense that in engaging with science, where there is a focus on usefulness, my primary aim is not to infect

the social realm with novel material, I merely wish for the idea in the work to act as infectious agent[30].

I therefore set out below another reading of art that engages with living material, one that frames the work in terms of its relationship to the domain of science.

2.1.1 Behind Glass

There is a particular aesthetic that pervades many works of vitalist bioart, which I will term ‘behind glass’: the tendency (often a necessity) to house works behind glass, plastic or other forms of protective covering. I use ‘behind glass’ to describe the barrier between the audience and the work, but also to allude to the expressly scientific nature of the barrier in vitalist bioart. Artworks are often live and/or fragile and there may be concerns around contamination (of the audience or of the work itself). The barrier may even arise by virtue of the non-presence of the work in the gallery space (replaced instead by an image, film or audio). I attempt therefore to expand upon Robert Mitchell’s definition of bioart tactics (Mitchell, 2010, pp. 26–34) through an analysis of the formal parameters in the way that work is shown.

Figure 1: The Tissue Culture and Art Project, 2008. *Victimless Leather*, sk-interfaces, FACT, Liverpool, UK. Reproduced by permission of FACT.

Works presented behind glass are intrinsically associated with the space of the gallery and, perhaps more relevantly, the museum. The aesthetic inherently holds notions of value and of education but primarily of 'untouchability', a model that contemporary museums are keen to erode[31]. Much vitalist bioart necessarily employs metal, glass and plastic reminiscent of, if not directly associated with, the laboratory. The aesthetic is overtly scientific. Often instruments of science are brought directly into the gallery space to expressly link the disciplines of art and science (see for example, Howard Boland's *Banana Bacteria* (Boland, 2011) or Joe Davis and Katie Egan's *Audio Microscope* (Davis & Egan, 2000)) and others require scientific laboratory equipment in order to function as works of art (such as Adam Brown's *The Great Work of the Metal Lover* (Brown, 2012) and Tissue Culture and Art's *Victimless Leather* (Catts & Zurr, 2004), see Figure 1). I argue that this aesthetic, whilst to an extent necessary, holds a particular place in the fast-moving canon of bioart works and need not be the definitive model.

Robert Mitchell acknowledges this aesthetic as a part of what he describes as the 'vector' framing of vitalist bioart (Mitchell, 2010, p. 89). That is, the work draws spectators in whilst simultaneously keeping them at a distance and in doing so, encourages an

embodied experience in the viewer as both agent (there is always the possibility – sometimes intentional - of disrupting the barrier) and as material. Curator and media studies scholar, Jens Hauser also recognises the importance of 'the tension created between the viewer and the viewed' (Silvestrin, 2012) but consciously guards against ascribing this to the aesthetics of framing, preferring to avoid the term bioart. The presentation of works 'behind glass' is a boundary arising out of a necessity for containment, but I argue that in doing so it perpetuates an aesthetic that has the potential to limit the accessibility of the work. Whilst I agree with Mitchell in the power of the vector-frame to 'produc[e] a sense of fluidity between "life" and "art"' (Mitchell, 2010, p. 89), the overtly scientific aspect of this framing has the capacity to inure the audience and to compartmentalise the work. This compartmentalization operates on two levels: a specifically scientific framing locates vitalist bioart practice within the more nebulous terminology of 'sci-art'[32], encompassing many varieties of bioart practice that, whilst not falling under Mitchell's definition of vitalist, employ the trope of scientific framing nonetheless[33]. Secondly, and to an extent following from this point, audiences become more sophisticated in selectively categorizing work as bioart (and/or sci-art) through its aesthetic and become desensitized to the inherent tensions as a consequence.

The idea of containment is helpfully complicated by bio-philosopher, Marietta Radomska, whose thesis suggests that life is 'uncontainable'. Drawing from Rosi Braidotti's theory of *zoe* as 'a material force that pertains even after the life of an individual ends', Radomska understands life 'as a material, dynamic and excessive force of transformation that traverses the divide between living and non-living…and ultimately life and death, as they are currently conceived' (Radomska, 2016, pp. 31–32). How then, can lively material exist for the audience in a manner that encompasses a concept of uncontainment? In the context of art practice, artist and bioart practitioner, Marta de Menezes successfully negotiates this scientific framing through a theatrical staging of works that calls upon the audience to relate directly to living material. In the work *Immortality for Two* (de Menezes, 2014) de Menezes presents the immortalized immune cells of herself and her partner at the opposite ends of a table directly under the public gaze, with the absence of any laboratory equipment save for the simple containers that the cells sit within. On the long table, two projections overlap, showing the growing cells connected virtually, but which must remain isolated in reality, as their respective immune systems would reject the other. De Menezes talks of bio art, like 'life itself' as necessarily combining representation and presentation (High *et al.*, 2017, pp. 52–53). Engaging

philosopher, Jacques Rancière's concept of the emancipated spectator, De Menezes suggests that where artists work with living materials, '[w]e offer action, and we offer the idea that that action is shared between the artist and the audience. That by experiencing the artwork one is not only a passive spectator but a full responsible actuating participator.' (High *et al.*, 2017, p. 58). Thus for De Menezes, the glass barrier is minimized, containment becomes an explicit signifier in the work, and a performative context enables the audience to empathise with this position.

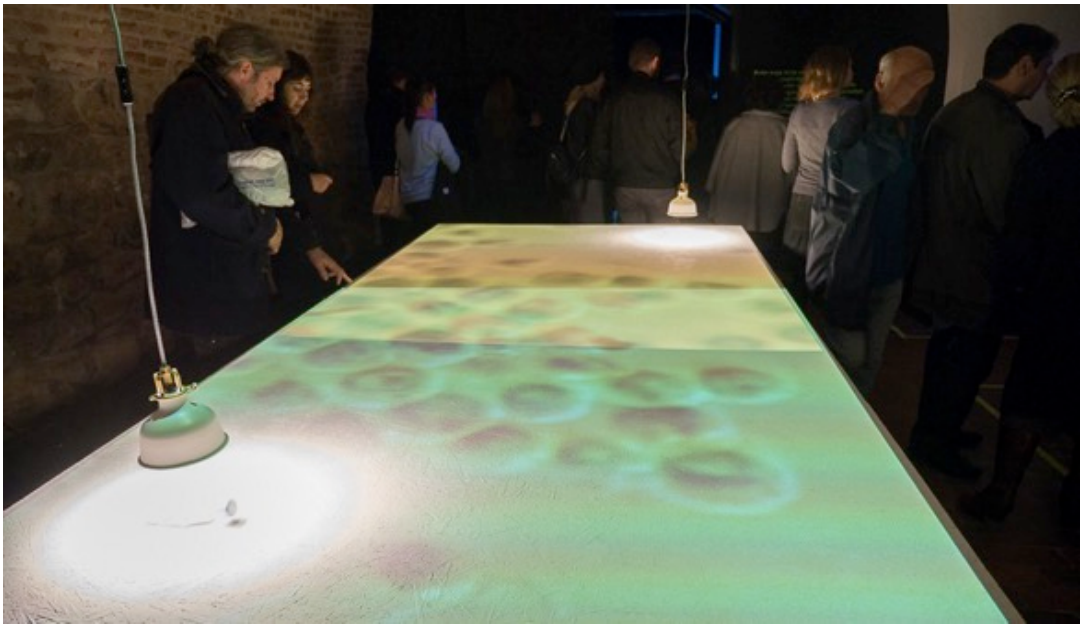


Figure 2: Marta De Menezes, 2014. *Immortality for Two*. Reproduced by kind permission of Marta de Menezes.

In my own work, *The Creators*[34], a durational performance as part of the installation *Oltramarino* in 2013 (Mackenzie, 2013b), I addressed the use of scientific materials in the gallery context by employing them as working props (see Figure 3). Whilst this work did not include living materials that had to be specifically 'contained' within a gallery context, the work addressed our relationship to working with living material through the presence of the organisms. A microscope, slides and flask of micro-organisms were present in the gallery, but solely for the purpose of staging a living, Renaissance style fresco of a starry sky as I adopted the role of scientist and 'played god' with the lives of the organisms[35]. The organisms were projected in all their lively animation and then stopped moving as the liquid medium on the microscope slide began to dry out. Each day of the exhibition, I replaced the slide, recreating the living celestial fresco. The scientific instruments, set out on a glass and metal table, undoubtedly acted as vector-frame but their role in the installation was not centre stage, they were essentially set out as tools to enable something

else: visible props for a performance that signified humanity's attempts to control the living.

Figure 3: Louise Mackenzie, 2013. *The Creators*, Oltramarino, Hatton Gallery, Newcastle, UK. Image: Colin Davison.

2.1.2 On a Pedestal

Related to bioart's inseparable association with science is the second boundary that I aim to address in my work, that of putting science on a pedestal, figuratively but often also literally. In employing the tropes of metal, glass and laboratory equipment, the work remains framed by the laboratory, which while it can draw the audience closer, simultaneously positions the material as out of reach or untouchable and in doing so, perpetuates a belief in the need for a clear demarcation between science and the rest of the world.

Thus whilst 'behind glass' refers to the ethical boundaries of presenting bioart, 'on a pedestal' refers to perceived knowledge boundaries. I consider this demarcation on two levels: firstly, there is the institutional boundary between arts and science and secondly, there is an epistemological/ontological boundary, that relates more closely to praxis and has its roots in feminist and critical culture studies of science. There is a sense, which has been in effect at least since C.P. Snow's *Two Cultures* lecture (Snow, 1959), of a boundary between science and the rest of the world. In his framing of arts and science as separate cultures with a lack of common discourse, the named boundary somehow became sharper and institutionally ingrained. Whilst in contemporary academia and art practice there are many attempts at eroding this boundary[36] and terms such as cross-disciplinary, trans-disciplinary and interdisciplinary abound, my experience is that building skills across disciplines is a life-long pursuit and there are few areas where the boundary is effectively dissolved. Even within the relatively niche sphere of vitalist bioart, there are artist practitioners who wholeheartedly engage with the science, such as Joe Davis and Howard Boland (who in his thesis lays out practical steps for conducting scientific experiments (Boland, 2013, pp. 78–122)) and others who readily admit to engaging scientists in order to make work (see for example, Oron Catts, Eduardo Kac, Christian Bök).[37] Attesting to the polymathic nature of bioart practice, there is a rise in artist practitioners (such as Špela Petrič, Mary Tsang and Jaden Hastings) who have prior training in science[38]. Similarly, those who have made a career in the field tend to have developed substantial scientific knowledge in the course of their work[39]. The extent of scientific training within the realm of bio art attests to the complex nature of the material and the difficulties in translation that lie therein.

In the presentation of work, there is an inevitable tendency to hide some aspects of complexity whilst disclosing others, in order to tell a particular story. This leads to a sense of aesthetic black boxing, in which the pedestal may as well be the artist's plinth, raising the focus of the work above the audience's need to grasp the detail[40]. I suggest that this tendency for masking the detail is more accurately defined as a communication device, and in order for black boxing to be an effective strategy, it must be fully acknowledged.

An approach that avoids black boxing altogether is the biohacker/grinder culture: those who, without the framework of an institution, are free to make and modify code and living material, often in relation to their own bodies, in the bedroom or garage, no glass or pedestal required. Biohacking takes many forms ranging from radical empiricist self-experimentation (see for example, Josiah Zayner (Zayner, 2017) to transhumanist technological body-hacking (see for example Grindhouse Wetware (Grindhouse Wetware, 2012))[41] but all are characterized by a DIY culture: an innate desire to gain the necessary knowledge to use living material as resource. Whilst most in the community are highly motivated to learn the requisite skills, there is no specific background in art or science required to hack, rather a non-institutionalised desire to share knowledge. The model is informative in bioart practice, where participation and interaction are increasingly important in engaging the audience directly, questioning the processes with which scientific knowledge is built[42]. I suggest that this is a radical participatory approach that lowers or removes the pedestal, providing a level of accessibility that goes beyond the usual confines of a bioart work 'behind glass'. Although referring to the object, Jens Hauser alludes to the importance of process in placing bioart under the phenomenon of the 'epistemic turn', which he defines as,

> 'not about presenting knowledge, but about questioning and showing how knowledge is being produced, through an aesthetic object. In my opinion, this kind of art is oriented towards the representation of its production' (Silvestrin, 2012).

In the case of bioartists, as opposed to bio-hackers, there is often an aesthetic element that serves as the focus for the interaction, which may involve a level of aesthetic black boxing, but the crucial aspect of the work is one of intra-action: the performativity of process and the audience's experiential engagement with this.

Secondly there is a gendered division of knowledge within science, evidenced in the feminist writings of science and critical post-human theorists such as Donna Haraway, Karen Barad and Rosi Braidotti who propose that the dominant deterministic model of scientific knowledge compartmentalizes and divides rather than relates and aligns (Braidotti, 2005; Crasnow *et al.*, 2015). I suggest that within some bioart practices, Hauser's epistemic turn is evident in challenging this through performative and interactive methodologies. Like science, the modes of engagement common to vitalist bioart practice involve working with new technologies and media but crucially, with different teleology. Whereas the dominant scientific dogma abstracts and concretises the object of study, art can revitalize it. Whereas scientific research aims to prove or refute a hypothesis, art questions the methods of doing so. Thus, through art practice, the philosophical relationship between mind and body are brought into closer alignment, problematizing a purely objective approach to material. What Robert Mitchell refers to as the vitalist tactic has its origins in new materialism and vital materialism, a philosophical topography that can be traced from Baruch de Spinoza through Henri Bergson, Friedrich Nietszche and Gilles Deleuze to contemporary theorists Bruno Latour (Latour, 1993, pp. 13–48) and Jane Bennett (Bennett, 2010, pp. 52–93). Vital materialism addresses the power of the object to have effects in the world and as such is closely tied to the relational approaches of feminist critical studies.

I therefore suggest that Mitchell's vector-frame analysis encompasses two aesthetic qualities that are undeniably related to bioartwork: containment and an attachment to science, but this latter aspect also relates to a formalism that, I argue, delimits a period in the history of bioart. Mitchell describes bioart as having already moved through three eras (Mitchell, 2010, pp. 35–51), suggesting bio-technology's adherence to Moore's law[43] and whilst it may be argued that era is too grand a term, following this accelerated pace of technological transformation, I will suggest that we may already be entering a fourth that acts to signify the uncontainability of living material.

Thus I propose that the most effective vitalist bioart works are performative works that, through radical participation and empathetic performance not only come out from behind the glass but also step down from the pedestal of scientific knowledge, to enable a form of 'being with' that is accessible and empowering beyond the realm of science alone. Works that provide an intimacy with material, such as Maja Smrekar's *K-9 Topology: Ecce Canis* (2014), which explores the emotional connection between humans and dogs (see Figure 4)

or Špela Petrič's *Skotopoesis* (2015), which explores our (dependent) relationship with the vegetal other (see Figure 5). The tension provided through the vector-frame that Mitchell suggests is effective but problematic in its ultimate ability to segregate, and elevate, science from society at large. As such, over the course of this thesis I create artworks that test the vector-frame and ultimately attempt to find a format that removes the glass, reduces the pedestal and (to expand Mitchell's analogy) spreads infection.

Figure 4: Maja Smrekar, 2014. *K-9 Topology: Ecce Canis*. Photo: Borut Peterlin. Reproduced by kind permission of Maja Smrekar.

Figure 5: Špela Petrič, 2015. *Skotopoesis, Confronting Vegetal Otherness*, Click Festival, Helsingor, Denmark, 2017. Photo: Miha Turšič. Reproduced by kind permission of Špela Petrič.

2.2 Practical and Ethical Engagement with Lively Material

It is not possible within the scope of this project to enter into a general discussion on the ethics of bioart[44]. Instead I focus on the practical and ethical parameters that frame the works that I have brought into a public context. Drawing upon the observations regarding exhibiting genetically modified organisms in the UK made by Howard Boland (Boland, 2013, pp. 194–204), I develop an approach to exhibiting lively genetically modified material that is first rooted in the material. The ethical parameters I encountered can be broadly grouped into human and nonhuman: issues of public safety, and safety for the organisms. Further, the ethical parameters are delineated by the choice of medium. There are no biotechnological ethics requirements for exhibiting organisms that exist naturally outside of the laboratory for example, or for exhibiting inert DNA. However there are considerations of public health and safety in bringing DNA and/or living material into an exhibition space. I have therefore developed a practical ethics for artworks that include inert plasmid DNA and for genetically modified *E. coli*, GM Level 1, the lively materials that I work with in this thesis, sub-categorised into human and nonhuman ethics.

2.2.1 Human Ethics

2.2.1.1 Plasmid DNA

Plasmid DNA is not a living organism, it is an inert chemical and does not fall within the UK Health and Safety Guidelines for contained use of genetically modified organisms (‘Health and Safety Executive’, 2014, p. 8). DNA after all, is everywhere; we ingest DNA every time we eat a salad[45]. Two projects by speculative designer, Charlotte Jarvis: *Blighted by Kenning* (Jarvis, 2012a) and *Music of the Spheres* (Jarvis, 2015) can be considered as a precedent in art practice, where in both cases, inert DNA was combined with objects that were then distributed amongst public audiences (sprayed onto an apple to be eaten and mixed with bubbles to be popped on the skin). Jarvis has published correspondence with scientists on her website, showing the extent to which *Blighted by Kenning* raised ethical questions, most notably in the earlier stages where she had hoped to infect an apple with a fungus (genetically modified to contain a passage from the

Declaration of Human Rights). During these exchanges, over the course of which, the proposed approach was changed to spraying DNA onto the surface of the apple, one correspondent points out that DNA is inert and very stable, 'it will stay on the surface of the apple for years', whilst another mentions that, 'there is a small chance that DNA that is ingested is taken up by either host cells (human gut cells) or by cells present in the digestive tract (micro organisms), which is part of a process called 'Horizontal Gene transfer"' (Jarvis, 2012b).

Synthetically developed DNA plasmids often carry specific genetic information, such as resistance to penicillin, therefore although there are no restrictions in taking the DNA out of the laboratory, one may feel a certain obligation to ensure that it is not ingested[46]. Microbiology artist, Anna Dumitriu is publicly exploring her intent to display 'wild antibiotic resistant plasmids' as part of a forthcoming project on ethics in art practice (Dumitriu, 2017). The plasmids that she intends to use are found in nature and therefore this enters into interesting ethical territory in examining whether these are more, or less, contentious than those designed within a laboratory. Given that Dumitriu's plasmids exist in nature, she raises the question of what, if any, public risk there is in isolating them and bringing them into the gallery. Ethical concerns may appear to be primarily focused on a risk to human health yet bringing lab-grown plasmids into the gallery raises non-anthropocentric ethical questions around responsibility for the integration of novel materials into the environment. In working with lively material on the nano-scale, we primarily concern ourselves with an ethics of the now, whereas our intra-actions in the present have a temporal and spatial resonance that should perhaps lead us to consider an ethics of the future to come[47].

As above, so below. There is a useful comparison between our technological investigations on the nano-scale and space exploration. Both are technologically embodied, impossible to access without prosthetic senses. Also in both, our sense of space (distance) is technologically embodied but not our sense of time. With astronomy-related research fields, our ability to act is limited by our physical bodies and thus we send technology to remote locations over deep time frames and monitor the results across generations of human subjects[48]. As individual subjects we cannot know the outcome of this kind of deep time research[49] but some of the intra-actions have already come to light in the shape of trash satellites orbiting (and even crash-landing on) the Earth (Taylor Redd, 2013). Similar consideration is now being afforded to our material intra-actions here on

Earth. Bonnie Basler's research for example (see Section 3.1.2) emphasizes the importance of intra-generational communication in microbial communities and I suggest that when we combine this with our own intra-species intra-actions we reach a kind of temporal, technological dis-embodiment, in that (just as we could not have foreseen the extent of our space trash) it is not possible for us to predict the consequences of our microbial intra-actions.

2.2.1.2 *E. coli*, GM activity class 1

The ethics surrounding public contact with live genetically modified organisms are relative, with legislation on safety requirements varying between countries[50]. The organisms that I have been working with in the laboratory, GM activity class 1 transgenic *E. coli* according to UK Health and Safety legislation, are available commercially in the United States, where such organisms are considered simply as biological media with a wide range of applications from the commercial *GloFish®* (Spectrum Brands, 2017), aquarium pets genetically modified with fluorescent proteins, to educational kits that allow school children to learn how to genetically modify bacteria, such as Amino Labs' *DNA Playground* (Amino Labs, 2017). In Europe, there are countries where genetically modified crops are grown within a blustery breeze of countries where genetically modified crops are banned and many countries that ban GM crops still allow the trade of genetically modified animal feed (Science Literacy Project, 2016). Regardless of the laws that we construct therefore, the gate is open and genetically modified material is available within the public sphere. As a planet, we are already consumers of genetically modified material and as such it is simply a question of time before genetic modification is normalized across society as a whole.

This is not a position that I am taking sides on, I simply state it how I see it. Now that *GloFish®* adorn children's bedside tables (and inevitably end up flushed down household toilets, or perhaps more ceremoniously buried in the garden) we have already entered cultural theorist, Villem Flusser's microbiological Disneyland future (Flusser, 1988, p. 9). It is with this in mind that I undertake to test the boundaries of what is acceptable within the UK. A GM activity class 1 organism is considered non-hazardous and thus ostensibly does no harm to the environment. The specific laboratory 'brand' of *E. coli* that I will modify are already genetic mutants, modified to die on contact with the world outside the

laboratory[51]. Despite this precaution, within the UK it is not possible to present genetically modified organisms in a public space, unless that space has been granted a licence to contain genetically modified material. Most of the 948 centres registered on the Genetically Modified Organisms Public Register in the UK (UK Health & Safety Executive, 2017) are university premises, research facilities, pharmaceutical companies or biotechnology companies. While a number of spaces within the UK have exhibited forms of bioart[52], and some scientific institutions may have facilities in which GM artworks could be exhibited, at the time of writing there are only two premises on the GMO Public Register in the UK that could be considered autonomous creative public-facing spaces: the London Biohackspace and, as of March 2017, ASCUS Lab in Edinburgh. Both are purpose-built laboratory spaces with public access. I worked with ASCUS to help them obtain their licence (making them the first public access venue of this kind in Scotland) specifically so that I could run a workshop that featured genetic modification. I am currently working with the Faculty of Health & Life Sciences at Northumbria University to extend their GM licence to a section of the art gallery facilities at Northumbria University. This extension of genetic media to the realm of art practice acts to lower the pedestal of scientific knowledge and thus challenges institutional approaches to genetic modification by enabling a situated discourse around ethics that expands the field to everything from anthropomorphic care for the organism to, as artist Adam Zaretsky suggests, the possibility of creative practice for genetic diversity and 'off-target, anti-enhancement' genetics (Zaretsky, 2017a).

2.2.2 Nonhuman Ethics

I have defined the following ethical principles as nonhuman ethics. Not because I aim to suggest an ethics for all non-living entities as well as living entities, but because in my work, I encompass entities that are not normally considered to be sentient, yet are nonetheless 'lively'. In my specific examples I am referring to DNA and micro-organisms, but it would be an interesting theoretical exercise to extend the notion to other potential forms of nonhuman sentience such as a synthetic cell or artificial intelligence[53]. Through practice-led research, I argue a case for the term sentience to be reconsidered as a 'way of knowing' that can be extended to the level of the micro-organism and therefore it is not much of a leap for those who choose to include non-sentient life in broader ethical

considerations (see for example Jane Bennett's discussions on the force of things and the agency of assemblages (Bennett, 2010, pp. 1–38)).

The safety of the organism may seem like an unusual consideration when referring to micro-organisms. Issues of safety for nonhuman subjects are generally tied to issues of sentience and whether it is believed that the subject is capable of 'having the awareness and cognitive ability necessary to have feelings' (Broom, 2016). Without exploring this topic at length, it is useful to summarise that the sentience of specific animals is a relatively unresearched topic in animal welfare (by way of example, a journal dedicated to the topic, *Animal Sentience* was first published in 2016); animal welfare is generally assessed according to principles of the Five Freedoms, Five Domains and/or Quality of Life[54] and recent research argues for the sentience of invertebrates. A useful summary of the field can be found in (Proctor, 2012). When descending to the lowly levels of the micro-organism, ethical considerations of sentience do not exist as we enter into the realm of the non-animal (non-living?) nonhuman.

The closest reference point to an ethics of sentience in the nonhuman is perhaps panpsychism[55]. A broad philosophical field with many branches, panpsychism is experiencing something of a revival particularly in consciousness studies, where for example neuroscientist and psychiatrist Giulio Tononi's idea of Integrated Information Theory suggests that consciousness is indicated by the amount of power that an object has over itself (Ghose, 2016). There are undoubtedly potential alignments between elements of panpsychism and an ethics of the nonhuman, which I begin to explore through my practice. I relate an ethics of the nonhuman specifically to the notion of the bioassemblage and propose that although lively material and lively bodies may not have a sentience found in current definitions of ethics, a broader relational ethics can be applied. Diann Bauer, artist and member of xenofeminist collective *Laboria Cuboniks* articulates a distinction between sentience, 'one that has awareness of their surroundings but not necessarily the capacity to reflect and deliberately act on it' and sapience, 'the human ability to use reason to both reflect and consciously act on our world and by extension to construct it' (Cuboniks, 2017). The awareness that Bauer describes I suggest encapsulates a way of knowing that may extend beyond human understanding. Bauer's assertion that sentience does not include the capacity to 'deliberately act' implies that the capacity to act does exist nonetheless. I describe DNA as lively material. Although inert, it has what philosopher Manuel DeLanda (referencing Deleuze, Spinoza and Leibniz) describes as capacity (DeLanda, 2011b); that

is, there is a capacity to act, and this capacity is always in relation to something. In this case there is a capacity within DNA to transform once within a living body.

Thus I argue that DNA is lively material, and in holding the capacity for transformation, DNA demonstrates an awareness (a capacity to act, although not necessarily reflect) that is articulated through the relation between the lively material and the living body. Given that DNA is incredibly robust and can exist in its inert state over an 'exceptionally long lifespan'[56] (Goldman *et al.*, 2013), such an awareness may not be apparent to humanity even within our lifetime, but the capacity exists and as such it must become part of a nonhuman ethics.

An ethics that encompasses awareness in the nonhuman can be extended from DNA to the organism more readily. The organism has awareness of its environment and the capacity to act within it. As I experienced whilst making *Oltramarino* (Mackenzie, 2013b), cyanobacteria exert their capacity to act by increasing production of pigment under conditions of stress (Brain and Caldwell, 2015). Not only does this capacity to act have a quality of relation between the organism and the environment, but also between the organism and other organisms, as identified in Bonnie Bassler's research on quorum sensing (Bassler, 2009). This capacity to act is also implied in the current crisis of antibiotic resistance, where through increased interaction with antibiotics, organisms develop a slow and gradual resistance (O'Neill (Chair), 2015). Thus, this extended relational quality can be viewed as a form of nonhuman sentience, an awareness that I read through my practice as a slow communication over deep time amongst a sentient community-being of cells. Given our inability to see the organism but yet our understanding that the organism is in the air around us, on our bodies and in our bodies (as microbial material and as vital cellular material), I propose an ethics of empathic performative relation that considers my actions upon living matter as an action upon myself.

[21] iGEM Foundation, BioBricks Foundation and Synbiobeta are founding organisations which largely generate the conference circuit around the field.
[22] See for example, (Department for Business Innovation & Skills and Willetts, 2013) and (The Synthetic Biology Project, 2010). Within the UK, The Flowers Consortium, comprising leading

international synthetic biology expertise from Imperial College, Cambridge, Edinburgh, Kings and Newcastle universities, aims to provide a UK infrastructure for this growing new economy, incorporating both biotechnological and ethical research. Current funding opportunities within the field in the UK can be found Synthetic Biology Special Interest Group funding web page, (Innovate UK, 2017).

[23] The Nuffield Council for Bioethics in the UK produced a report on emerging biotechnologies in 2012, advocating the need for a 'public ethics' around the subject (Nuffield Council of Bioethics, 2012) and in February 2015, the European Commission published Part II of a Preliminary Opinion on Synthetic Biology, focused on risk assessment and safety (The European Commission, 2014).

[24] In 2012, the UK's Technology Strategy Board published a 'Synthetic Biology Roadmap', based on the research of the UK Synthetic Biology Roadmap Coordination Group, a consortium of science, commercial and social science/ethics parties, which focused heavily on the responsible expansion of the field. At this point, public consultation, as stated in the report, amounted to focus groups of 160 individuals across the UK and 41 additional interviews with consumer groups (UK Synthetic Biology Roadmap Coordination Group, 2012). Press interest in the topic at that time (even currently) is limited to science journalism, see for example, (Shukman, 2012); (Shukman, 2013); (Thomas, 2014); (Sample, 2015) although with the advent of CRISPR-Cas9 technology, aspects of synthetic biology do manage to briefly punctuate mainstream news (see for example, Devlin, 2017).

[25] Architect and synthetic biologist, Dr Martyn Dade-Robertson, commenting during Synthetic Biology & Design Workshop at Edinburgh University's Genome Foundry, 12 July 2016.

[26] Kac coined the term 'transgenic art' in 1998 to define artworks that 'transfer synthetic genes to an organism or natural genetic material from one species to another' (Kac, 1998).

[27] This sense of agency was arguably first alluded to in an art context in 1936 through the anthropomorphism of Edward Steichen's cross-bred delphiniums in the press release issued by the Museum of Modern Art in New York, which stated, 'To avoid confusion, it should be noted that the actual delphiniums will be shown in the Museum — not paintings or photographs of them. It will be a "personal appearance" of the flowers themselves' (Museum Of Modern Art, 1936).

[28] Oron Catts and Ionat Zurr regularly exhibit live bioart and often conclude their exhibitions with a 'killing ritual' performance, where audience members contaminate (and potentially therefore kill) the artworks by touching them (Johung, 2014). Tissue Culture and Art's *Victimless Leather* (Catts and Zurr, 2004) grew to such an extent during it's exhibition at MOMA in 2008 (the living stem cell 'jacket' was beginning to fill the incubator that supported it, thus blocking the essential nutrients that it needed to grow; the arm was also beginning to fall off) that the show's curator, Paola Antonelli, took the decision to kill the work, stating that "it felt cruel when I turned it off". One might question whether it would have been more poetic to allow the 'jacket' to continue to grow and block its own life support, thus in effect, committing cell-suicide.

[29] I use signifier in the broader material-semiotic sense, as a form through which meaning can be implied, as opposed to the specific linguistic sense implied by Ferdinand de Saussure (Chandler, 2002, p. 16).

[30] In doing so, I adopt the materiality of the biological body to deliberately conflate 'cultural contagion', as outlined for example in Dan Sperber's *Explaining Culture* (Sperber, 1996) with biological forms of replication.

[31] For a concise analysis of the reinvention of the museum, see the Introduction to Gail Anderson's, Reinventing the Museum: 'The museum is no longer sacred or untouchable; rather, the museum is open to scrutiny… this examination … has facilitated a paradigm shift in the way museum professionals, and some members of the public, regard museums.' (Anderson, 2004, p. 1)

[32] Whilst names can provide focus, the broad term 'sci-art' is an unhelpful label that is overused to encompass all forms of relation between art and science, whether critically engaged or otherwise.

[33] Google the term bioart and although the text often supports the growing vitalist bioart field as described by Mitchell, the images are saturated with the kind of colourful petri-dish paintings inspired by arguably the first bioartist Alexander Fleming (Dunn, 2010). Beyond this now archetypal image, there is an emergence of works that claim the title bio art through the use of biological media, without necessarily engaging with the nature of the material in the artwork (see for example Laura Capuozzo's review of Thomas Feuerstein's Parliament, 2009 (Capuozzo, 2012)).

[34] https://www.loumackenzie.com/the-creators
[35] The organisms became desiccated and were disposed of throughout the exhibition as each microscope slide dried out. The death of the organisms is an explicit part of the work, directly referencing the death of the organism in the laboratory. This is something that I find difficult in my work, as I choose to deal with humanity's domination over other forms of life, hence I limit my working with life to the microbial for this reason. I have also considered pursuing research where I perform a 'resurrection' and attempt the revival of the desiccated organisms as, at the level of the single cell, it is not inconceivable that these organisms survive in a desiccated state after we have presumed them dead (or dead to our purposes) (Holzinger and Karsten, 2013).
[36] During the first year of the doctoral project, I identified a list of organisations that provide opportunities to bridge the gap between the life sciences (particularly biology) and art practice. I considered, then rejected including this as an appendix. It was far from comprehensive as, given the rapid (one might say, evolutionary) growth of the field, any such list once compiled can only offer a momentary snap shot of the breadth of interest in cross-disciplinary bioart activity. SymbioticA, the art laboratory and interdisciplinary research facility founded by Miranda Grounds, Stuart Bunt and Oron Catts at the University of Western Australia, provides a reasonably comprehensive list of current events and opportunities within bioart in their regular e-letter (SymbioticA, 2017).
[37] In interviews with Oron Catts, Eduardo Kac and Christian Bök, all confirmed both their deep engagement with science and at the same time their requirement for scientific support in making artworks see Appendix III for transcripts of interviews with artists, where available.
[38] By way of example, among current practitioners in the field, Špela Petrič is a Doctor of Biochemistry and Molecular Biology, Mary Tsang (also Mary Maggic) has a Bachelor of Biological Science and Art and a Masters in Media Arts and Sciences and Jaden Hastings has advanced degrees in Biology and Bioinformatics.
[39] For example, poet Christian Bök makes clear that he has spent many years developing his understanding of genetics and molecular biology (see interview in Appendix III, Viral Experiments, Interviews) and artist Paul Vanouse evidences his skill in working with DNA technologies through public performances and workshops (Vanouse, 2017).
[40] The term black box has its origins in cybernetic theory (Ashby, 1956, pp. 86–117). It is applied across a range of disciplines but can commonly be described as 'something that has an unknown internal system. Only the inputs and outputs are known' (Gibas, Pauknerová and Stella, 2011, p. 33). In reference to scientific practice, Bruno Latour defines blackboxing as a process by which, 'scientific and technical work is made invisible by its own success... the more science and technology succeed, the more opaque and obscure they become.' (Latour, 1999, p. 304).
[41] For a summary of the field, biohack.me is a good source.
[42] Adam Zaretsky, Marta De Menezes, Špela Petrič and Mary Tsang frequently use participation or interaction as a means to engage audiences.
[43] In 1965, Gordon Earl Moore, co-founder of Intel, devised a general theorem, applied to technology, which states that the number of components within computer chips doubles each year (he later revised this to every two years). Similar rates of exponential growth are witnessed in the technologies of genetic science, evidenced in particular through the Carlson Curve. First attributed to Dr Robert Carlson in *The Economist* in 2006, the Carlson Curve describes the cost of sequencing the human genome, which began at over $1billion in 2003, sits at around $1000 in 2017 and is estimated to be as low as $100 in the years ahead as biotech companies vie to offer this as a service to the public (Humphries, 2010; Denning and Lewis, 2017; Herper, 2017).
[44] The ethics of bioart would constitute an entire thesis in itself and for this reason I have chosen to focus specifically on a practical ethics surrounding the lively material in my artworks. Various discussions on the ethics of bioart (and it's instrumental medium, synthetic biology) can be found in, for example (Catts and Zurr, 2003); (Triscott, 2012); (Dumitriu and Farsides, 2014); (Calvert, 2013); (Ginsberg et al., 2014) and more recently a paper by Nora Vaage, which begins to explore the convergeance of bioethics and broader ethical discourses from the field of aesthetics (Vaage, 2016).
[45] I was reminded of this fact by Dr Luciano Saieva, a colleague at the Institute of Genetic Medicine, when discussing the possibilities for transferal or absorption of DNA between species.
[46] Although, arguably, when we consider the amount of antibiotics given in feed to farm animals that humans then consume (O'Neill (Chair), 2015), presenting plasmid DNA for visual display comes

low on the list of health concerns. This does not mean that the risk should not be fully considered, however.

[47] I use philosopher, Jacques Derrida's concept of *l'avenir*, the 'future to come' as signifier of a future that we can never fully comprehend (Dick and Ziering Kofman, 2002).

[48] NASA's Voyager mission launched two spacecraft in 1977 on a mission expected to last five years. Harnessing their power from nuclear technology that converts heat produced from the radioactive decay of plutonium into electricity, the spacecraft have outlived initial performance expectations and information on NASA's website suggests that the spacecraft may keep returning data for another 20-30 years (*Voyager - Fact Sheet*, 2017).

[49] The concept of deep time originated with geologist, James Hutton who, from studies of the unusual angular rock formations in South East Scotland, proposed that the Earth was greater than 6000 years old. The phrase 'deep time' originates with John McPhee who used it to describe the almost sublime difficulty in comprehending the expansive realms of time (periods of hundreds of thousands of years) encountered in geology (Montgomery, 2003; Thompson, 2014). As increasing use of the term anthropocene (see for example (Stromberg, 2013)) enables us to focus on humanity's specific place in the wider nonhuman story of the world therefore, deep time can be a useful concept in considering the future as well as the past.

[50] The primary global agreements with regards to biosafety are the Cartagena Protocol (The Secretariat of the Convention on Biological Diversity, 2000) and the World Trade Organisation's Agreement on the Application of Sanitary and Phytosanitary measures, or SPS Agreement (World Trade Organisation, 2017).

[51] The safety data sheet for the E. coli 'brand' Top-10 classes the 'product' as non-hazardous (Thermo Fisher Scientific, 2017).

[52] For example, GV Art, Arts Catalyst, the Global Science Gallery Network (founded in Dublin), BOM in Birmingham and FACT in Liverpool have all exhibited bioart works (FACT (Foundation for Art and Creative Technology), 2008; GV Art London, 2013; Arts Catalyst, 2017; BOM, 2017; Science Gallery International, 2017).

[53] There are potentially interesting links to be drawn from a comparison of living and non-living ethics. Nick Bostrom and Eliezer Yudkowsky, in exploring the ethics of Artificial Intelligence (Bostrom and Yodkowsky, 2014, p. 325) discuss a subjective experience of time that could be usefully compared to lively material as a theoretical exercise beyond the scope of this project.

[54] The Five Freedoms as defined by the Farm Animal Welfare Council in 1993 are: "Freedom from thirst, hunger and malnutrition – By ready access to a diet to maintain full health and vigour , Freedom from thermal and physical discomfort – By providing a suitable environment including shelter and a comfortable resting area , Freedom from pain, injury and disease – By prevention or rapid diagnosis and treatment , Freedom from fear and distress – By providing sufficient space, proper facilities and the company of the animal's own kind , Freedom to express normal behaviour – By ensuring conditions which avoid mental suffering". The Five Domain model is significantly more complex, encompassing inputs and outputs that in combination lead to a total of 15 negative and 13 positive affects and the Quality of Life model, "recognises that animals have both positive and negative experiences and focuses on the balance between the two" (Webster, 2016)

[55] Panpsychism is a philosophical view that considers consciousness to be a universal property of all objects, animate or inanimate. It has roots in Stoicism, Taoism and Buddhism.

[56] Use of the word, 'life' is often flexible. Note that the word lifespan is used to pertain to matter that is not considered alive, but that perhaps demonstrates liveliness, just as, for example, radio-active matter has a 'half-life' (Creighton, 2015).

3 MOIST MATERIALS, DRY CODES

In the first year of the doctoral project, I began a research website and explored different approaches to being with life that oriented the project around methods of relating to evolution, material and the genetic code. As a result I produced a series of experimental works made in response to my theoretical explorations of synthetic biology, genetics and evolution and to my attendance at workshops and residencies that connected practically with these themes. All works are documented in Appendix III, Viral Experiments[57]. In this chapter, I have chosen to focus on pivotal works that shaped my later thinking as work in the laboratory developed.

3.1 Early Encounters with Lively Materials

3.1.1 Performing with Lively Material

Before working in the laboratory, my practical engagement began by relating to evolution through material, considering ways in which I could instigate a process and allow it to unfold over time. An invitation to exhibit work for *Paper, Table, Wall and After* at the National University of Arts, Taiwan (Dorsett and Bowen, 2015) in the shape of a folded map prompted me to consider humanity's attempts to chart and control the process of evolution. I made two works, one that contained my microbiome (in the form of my spit) and one that did not. In *Unknown Territory* (Mackenzie, 2015e)[58], I evoke the Miller-Urey experiment (Miller, 1953)[59]. I combined pigment from three materials (carbon, copper and the micro-algae, spirulina[60]) with salt water to make three individual drawings that were folded together and placed in a salt-water bath, through which an electric current was passed[61]. I felt somehow cheated by the addition of wires and a battery, distancing myself from the work. The current did not lead to any Frankenstein moments (yet[62]) but enabled the generation of three unique images that were left to dry in their folded state.

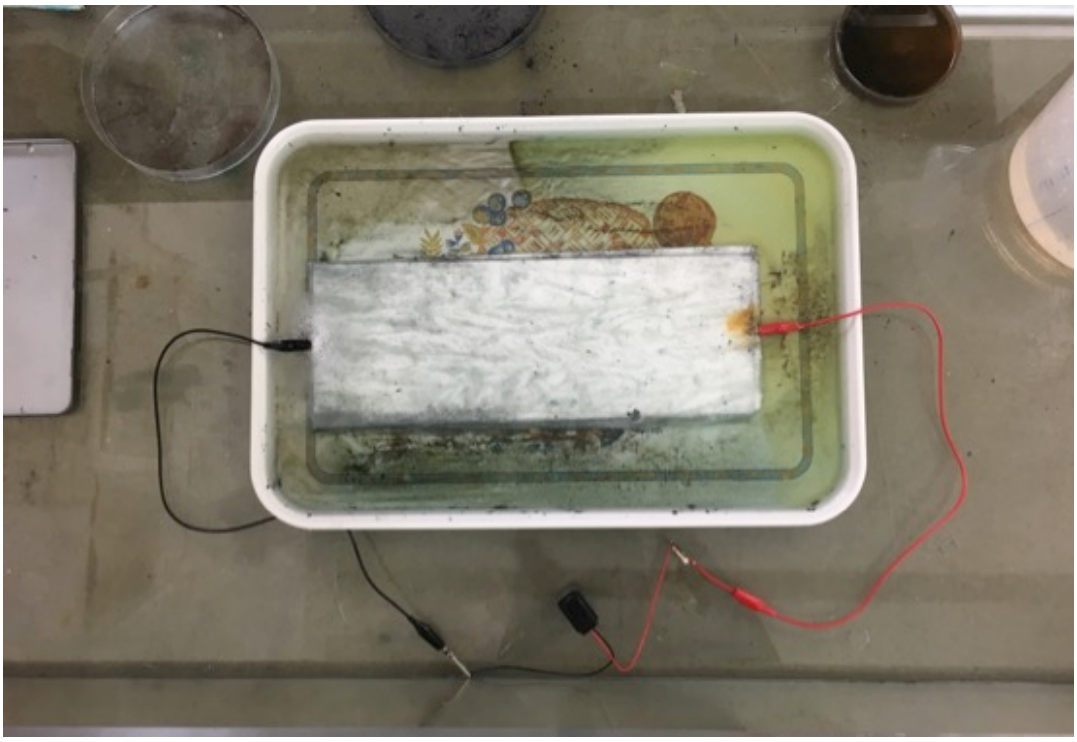


Figure 6: *Unknown Territory*. Research documentation, 2015. Photo: Louise Mackenzie

For the work, *Combined Knowledge, Unknown Territory* (Mackenzie, 2015a)[63], I performed to camera in my studio the act of communicating with the organism. I mixed powdered forms of carbon, copper and the pigment derived from spirulina (phycocyanin) with my spit (my extended microbial DNA) and drew the form of a phage[64] onto Japanese Tosa Washi paper[65]. In the head of the phage on each drawing, I wrote my thoughts, securing the text in the manner that a phage holds DNA ready to impart into another body. The resulting three drawings were first chewed and regurgitated individually before being combined in my mouth and regurgitated together as a folded map that was then hermetically sealed, containing the materials and also hastening the evolutionary process by trapping moisture. The process is documented as a studio-based experiment in an unedited, single channel video. The performative exercise becomes the first iteration of relating to the organism that is repeated at the core of this project (see Chapter 5).

Instructions for the work are that the map, which continues to change form over time, is to be displayed in its concealed form, visible only through the hermetically sealed plastic[66]. The unknown territory of the map is constantly changing and thus can never be fully revealed.

Figure 7: Louise Mackenzie, 2015. *Unknown Territory*. Graphite, Copper, Phycocyanin, Japanese Tosa Washi paper, Salt Water, Electric Current. 3 drawings, each 42cm x 60cm. Photo: Louise Mackenzie

Figure 8: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory*. Video still. Image: Louise Mackenzie

Figure 9: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory.* Video still. Image: Louise Mackenzie

Figure 10: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory*. Photo: Louise Mackenzie

Figure 11: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory.* Photo: Louise Mackenzie

3.1.2 Observing Communication in Lively Material

After expressing an interest in communicating with microbes, I was invited to attend the *Microbes as Material* workshop run by microbiologists Dr Rod Dillon and Dr Jackie Parry of Lancaster University in collaboration with Abandon Normal Devices (ANDFestival, 2015)[67]. We were introduced to the research of molecular biologist, Bonnie Bassler, whose TED talk (Bassler, 2009)[68] suggests a potential alternative to antibiotics through appropriation of bacteria's signalling mechanisms. Bassler's research has implications beyond the instrumental, allowing speculation on how the phenomenon of social communication develops in non-sentient organisms. We were supplied with a range of bacteria that 'communicate' via quorum-sensing: 'talking' and/or 'listening' to each other through chemical signals, depending upon their density and proximity to other bacteria. I attempted to mirror human social infrastructures to explore whether the bacteria could communicate between levels and across spaces. Thinking about images of tenement flats in my Scottish home, where clothes-lines once weaved between flats and conversations flowed as the laundry was hung, I created sculptural tower-blocks[69]. Over time, the bacterial communities spread down and across, showing evidence of uncontainable mixing and sharing messages beyond the confines of their original dwellings.

Following on from this workshop, I was invited to join AND Festival 2015's *Night of the Living Deadwood* workshop in Grizedale Forest, Cumbria (Dillon and Parry, 2015)[70]. During dancer and performer, Rita Marcalo's improvised group exercise: *Microscope of the Mind*, I started to sense that our methods of understanding the organism are distorted through the primacy of a visual lens. Marcalo's exercise, adapted from dance and sports training as a way to visualise and heal injury, led us into ourselves, sensing parts of our body from within. The experience of sensing my breath, organs, limbs and digits was powerful, yet when Marcalo suggested visualising microbial life within us, as if through a microscope, the experience failed for me because the connection (for me at least) is not *visual*. It is more palpable, somehow bodily. I return to this sensation in Chapter 4, where I create scenarios that look to expand upon the visual sense.

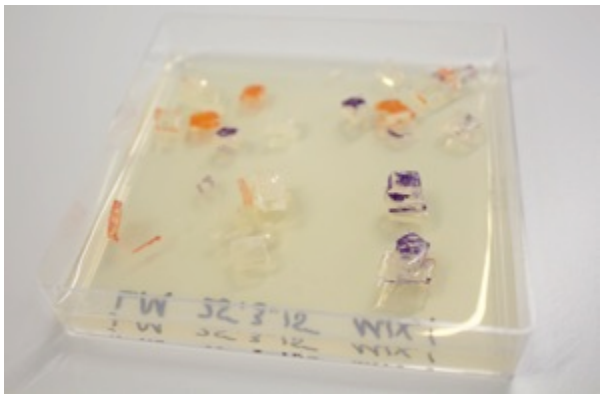


Figure 12: Day 1, Microbes as Material Workshop, ANDFestival and Lancaster University. Research documentation, 2015. Photo: Louise Mackenzie

Figure 13: Day 2, Microbes as Material Workshop, ANDFestival and Lancaster University. Research documentation, 2015. Photo: Louise Mackenzie

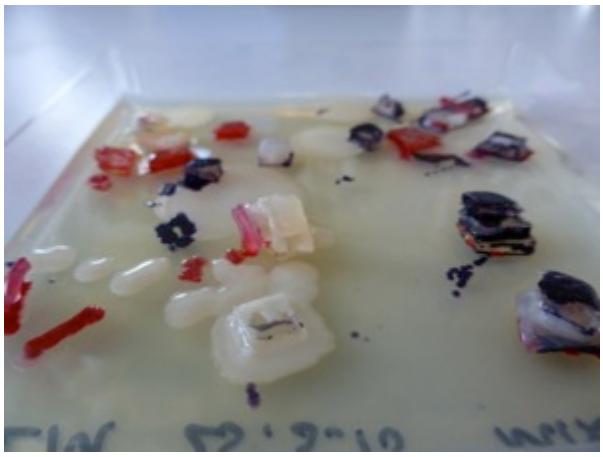


Figure 14: Day 5, Microbes as Material Workshop, ANDFestival and Lancaster University. Photo reproduced with permission of Microbes as Material.

3.2 Endlessly Unravelling Code

The genetic code is often described as 'the language of life'[71]. This phrase has been instrumental in the development of the Human Genome Project and the vast bio-databanks that exist worldwide[72]. Through the Human Genome Project and multiple spin-off ventures[73], science attempts to define all living organisms at the level of our genetic information, so that we can better understand and use this information for the benefit of humanity.

The genetic code describes how the sequence of base pairs in DNA relates to the sequence of amino acids in proteins that we find within organic matter. It is described as a cypher that enables DNA to be read as a set of instructions. This coding metaphor, arguably derived from the work of Francis Crick and James Watson (Crick and Watson, 1953)[74] leads to a denotative semiotic understanding of biology, in which basic units within DNA become the minimal functional units or 'figurae' (Hjelmslev, 1961, p. 41) in an articulated system of meaning (Enguix and Dolores Jiménez-López, 2012).

3.2.1 Using My Head

Lab Diary, 12 September 2016:

I want to find the sequence for the protein keratin. It's found in hair. My hair has grown a lot since I started this thesis. In fact, I won't cut it. It's as if all the knowledge that I have accumulated is writ large right there: a visual record of everything that I have taken into my head.

The four nucleic acid base pairs found in DNA and RNA form triplets, known as codons, which combine in turn to represent the different amino acids that form proteins found in the human body. Amino acids are transcribed (copied) and then translated into proteins through a series of processes that take place within a living cell. As there are four base pairs: Adenine, Cytosine, Guanine and Thymine (or Uracil in the case of RNA), there are 4^3 possible combinations of codons (Figure 15).

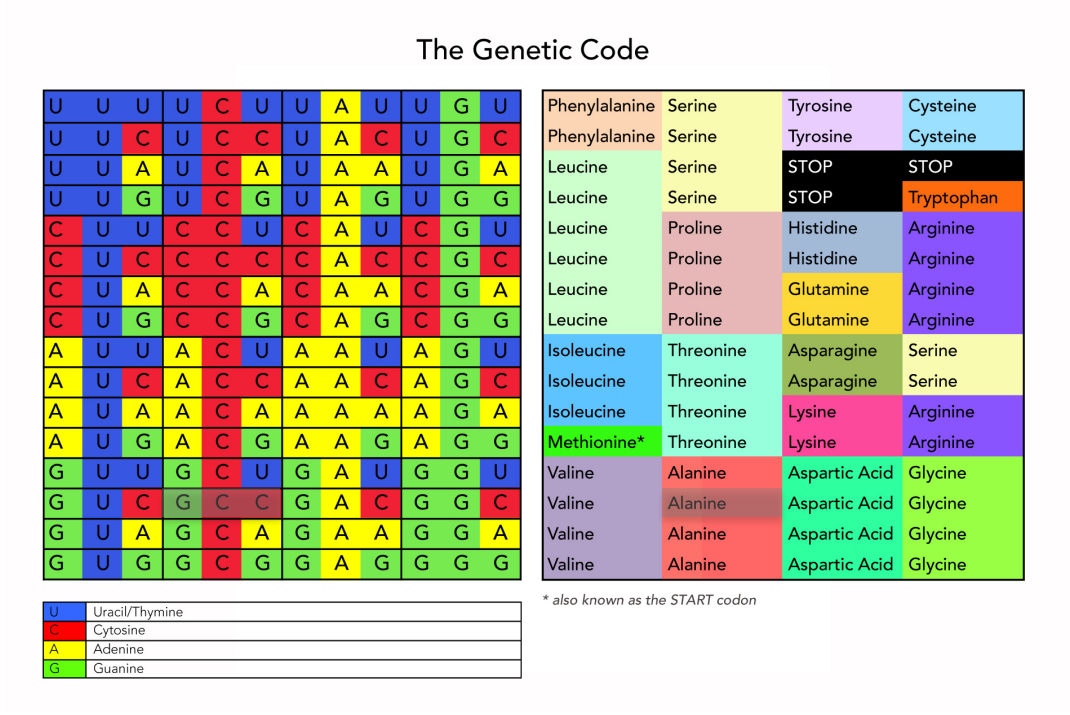


Figure 15: Representation of the Genetic Code. Research documentation, 2015. Image: Louise Mackenzie

A string of DNA may contain within it the following bases (represented as codons within the left-hand table. The first codon in the below sequence, GCC, is shaded):

GCC AGG TGC AGC TGG GGT GTG AGT GTG

This would translate into the corresponding amino acids (highlighted in the same position on the right-hand table in Figure 15).

Alanine – Arginine – Cysteine – Serine – Tryptophan – Glycine – Valine – Serine – Valine

The above sequence of amino acids happens to form a very small component of the genetic sequence for the human protein, *Keratin 18*. Keratin is described as a filament-forming protein necessary for structures such as hair and nails in humans (Schweizer *et al.*, 2006, pp. 169–174). I searched the database of the National Centre for Biotechnology Information to find a protein DNA sequence for keratin and after narrowing the search to 'homo sapiens keratin 18', I found 1482 examples (NCBI Nucleotide Database, 2017). Therefore, whilst it is possible to match genetic information to proteins, the range of

possible outcomes appears to be as varied as the colour, length and thickness of the individual hairs on my head.

3.2.2 Playing with Language

Genetics has become inextricably entangled with linguistics and information theory, influenced - in cultural memory at least - by the introduction of the term 'The Central Dogma' by Francis Crick in 1958 to illustrate his speculations on the flow of genetic information within the body (Crick, 1958)[75]. Drawing from the rise of information theory in the 1950's, linguist Roman Jakobson initially developed a mathematical approach to linguistics that he later applied to biology, describing DNA or 'genetic information' as an inscription 'in the chromosomes...exactly like in a phrase in a text' (Lily E Kay, 2000, p. 307). Semiotician, Ferdinand de Saussure distinguishes between *langue* as a system of language and *parole* as its utterance (Saussure *et al.*, 1986, pp. xli–xliv). Using Saussure's terms, the genetic code is *langue*: the system, as opposed to *parole*: the individual conversations spoken by the body on a day-to-day basis.

Mirroring Crick's earlier determination to mark out a genetic code, in contemporary synthetic biology, there is a race to develop a universal biological coding language, with a standard syntax and grammar, to aid the design and build of novel biological organisms[76]. Thus from the development of speculative language systems, there is a desire to produce specific physical forms with clearly defined functions. Science historian, Lily E. Kay challenges the foundations of such genetic-linguistic comparison as a Derridean catachresis – a double metaphor that problematizes the concept of a closed system and instead layers interpretation of meaning[77]. In marking out a *langue* for DNA, I sense Derrida's *trace* in the remaining spaces (and materials) within the body. Philosophers Michel Foucault, Manuel DeLanda, author, William Burroughs and composer, Alvin Lucier (among others) instead begin from an expansive reading of life processes that align more closely with the slippage of meaning found in the writing of Derrida, introducing chance and doubt to allow for multiple readings in ways that the overarching doctrine of Crick's central dogma cannot. It is this more expansive approach that inspired me to ask, *Can playing with language extend ways of relating to genetic material?*

In *The Order of Things*, Foucault begins the Preface with an excerpt from a Chinese Encyclopaedia in Borges' *The Analytical Language of John Wilkins* that contains categories so far from our common taxonomical understandings of the world that they force us to reconsider the very idea of a system of thought (Foucault, 2005). Both psychologist, Steven Pinker and artist and philosopher, Manuel DeLanda have argued that the institutionalisation of language (that is, our propensity to impose a correct definition of words) acts to stultify (Pinker, 2005; DeLanda, 2011a). Pinker uses the example of the French National Academy of Language, which insists that the French term for the 'World Wide Web' is the arcane, 'la toile d'araignée mondial' (Pinker, 2005). Thus the structuring and codifying of information via semantics, syntax and grammar, whilst serving a useful purpose in understanding systems of communication, acts to 'map the territory' (Korzybski, 1958, p. xvii). This act however defers the real, rather than dynamically interacting in the landscape.

3.2.2.1 Viral Virus

William Burroughs and the Dada poets approach the abstraction of language unencumbered by scientific mapping strategies. Burroughs speculates that 'the word is …a virus' (Burroughs, 2005, p. 5). Language is viewed literally as a virus that infected our pre-lingual ancestors, and thus as theorist, Christopher Land, points out, the human is read as 'a symbiotic relationship of body and word-virus' (Land, 2005, p. 450). Imagining the genetic code as language, I began to experiment with text using Burroughs' and fellow artist Brion Gysin's cut-up method[78] and other strategies for working with language in abstraction.

Viral Virus (Mackenzie, 2015f)[79] uses the principle of the 'pass on the whisper' game to play with the deferral of meaning through translation. Using *Google Translate*, I began with the word 'viral' in English and then worked systematically to translate this word through every language, in the order given. With each language, I translated back into English to determine if the meaning offered by *Google Translate* had changed. At every point where the meaning changed, I captured this as a line of different (Google) coloured text for my viral poem, thus:

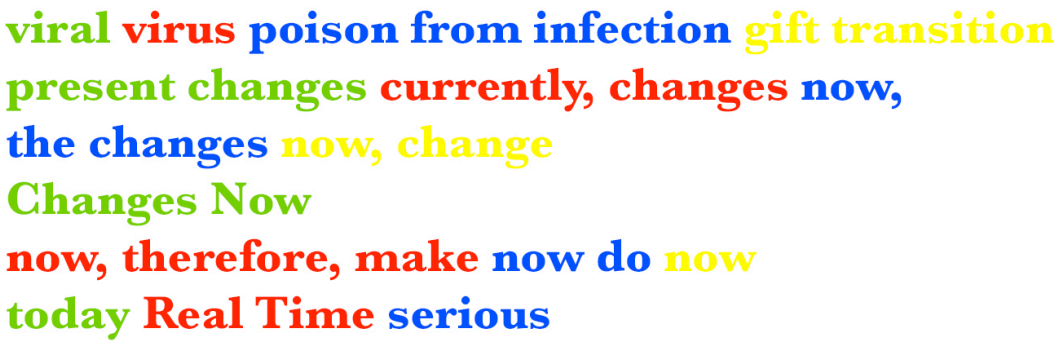


Figure 16: Louise Mackenzie (2015), *viral virus*. GIF. Image: Louise Mackenzie

3.2.2.2 Ouroboros

Ouroboros (Mackenzie, 2016a)[80] takes its inspiration from the DNA plasmid. The plasmid is described as a circular piece of DNA that floats freely, and thus has the capacity to move, twist and fold, within the body of the bacterial cell. The plasmid is not a circle. That is an abstract form. The plasmid is a continuous section of DNA. One can imagine that the plasmid may take on a variety of forms as it changes position within the cell body, or perhaps it does not move at all, but this is unlikely given that no two images of plasmid DNA I have found look the same (see Figure 34).

Ouroboros originates from the Greek, oura – 'tail' and boros – 'eating'. The symbol of a dragon or serpent eating its own tail is ubiquitous throughout world history. Found in texts and imagery as far back as 3000 years ago, the ouroboros has been noted in ancient Egyptian, Greek, Norse and Hindu cultures. One of the earliest depictions is found in the Enigmatic Book of the Netherworld found at Tutankhamun's tomb (Hornung and Lorton, 1999). Plato's character, Timaeus describes the cosmos in the manner of a circular creation that eats its own waste[81] and the symbol of the ouroboros has frequently been associated with alchemy since appearing in *The Chrysopoeia of Cleopatra* (Beyer, 2017).

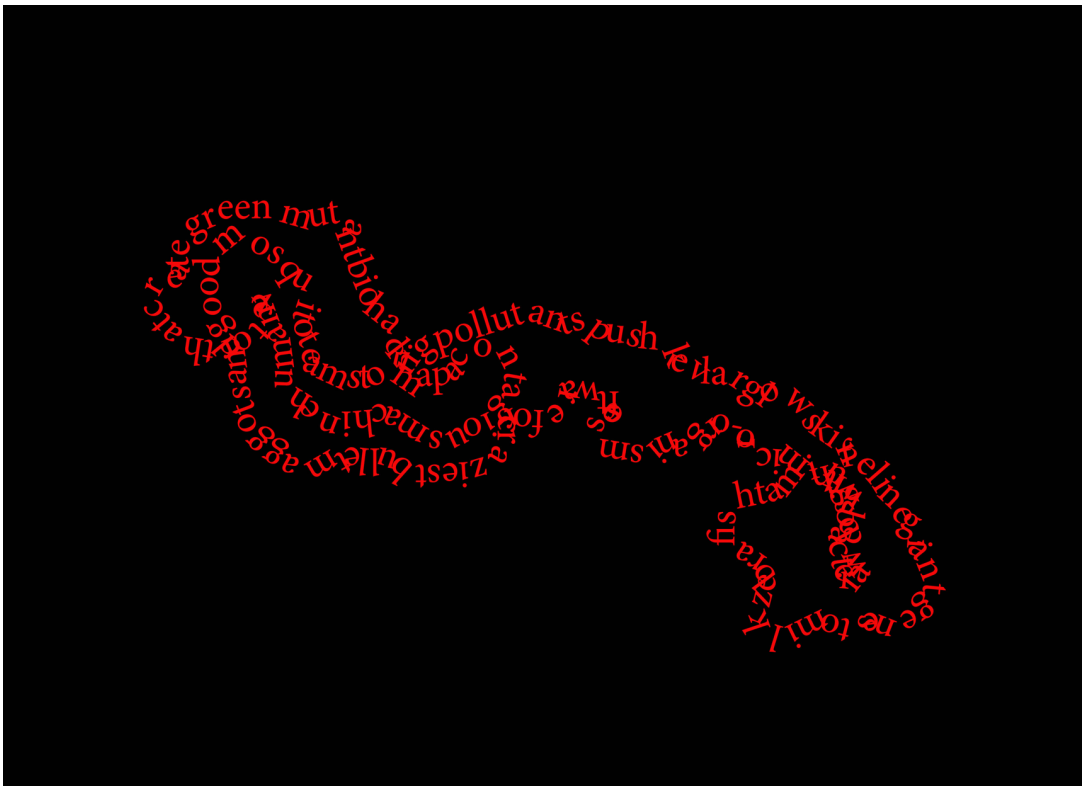


Figure 17: Louise Mackenzie, 2016. *Ouroboros*. GIF. Image: Louise Mackenzie

Ouroboros was created as a GIF so that motion of the plasmid is suggested. It is comprised of appropriated text, cut and pasted from biotechnology headlines. I deliberately acted quickly; not overthinking which words went where in the circle. The text has no start or end and as such, can be read as a poem beginning at any point and ending at any point, or read continually and indefinitely. One possible reading is:

push kevlar
glow skin feline giant
genes to milk zebrafish
taming bacteria webs
with micro-organisms
software
for craziest bullet
maggots
and good
mosquito teams
to map
a contagious machine
human vector
that create
green mutant
biohacking pollutants

I like the form this reading takes; perhaps it is an organ or a body part.

[57] *Viral Experiments* is the title of my research-based website, referenced in Appendix III (http://www.viralexperiments.co)
[58] http://www.viralexperiments.co/unknown-territory

[59] Chemists, Stanley Miller and Harold Urey showed that it was possible to form complex chemical compounds through a combination of base elements with electricity in an attempt to simulate the conditions that began life on earth. This work was recreated in a gallery context by Adam Brown and Robert Root-Bernstein, in Brown's ongoing work, *Origins of Life* (Brown, 2010).
[60] Carbon, spirulina and copper (all recurring materials in my work) were used to signify life, the sublime and technology respectively.
[61] Experimenting in this way tested my chemical as well as biological knowledge. This type of experiment should only be undertaken after appropriate guidance and in a well-ventilated room with the proper safety equipment. The procedure releases small bubbles of gas: most likely very small amounts of chlorine, but with the addition of the other materials in the drawing, it is possible that other gases were produced.
[62] My instinct is that monsters are created slowly, over a timespan that is difficult for humanity to comprehend.
[63] http://www.viralexperiments.co/combined-knowledge
[64] I introduce the figure of the phage to signify the human as parasite.
[65] Tosa Washi paper is a durable, yet incredibly fine paper, traditionally hand-made from water and kozo, the paper mulberry tree, using a technique that dates back over 1000 years. The woven fibres in the paper mean that it is incredibly durable, even when wet, this combined with its organic and ancient origins made it an ideal choice for a durational experimental work of this nature. The work itself may prove more durable than the lab plastic that it is hermetically sealed within.
[66] Both works were offered for exhibition, but as the work was travelling to Taiwan as part of a group exhibition, there were no customs dispensations for work that included bio-material. Thus Combined Knowledge, Unknown Territory was deemed unsuitable for transport. Given that the only known bio-material in the work was my spit (a common element in many an artwork, whether declared or not) the decision not to show the work stemmed instead from its visible containment, within a sealed plastic bag. A first indication of the tension presented by the 'behind glass' frame.
[67] https://www.andfestival.org.uk/blog/announcing-participants-microbes-as-material-workshop/
[68] https://www.ted.com/talks/bonnie_bassler_on_how_bacteria_communicate?language=en
[69] To be more visually accurate, I constructed something akin to a shanty-town or favella: the technicalities of constructing agar gel towers were not to be mastered in the space of an hour.
[70] The *Night of the Living Deadwood* workshop invited artists and scientists to collaborate on the theme of dynamic decomposition during AND Festival 2015. The workshop was led by microbiologists Dr Rod Dillon and Dr Jackie Parry, based at Lancaster University and formed part of an ongoing collaboration with Abandon Normal Devices to explore current concepts in the biological and biomedical sciences (https://www.andfestival.org.uk/events/night-of-the-living-deadwood/).
[71] The 'language of life', the 'code of life' or the 'genetic code' are phrases often attributed to DNA and elements of its structure. Such terminology can, in part at least, be traced to Dr. Francis Collins, head of the Human Genome Project for 15 years, whose 2010 book, *The Language of Life: DNA and the Revolution in Personalised Medicine* was hailed by then President of the United States of America, Barack Obama as, "groundbreaking work [which] has changed the very ways we consider our health and examine disease". Collins also wrote a more personal reflection on his work in 2007, titled *The Language of God: A Scientist Presents Evidence for Belief* (Collins, 2007, 2010).
[72] Institutions such as the European Bioinformatics Institute in Cambridge store the growing mass of genomic data currently being captured for all species (and differences within species as described taxonomically) of life on earth (EMBL-EBI, 2017)
[73] As well as the Human Genome Project, there are projects to map the genome of a variety of animal species, the human microbiome (that is, the microbial life that exists on and within the human body), extinct species of animal and even Neanderthals (Federation of American Societies for Experimental Biology, 2013; Palkopoulou *et al.*, 2015; Paabo, 2017). Most significantly, as well as attempts to map, there are also plans to *synthesise* the (capitalized, declarative) Human Genome (Endy and Zoloth, 2016).
[74] See Appendix II, A Genetic Story, for a brief version of events leading to the commonly understood definition of the genetic code.

[75] See Appendix II for a brief digression into the history of genetic code and the concept of the central dogma.
[76] UK based synthetic biologist, Matthew Pocock, is part of a group of researchers working on this project (Myers *et al.*, 2015). In conversation, we discussed his plans to arrange a workshop to discuss the need for symbols to represent specific elements of biological language and the perceived importance of artistic engagement in this process.
[77] I am particularly grateful to Ionat Zurr for drawing my attention Lily E. Kay's, *Who Wrote the Book of Life?* (Lily E Kay, 2000), which gives a thorough and insightful account of the relationship between genetics and semiotics and demands further reflection beyond the scope of this thesis.
[78] Gysin is commonly credited with the cut-up technique although it is found earlier, for example in Dadaist poet, Tristan Zsara's *To Make a Dadaist Poem* (Tzara, 1920).
[79] http://www.viralexperiments.co/viral-translation-poetry
[80] http://www.viralexperiments.co/ouroboros
[81] 'The living being had no need of eyes because there was nothing outside of him to be seen; nor of ears because there was nothing to be heard; and there was no surrounding atmosphere to be breathed; nor would there have been any use of organs by the help of which he might receive his food or get rid of what he had already digested, since there was nothing which went from him or came into him: for there was nothing beside him. Of design he created thus; his own waste providing his own food, and all that he did or suffered taking place in and by himself […] and he was made to move in the same manner and on the same spot, within his own limits revolving in a circle.' (Plato, circa 360BC)

4 TECHNOLOGICALLY EMBODIED RELATIONS

> Scientific activity is not "about nature," it is a fierce fight to construct reality. The laboratory is the workplace and the set of productive forces, which makes construction possible. (Latour and Woolgar, 1979, p. 243)

My initial engagement with the laboratory embraced biotechnology as a means to help me find a closer relation to the organism, through asking, *Can technology be used to develop an embodied experience of the organism?* Conversely, I found myself becoming further removed from it.

Bruno Latour's account of 17th century natural philosopher Robert Boyle is our first encounter with the laboratory as a space of construction. Through Boyle's experiments with vacuum pumps, the laboratory becomes a site for the construction of facts through the undertaking of observable experiments in an artificial environment (Latour, 1993, p. 18). This artificiality of space (the sterile laboratory) is one construction upon which I will set another layer of construction: the artificiality of the apparatus. Thus there is the construction of a space within which the object must be observed and then there is the construction of the apparatus with which to observe the object: glass dome (in Boyle's case), microscope, telescope and so forth.

Whereas the construction of the space is a means to reduce the object of study, the construction of the apparatus acts to enhance the subject undertaking the study. It is a technological embodiment; a means to enable us to do (or be) more than we were previously capable of. Within this chapter, I explore two attempts to relate to the organism through technological embodiment as presented within the constructed space of the laboratory: technology as extension of perception and technology as construction of language. In working with technological extensions of perception, I develop a theory of technological layering that is based upon the incremental choices that I make whilst using technology in my attempts to perceive the organism, which have the effect of limiting my perspective in a particular direction and I define the generation of alternative perceptions as alchemical sensing. In exploring technology as construction of language, I try (and fail) to find a way to relate to the genetic code, realizing ultimately that it is an abstract construction, which I can only translate through constructions of my own.

4.1 Extending Perception Through Technology

> 'Contemporary science is experienced as embodied in and through instruments. Instruments are the "body" that extends and transforms the perceptions of the users of the instruments.' (Ihde, 2007, p. 5)

4.1.1 Extending Visual Perception

Before undertaking this thesis I had viewed the micro-algae, *Dunaliella salina* under the microscope[82]. I was researching cyanobacteria and other micro-algae to understand how they are used as scientific resource, leading to the exhibition and publication, *Oltramarino* (Mackenzie, 2013c)[83]. I worked with scientists from Newcastle University's School of Marine Science and Technology (MaST), where micro-algae are studied for their potential commercial uses within the health and pharmaceutical industries[84]. I was struck by their celestial resemblance and, having discussed this with scientist colleagues[85], was surprised to learn that they are rarely viewed in this way. Instead, visual information is generally taken at a higher resolution, or from more powerful microscopes that transfer data reflected from lasers directly to computer screens. Interest tends to be focused on the genetic structure of the organism itself and the mechanics of the cell and flagella (the tail like structure with which the organism 'swims').

This shift of context opened up possibilities in thinking about how scientific information is interpreted and whether one perspective is necessarily more accurate than another. The visual referent, constructed through the microscopic gaze, of the motile *Dunaliella salina* had the same effect as looking towards a night sky filled with twinkling stars. The movement of multitudes of organisms at this resolution was technologically sublime. Here were living organisms that I could only see aided by technology, so small that I had no direct comprehension of them (nor they of me, I imagine) and yet through the microscope I could experience them as alive. Bio artist, Marta De Menezes draws attention to Nigel Thrift's work on representational theory to reference our fascination with movement as something that is potentially 'hardwired into our brains' (High *et al.*, 2017, p. 53). I align this with Rosi Braidotti's vital materialist account of nomadic affectivity, in which she affirms 'the intelligence and mobility of matter' (Braidotti, 2005). The sensation of movement in the organisms had an almost palpable connection to my own experience of

being alive and yet at the same time their invisibility without technological intervention also rendered them alien to me. I wanted to further enhance my experience of them and I began to investigate ways in which to do so.

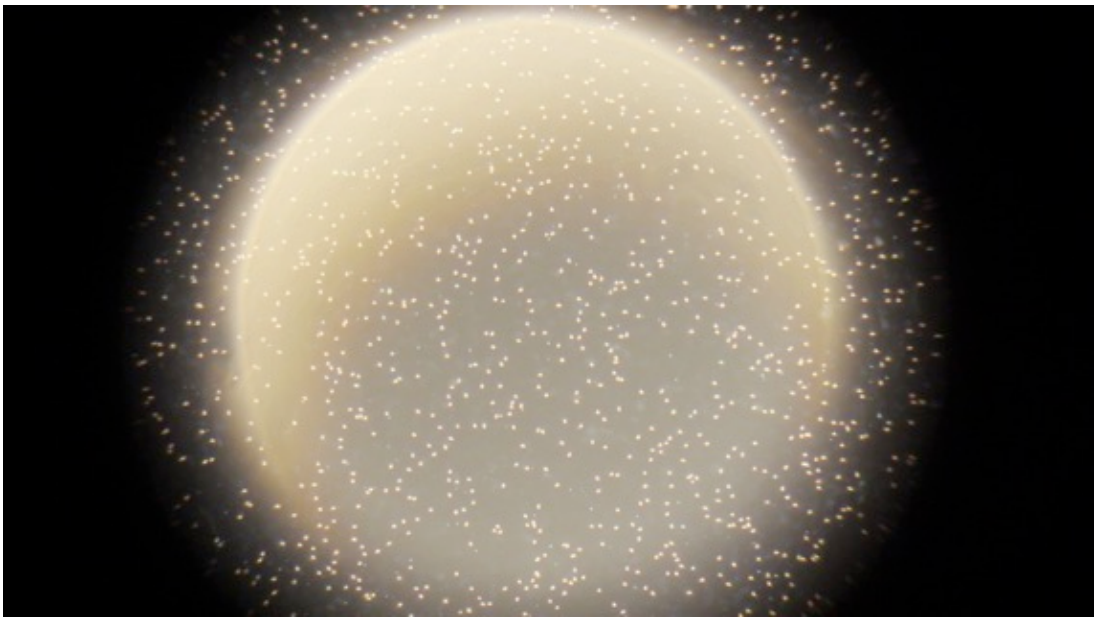


Figure 18: *Dunaliella salina*. Video still. Research documentation, 2013. Image: Louise Mackenzie

For the installation, *The Stars Beneath Our Feet* (Mackenzie, 2015d)[86], I wanted to create an environment that would convey the other-worldly quality that I had experienced when observing *Dunaliella salina* for the first time. The aim was to create an immersive installation that allowed an alternative perception of these organisms, based on the use of scientific technology but placing the viewer in relation to the organisms in an expanded, non-scientific context.

Generating the images required varying degrees of technological intervention and a number of aesthetic choices on my part, which I describe as a series of layers:

- Micro-organism viewed through microscope at x400 magnification
- Microscope image viewed through DSLR camera
- Internal microscope lighting adjusted to desired levels
- Room lighting adjusted to desired levels

This method of observation of *Dunaliella salina* was several layers of technology less than is possible with higher specification microscopy. With TIRF (Total Internal Reflection

Fluorescence) microscopy[87] for example, it is possible to view *Dunaliella salina* coming in and out of focus as they move towards and away from the coverslip, allowing a sensation of depth in a distance of less than one micron (there are 1000 microns in 1 millimetre). The translation of data captured via TIRF into a digital image can itself be broken down into a number of layers, as one might whilst using a digital image application such as *Photoshop*. In fact, the digital applications used to process high resolution microscope images are not dissimilar to those used in art practice, requiring skilled practitioners to train in the use of both microscopes and imaging methods[88].

The resulting film for the installation combined edited video footage captured with standard resolution microscopy (x400 magnitude) and TIRF microscopy. There was minimal editing of the original footage, only changes in scale and adjustments of contrast. Once again this added technological layers to the work, similar to techniques used with scientific imagery to find the most accurate representation of the story to be told (i.e. adjusting hue or saturation to target a specific area of interest)[89]. Thus perception is both extended by technology but also narrowed, as layers of technology increasingly channel perception towards a specific outcome.

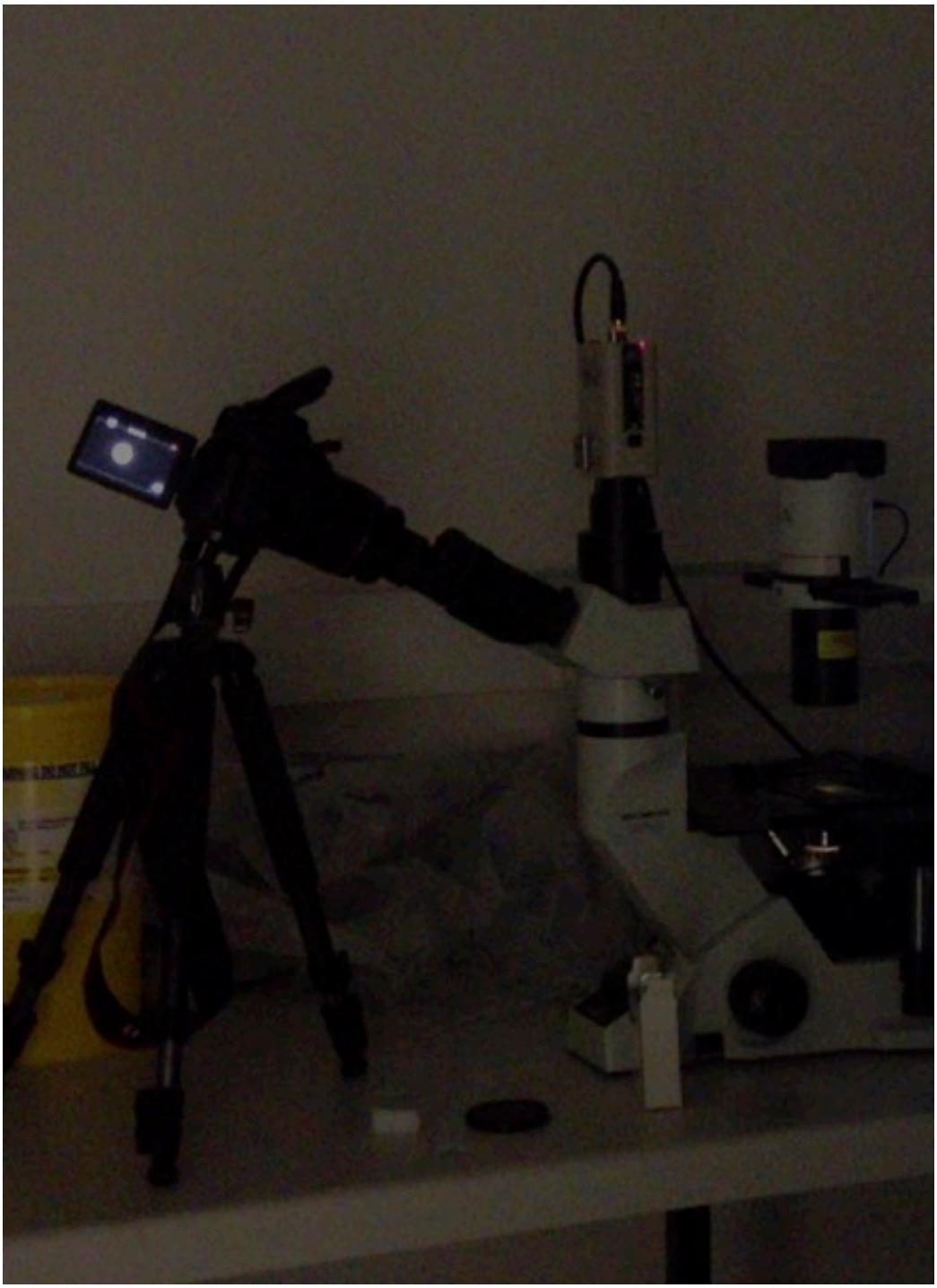


Figure 19: Working in darkness in the Microscope Room, School of Marine Science and Technology, Newcastle University, UK. Research documentation, 2015. Photo: Louise Mackenzie

4.1.2 Looking Without Seeing

It is universally accepted practice within science to visually examine living cells and components within living cells without the use of optics. Advances in microscopy in the past century (techniques such as confocal microscopy, spectral imaging and multiphoton imaging) have led to the use of laser technology and mathematical algorithms to compute complex reflections of light in order to create digital images of cellular structures that are instead viewed via the medium of the computer screen. As the discovery and pursuit of knowledge on the nano-scale increases, additional layers of technology are used to gain an understanding of the world beyond standard human levels of perception. The development of super-resolution microscopy techniques such as TIRF (Total Internal Reflection Fluorescence), PALM (PhotoActivated Localization Microscopy) and STORM (Stochastic Optical Reconstruction Microscopy) enable a technological enhancement of the visual sense that extends and simultaneously narrows our field of vision.

This extended visual sense, which increases the distance between the eye and the observed, changes our perception of the object. We gaze through layers of technological development: optical lenses, lasers, chemical dyes, computer algorithms, upon a screen at a recreated image, rather than using our eyes directly to perceive. This distance from the object through multiple layers of technology might be construed as looking without seeing. The focus becomes increasingly specific, or reduced, in attempts to identify single cells or molecules within cells, akin to the action of looking or ‘directing one’s gaze in a specified direction’, as opposed to the arguably more holistic perspective of seeing: ‘to perceive with the eyes’[90] when we engage all aspects of our visual capacities: scanning, peripheral vision, and so forth.

Of course, the distinction is not quite so clear cut, as science uses technology in order to comprehend, but the focus of comprehension is so specific and the field of vision so narrow (at times limited to individual particles within cells, seen via the reflection of specific wavelengths of light) that what is perceived is necessarily reductive. Thus the breadth of visual comprehension is limited to discrete, atomic perception (which I suggest falls under the definition of ‘looking’), rather than perception across a visual plane (which I suggest falls under the definition of ‘seeing’).

4.1.3 Extending Auditory Perception

> ‘An inquiry into the auditory is also an enquiry into the invisible. Listening makes the invisible *present* in a way similar to the presence of the mute in vision.’ (Ihde, 2012, p. 25)

Like all living organisms, microbes move, thus the possibility of perceiving their movement in multiple ways may provide a more rounded understanding of organisms that are beyond our natural perception. Philosopher and sound theorist, Don Idhe describes the mute object (in his example, paper clips) as perceived through vision, being interrupted by the passage of a fly that gives rise to a second level of objects characterised by movement, ‘a moving, active being upon the face of the visual “world”’ (Ihde, 2012). Idhe follows the visual argument that the moving fly sits against a backdrop of stability and counters that the mute object sits against a backdrop of silence, interrupted by the buzzing of the fly. Thus silence and invisibility are foils interacting in related perceptual spheres, incorporating both time and space. With the combination of sound and vision therefore, the fly is defined through process and not a fixed notion of matter. The liveliness of the organism becomes apparent. Marta De Menezes suggests that it is this quality of motion that appeals to many artists, ‘[v]ery simply movement stands for life while stasis means death’ (High *et al.*, 2017, p. 53) and thus in my attempts to relate to forms of life that cannot be seen, sound plays a significant role in encountering liveliness.

In considering the possibility of listening to micro-organisms as well as looking at them, the first question that arose was, *how to listen?* Embodied techniques for listening can be grouped into recording, audifying and sonifying and within this chapter, each is engaged to explore different methods of enhancing experience of the organism.

4.1.4 How to Listen to the Organism

4.1.4.1 Sound Recording

Conventionally one thinks of recording sound with a microphone, although in the case of the organism, the means by which to do this is not obvious and gives rise to more fundamental questions of perception based around what it is possible for the human ear to ‘hear’ in comparison to how an organism might experience what we define as ‘sound’. I

discussed this with sound recordist, Chris Watson during a sound walk in 2015[91]. Watson has recorded examples of minute but visible organic life, such as cabbage white larvae (a few millimeters in length) and sand flies using highly specialized instruments (such as a particle velocity microphone) and custom designed contact microphones. Most sound recording is of noises through air. It is possible to pick up noise in water through the use of a hydrophone, but not at a particularly fine level of detail (a hydrophone would be unlikely to pick up microscopic organisms). There is extensive and growing research on the development of animal sound recordings[92] but attempts to listen to a soundscape of microscopic organisms, moving in their environment has eluded the reach of audio recording equipment alone.

In collaboration with sound artists Mark Reed and Daniel Tyson, I considered possibilities for listening to *Dunaliella salina* and, although aware that our range of auditory perception prohibits our ability to access the ümwelt[93] of the organism, we tested out DIY methods, open to what might result. Our constructed aim was to detect an audible change in the organisms under conditions that might be similar to the environmental stress of laboratory testing. I brought *Dunaliella salina* out of the laboratory and into the sound booth and set up a dark room, complete with red light, similar in wavelength to that used in the stress experiments at MaST. We set up contact microphones on the outside of the glass container and hydrophones within the liquid medium of the micro-algae, to see if there was any way we could pick up sound from the organisms.

Our reaction to the resulting sound[94] was a mix of disappointment and delight. We hoped, contrary to what we understood, that perhaps, when the red light was switched on we might detect some subtle change in sound. The equipment we were using was, as expected, not sensitive enough to pick up anything directly from the organisms. We did however hear various taps, clicks and buzzes (presumably interference from the range of electronic equipment that we were using) along with the background noise of our conversation outside the booth. I initially read this as an empirical failure to relate to the organisms but significantly I came to realise that my first relation to the organisms through this means of observation was simply one of noise, electricity and feedback loops.

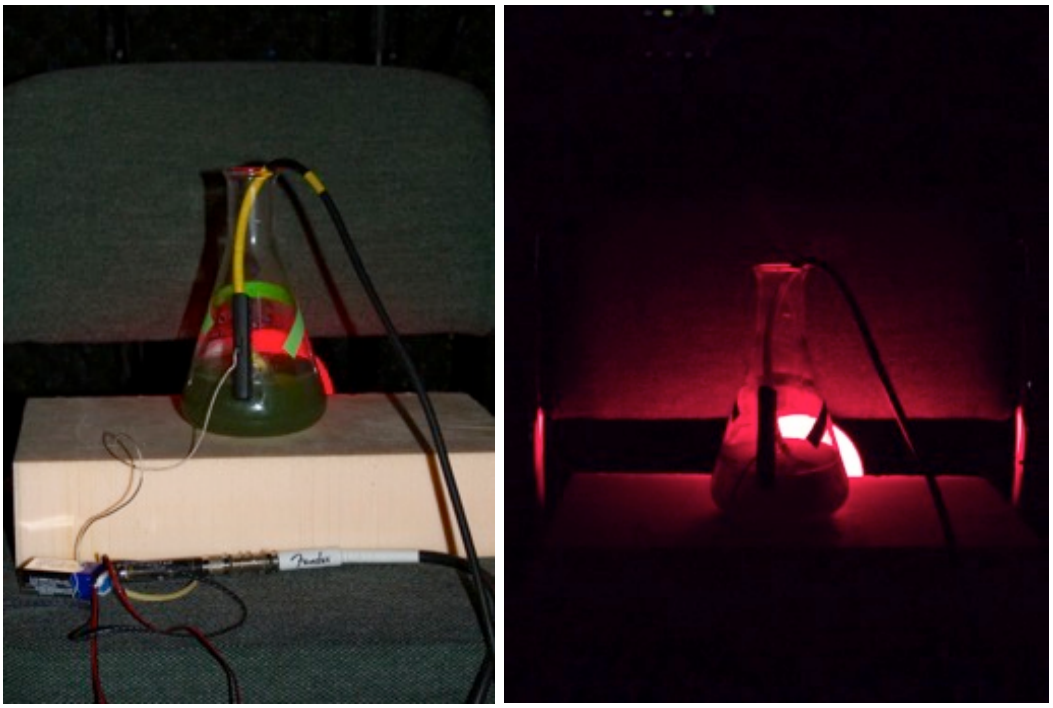


Figure 20: *Microbial Sensing.* Research documentation, 2015. Photos: Louise Mackenzie

4.1.4.2 Sonification and Audification

As with our visual sense, advanced technological layering has also been used to develop means of listening that reach beyond standard levels of human perception. In science, early examples of sound technologies exist in the stethoscope, ultrasound, the Geiger counter and SONAR (SOund Navigation And Ranging). There is, perhaps surprisingly, an example from as early as 1881 of listening to the reaction frequencies of muscle cells (J. Bernstein and C. Schönlein, first published in 1932).[95] Sonification and audification are now emerging fields of research that make use of various layers of technology to perceive information as sound. Examples can be as varied as stock market analysis and images of human body tissue. Sound theorists, Florian Dombois and Gerhard Eckel, writing in The Sonification Handbook, allude to technological layering, stating that, '[b]y extending the human auditory sense with technology, the process of listening to data can be thought of as involving data, conversion, display and perception' (Hermann *et al.*, 2011, p. 304). This technologically extended approach to listening, much like looking without seeing, focuses on a narrow field of perception, by attempting to single out sounds in order to derive meaning from the information held within.

Audification is a means to listen closely to specific information. It is essentially, 'the direct translation of a data waveform into sound' (Hermann *et al.*, 2011, p. 301)[96]. Audification has been used to change the pitch of a signal usually inaudible to human ears, such as the call of a bat, and to speed up the vibrations of an earthquake to a pace that allows the human ear to detect particular rises and falls, for example. Sonification is a means of generating sound from data in order to convey information regarding that data. The crucial difference between sonification and audification is that sonification imposes a mapping on the data. That is, different sounds are chosen to correspond to specific forms of data, and any form of sound could in theory be used[97].

Audification has been used to pick up specific sounds at the microscopic level. In 2000, artist Joe Davis and scientist Katie Egan developed Audio Microscope as part of *Microbial Farm* for presentation at Ars Electronica. Originally working to understand whether it might be possible to listen to plants, Davis and Egan investigated the possibility of developing a 'micro-acoustic signature' for organisms that would not normally be detected by the human ear (Davis and Egan, 2000b). Davis and Egan constructed apparatus to enable detection of the light that is reflected from the surface of specimens and developed a means of translating the reflected light into sound to enable the depiction of unique acoustic signatures for different specimens of paramecium and other micro-organisms.[98] Thus for the first time, technology (through an approximated five layers: laser, electrical signal, equalizer, speakers) provided us with the enhanced capability to 'listen to' micro-organisms, as if experiencing a super-sense.

In 2002, nanotechnologist James Gimzewski and physicist Andrew Pelling used Atomic Force Microscopy to sense motion within living cells[99], and collaborated with media artist Anne Niemetz to create audio-visual installation, T*he Dark Side of the Cell* (Pelling, Andrew; Niemetz, 2004): a work in five movements that includes the 'sounds' of yeast cells and human bone cancer cells. Thus, just as Chris Watson had technologically amplified the munching sound of the cabbage white larvae and Davis and Egan used laser technology to reveal the sound of a moving paramecium, Gimzewski and Pelling were able to use advanced microscopy to audify the sound of movement within a cell membrane[100].

As Idhe has alluded, the relationship between works of sound and works of vision are entangled and thus in the above examples, defining the precise source of the sound is not straightforward. In the case of Davis and Egan, it would appear to be the motion of the

organisms (in their medium) that generates sound, whereas with Niemetz and Pelling it is the movement of the cell membrane itself. In identifying different micro-acoustic signatures as the organisms move under the microscope, Davis suggests that, '[d]ifferent organisms make different sounds in the way that say, the sounds of horses are perceived as different than the sounds of sheep.' (Davis and Egan, 2000a). In making this comparison, Davis draws attention to *what* exactly we are listening to, which on the scale of the paramecium may not seem much, but perhaps it should matter a great deal. My sense of the sound of a sheep may be (in some part) based upon its movement but it is also based on the vibrations of its vocal chords, its age, size and distance from me, perhaps even what it ate for breakfast this morning. So far, our acoustic (and visual) sense of an organism has only a fraction of this information.

4.1.4.3 Atomic Force Microscopy as a technique for 'Listening'

Returning to the sensation of movement as an expression of liveliness, I collaborated with Dr Richard Thompson of Durham University to study the motion of *Dunaliella salina* using an Atomic Force Microscope (AFM). The AFM works by detecting deflections on a surface at the nanoscale. It is more commonly used for force measurement and imaging of materials. It uses a cantilever tip, which rests against the sample, and a laser is used to record any deflections in the beam as the cantilever tip scans across the surface of the medium. By flowing liquid medium[101] containing the *Dunaliella salina* into the chamber directly under the line of the laser, it is possible to detect the *Dunaliella's* movement as fluctuations in the scattered laser beam (see Figure 21)[102].

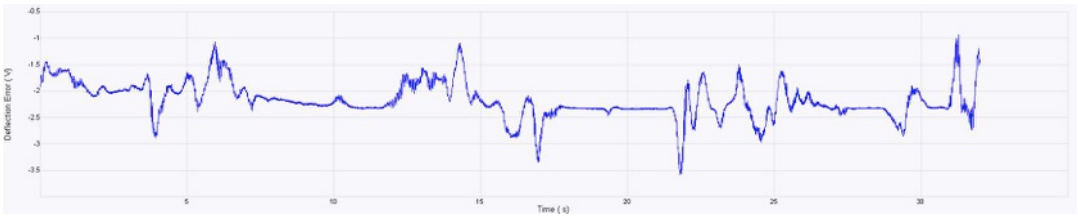


Figure 21: AFM Readings with Dunaliella salina (32 seconds). Research documentation, 2015. Image: Louise Mackenzie.

The data gathered from the phenomenon observed using the AFM is already a number of levels removed from sound as perceived by the human ear, further distancing the organisms' agency from what one hears. In translating the data captured by the AFM, I tried to find as simple a method as possible, one that, whilst requiring aesthetic decisions,

enabled a clearly defined path through the layers of technology. Thus I aimed to reveal how the choices I made within each layer contributed to an outward spiral of possible interpretations. The information gathered is translated through the following sequence of events:

- Movement of *Dunaliella salina* in medium f/2 (constructed space)
- Deflection of laser beam by *Dunaliella salina* in the AFM detection system
- Variation in beam deflection represented numerically over time
- Numerical representation of distance plotted graphically
- Graphical representation depicted as sound wave

This final step, the depiction of the data as sound, necessitates further technological layering to listen to the data[103]. Already I understood that I could not reach the organism, but I wanted to try to generate sound in as direct a manner as possible. I began with audio editing software, *Photosounder*[104], but the resulting sound[105] - a computer generated tone reminiscent more of moving bytes than moving organisms - was not how I *imagined* organisms would sound if I were able to be amongst them. So, I approached sound expert, Dr Paul Vickers and we trialled two further techniques: parameter mapping sonification using multimedia visual programming language, *Max/MSP* and audification using *Python* code script. Whilst all three methods created the same peaks and troughs of pitch as the oscillating data, both Photosounder and Max/MSP signify the data (in the case of Max/MSP, via an oscillating sine wave[106]) adding further technological layers, whereas the Python script helps to construct an audification through direct translation of the original phenomenon to sound. Gratifyingly, the sound generated using the Python script presents as a deep, almost 'watery' rumbling, that could be construed by the human ear as the sound of creatures moving (even swimming). The sound possessed a resonance that I imagined befitting of the other-worldly quality of the *Dunaliella* I have previously alluded to, although given the series of steps we undertook to get to this point, I am under no illusion as to the levels of technology required to achieve this limited perspective, chosen by me, to represent the organisms.

4.1.5 Listening without Hearing

As with the visual sense, the extended perception afforded via technology broadens the possibilities for interpretation such that we are no longer hearing conventionally and must resort to what becomes a technologically embodied sense of the origin of the data. The distinction made in sound research between sonification and audification prompts a similar consideration with visual technology. How might we understand an image that is only readable through the light emitted by fluorescent dyes inserted within the observed object? Further, how do we contrast the translation of an image that is generated through the reflection of this light with one that is generated through the diffraction of this light? Just as there are multiple ways in which we translate sounds from data, '[e]very image embodies a way of seeing' (Berger, 2008, p. 10). Thus in simultaneously extending and narrowing our perception through a technological reading, our attempts to locate referents in the image or the sound are simultaneously extended and narrowed.

Sonification and audification techniques, whilst having the capability to communicate precise data, have also been used to generate abstract compositions, notably by Alvin Lucier, whose *Music for Solo Performer* (Lucier, 1965) amplified Lucier's brainwaves and then played the amplified vibrations through 16 percussion instruments. The work combined audification (in the amplification of the brainwaves) with sonification (the use of percussion) and performance, with fellow artist John Cage assisting Lucier by controlling the volume and balance of instrumentation live whilst Lucier's brainwaves were transmitted (Straebel and Thoben, 2014, pp. 19–20). The resulting work depicts Lucier's brainwaves, but does so in a richly mediated manner as opposed to a focused or narrow reading. Sound art performances such as Lucier's demonstrate the variation in approaches to use of sound that are perhaps most easily described in terms of their semiotic connection to the sound source. In providing a subjective interpretation of his brainwaves, Lucier acknowledges the narrow focus required to produce the sound, but expands the possible readings, enabling us to imaginatively hear, as well as narrowly listen to technologically embodied information.

4.2 Alchemical Sensing

Looking without seeing and listening without hearing then can be seen as narrowed forms of technologically embodied perception. The consideration of sound art within the context of sonification and audification therefore acts as a means to add breadth to the technologically embodied sensory realm. In both broadened and narrowed perspectives, technology becomes prosthesis (Haraway, 1991, p. 195; Ihde, 2007, p. 248), enabling the brain to interpret information in new ways. I describe this as an alchemical sense, adding to our means of reading the world and at the same time clouding our understanding of the thing-in-itself[107]. Alchemical sensing therefore raises the question of what we understand to be 'out there' in the world as defined through scientific technologies. As Bruno Latour points out, the separation of nature/culture allows the endurance of 17th century alchemist Robert Boyle's argument that 'we know the nature of facts because we have developed them in circumstances that are under our complete control' (Latour, 1993, p. 18). Whilst it is possible to produce precise data from things using the laws of computing science, physics and mathematics, to lay publics these facts are generated through so many layers of technology that they must be translated via scientific authority. Belief in such interpretations, therefore, is reminiscent of practices more closely aligned with a magical or spiritual sense of perception: the kind that requires a level of faith.

Feminist science theorist, Karen Barad brings to our attention Niels Bohr's definition of apparatus as matter that materialises in its relating to other matter (Barad, 2007, pp. 132–185). This agential realist view positions the human as one actor amongst many in the observation of a phenomenon. I experience this materializing of matter as technological layering, through the multiple choices made in using the apparatus that reduce the phenomenon to a technologically layered instance. Thus the meaning that we bestow upon matter via apparatus is simply meaning in a moment, according to the particular configurations of the apparatus that we have chosen to make.

Latour, commenting on this technological layering in relation to the communication of scientific research, states that: '[w]e can see more [in the lab], since we have before our eyes not only the image but what the image is made of… on the other hand we see less… because each of these elements… could be modified so as to produce a different visual outcome' (Latour, 1987, p. 66). Latour's statement suggests looking without seeing

through the building of technological layers to point at a specific outcome. By adding layer upon layer of technology, we enable a multi-faceted use of scientific apparatus: the adjustment of a lens or light level on a microscope, the colour of dye, the reflection or diffraction of the laser used in conjunction with the object of interest, the augmentation of hue on the resulting computer image, all constructed to convey a narrative that is simply one of many possible interpretations.

Attesting to the alchemical sense of their work, Niemetz and Pelling state, 'much mystery is brought forth by the discovery of cellular sound, and few answers can be given.' (Pelling, Andrew; Niemetz, 2004). Once this technological layering is understood as a means to derive many possible interpretations, the ways in which we can relate to the thing-in-itself opens up. Art practice that engages with biotechnology is uniquely placed to engage in the exploration of alternative perceptions that extend the focused viewpoint. Technological layering can be diverted tangentially, or interrupted horizontally, opening up the possibility for interpretation that includes novel views, soundscapes[108] or other forms of sensation, as a means to alchemically augment perception. A sense not grounded in faithful allegiance to scientific dogma but in an understanding that what we perceive is guided not only by technical apparatus but by our own actions in using it.

4.2.1 Performing with the Organism

Following *The Stars Beneath Our Feet*, I developed a collaborative performance, *Natura naturans* (Mackenzie and Reed, 2015)[109] with sound artist, Mark Reed, and the living material in a flat within an empty Salford tower block, commissioned as a part of Domestic II, 2015. The premise for this work was to move beyond the very specifically staged perception of the organism in *The Stars Beneath Our Feet* to one that, through live technological intra-action, embraces our alchemical sense as a form of performance and in doing so, considers philosopher Jacques Derrida's approach to hospitality (Derrida, 1988, pp. 255–287, 2000, pp. 2–155) to ask whether we are guests before the organism.

Visiting the site a week in advance, we captured the yeast from the air in the room to grow within a sourdough, left food traces (hoping to encourage bacterial/fungal growth), collected moist material, dust and mud from the corners and pipes and found tiny insects in the cracks and crevasses. We returned a week later and in the blacked out flat,

we projected and amplified our living material traces back into the flat, finding additional material to ‘coerce’ or ‘cajole’ into collaboration throughout the five-hour performance. As a site-specific work, if repeated the phenomenon experienced would differ directly in relation to the individual organisms found in the space, but also in relation to the choice of technological apparatus and the choices made in how the organisms are technologically projected and amplified. By bringing technology into an apparently uninhabited space, *Natura naturans* extends our sense of the organism by constructing a microbial ‘performance’, revealing the organism as host and the spectator as one who imposes upon the host. Extending the visibility and audibility of organisms found in the seemingly empty space technologically altered their presence to the status of (unwitting) collaborator or performer, thus the work began to question the nature of our perceived relationship to the organism.

4.3 Parasitic Imposition Between Code and Life

This brief section attempts to form a connection between perception of the organism through technology and construction of the organism through models. How better to do so than with the phage – a parasitic entity that is both inert and lively, information and physical matter?[110]

There are many indicators of what is 'living' but perhaps none more so than genetic material. An organism is not considered to be 'alive' if it does not contain genetic material, yet not all organisms that contain genetic material are considered alive. As virologist, Luis P. Villareal states, 'Viruses are parasites that skirt the boundary between life and inert matter' (Villareal, 2008, p. 102). The virus or phage might be construed as genetic material that can make more genetic material - lively material indeed. The concept of the virus or phage as lively is a bounded notion of liveliness on the level of the organism. Thus the virus is used within scientific research as a means to pass on information from one organism to another. This can be contrasted with an unbounded notion of liveliness on the level of the organism as a body within bodies. Genetic material alone is considered inert and therefore things that are 'dead' also contain genetic material. However, as I had explored at the *Night of the Living Deadwood* workshop (Dillon and Parry, 2015) and as further elucidated in the thesis of biophilosopher, Marietta Radomska, the distinction between life and death is not so clear. What we historically constitute as dead decomposes and in decomposition there exists other forms of life (Radomska, 2016, pp. 32–36).

Thus, it is through genetic material that we can understand something as being 'lively' if not alive. This appears to sit in contrast to the cybernetic, information-processing approach to DNA. The genetic code is not alive: it is a theoretical model, constructed to enable us to understand how genetic material translates from DNA into amino acids into proteins and so forth. There is liveliness inherent in the material that comprises the genetic code however: a liveliness that enables its expression through the material body. Scientific knowledge of synthetic biology is therefore built on a model that acknowledges a lively exchange of meaning, but also that tends to narrate the meaning-in-exchange as fixed rather than in constant dialogue.

Michel Serres defines cybernetics as a parasitic form of exchange, where material is exchanged for thought, 'the parasite … obtains energy and pays for it in information.' (Serres, 2007, pp. 34–36). In Serres' tale, the paralytic man guides the blind man who carries him where he wants to go. The transaction has a governor and producer: only one has all of the information, the other must produce the journey from the information he is given. I therefore began to consider my approach, working with synthetic biology in the laboratory, through the question, *In adopting a cybernetic account of DNA, do I become a parasite upon the material of the body?*

4.4 Constructing Language through Translation

> Translation is always interpretative, critical, and partial. Here is a ground for conversation, rationality, and objectivity - which is power-sensitive, not pluralist, 'conversation'. (Haraway, 1991, p. 195)

Processes of translation are a recurring theme in my practice. In *transformation content* (Mackenzie, 2014)[111], I devised a cypher with which to translate patterns of dust taken from planks of organ wood into a musical composition, giving a voice to the dust, or more literally (if you are willing to believe that the composition of dust is in the large part, human cells), to the community of former congregation, organist and clergy of the now closed church that the organ once related to.

I was interested in multiple readings of an object, allowing new experiences. I began translating objects in an attempt to reveal something fundamental about them, their essence perhaps. Without knowing what I was searching for, I had hopefulness, a faith perhaps, that the object had more to reveal about itself than could be experienced ordinarily. I have come to realize through working in this manner that paradoxically, in seeking to find the essence of an object, I inherently produce more variation.

Figure 22: Louise Mackenzie, 2014. *Transformation Content*. Holy Biscuit Gallery, Newcastle, UK. Photo: Alison Merritt-Smith

Figure 23: Louise Mackenzie, 2014. *Entropy*. Composition, live performance, digital recording, radio broadcast (29:12). Photo: Louise Mackenzie

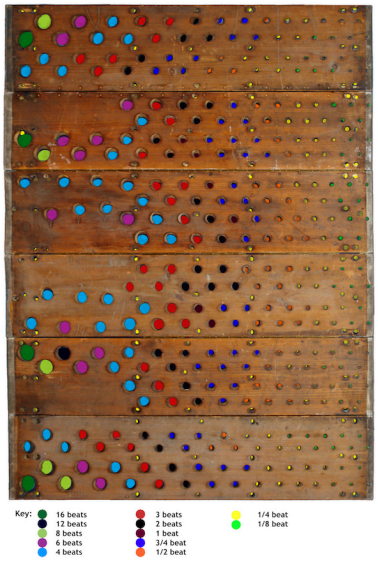


Figure 24: Louise Mackenzie, 2014. *Colour Coded Score*. C-type Print. Image: Louise Mackenzie

There is a subtle distinction between the kind of alchemical sensing I describe in Section 4.2 and the act of translation. Whilst the former begins from a point of objectivity, the latter is intuitive and as such, has no empirical basis. My translation of the organ wood

was a subjective reading of the patterns in the wood. I saw them almost as if they were notes on a stave: the size and the arrangement in space of circular holes in each plank of wood became syntax, corresponding to the depth, pitch and duration of notes in a composition. The decisions I took to translate the patterns in the wood in this way were simply one possible reading of the material. Coming together initially in the dust print, they expressed a relationship between the organ, the congregation and myself. Thus by translating the object in this way, I was able to bring forth a new way of relating to the material.

In contrast to technologically extended perception then, translation can be seen as an opening up, a revealing of multiplicity. Understanding of matter through translation is not a revealing of an ontological sense of presence, an *aletheia*, as Martin Heidegger suggested (Suvák, 2000, pp. 8–13), nor an epistemological revealing of truth as certainty, rather it offers an uncovering of subject positions: an expansion of interpretation. Translation thus sits tangentially from representation. It is not an attempt to directly perceive and establish iconic or indexical signs that ultimately simulate reality rather it embraces the subjectivity of perception through symbolic gesture. Translation thus is both techne and poesis: the act of bringing forth and of transformation.

In addressing my relationship to the organism as synthetic biology tool I had chosen within this project to genetically modify life. In doing so, I planned to create a means by which I could translate DNA into a new form of experience that revealed the liveliness inherent in genetic material. Thus, I chose to create a cypher as a means to translate the liveliness that I hoped to find, and to use this cypher as a means to share information (my subjective experience) as material substance (plasmid DNA) within the body of an organism, thus storing a thought from my mind within the organism. In doing so, I asked two questions:

- *How does translation of the genetic code in novel ways open up possibilities for extending our experience of genetic material?*

- *How might material relate to the subjective thought now embodied within it?*

4.5 Forms of Translation / Constructing Codes

My experience of translating the genetic code led me into labyrinthine layers of language that draw me further from the organism yet again. As Oron Catts and Ionat Zurr have said, '[w]hen one reduces life to the code or abstracts the complexity into its chemical components, the visceral sentient life is being pushed farther away.' (Catts and Zurr, 2008). I found semiotician and literary theorist, Roland Barthes use of denotation and connotation instructive in relating to different readings of DNA as code (Barthes, 1977, pp. 32–37)[112]. As the following sections show, precedents for translating the genetic code into other forms of information range in semiotic complexity from more direct, denotative readings to complex connotative readings and in translation, such readings are effortlessly mixed or even collaged together, thus complicating declarative notions of information as meaningful. In developing a cypher to use as a method of information storage, therefore, I was also faced with the complex unraveling of the question, *Where does meaning reside in a practice that constitutes the living as codifiable?*

4.5.1 Precedents for Translation of Genetic Code

In 1996 artist, Joe Davis published a paper in Art Journal, titled *Microvenus* (Davis, 1996). The article references a quote on contemporary sculpture from Jack Burnham that ends,

> '… the Greek obsession with "living sculpture" will take on an undreamed reality' (Burnham, quoted in Davis, 1996, p. 70).

Davis worked with molecular geneticist Dana Boyd in 1986 at Harvard and MIT to write 'extrabiological information' into DNA and clone this within *E. coli* bacteria (Davis, 1996). Based on a code first devised by scientists Carl Sagan and Frank Drake in 1974 to send a radio transmission into space, Davis created a visual representation of the ancient Germanic rune for 'life and the female earth' (Davis, 1996)[113]. This pivotal work was to transform the way artists (and scientists) think about DNA. *Microvenus* has been cited 14 times since its initial publication: in 3 arts and humanities publications and in 11 scientific publications (source: Scopus, accessed 14 September 2016). In particular, the practical implications of Davis' ideas are referenced in recent research on DNA as a method of data

storage (Church, Gao and Kosuri, 2012; Park *et al.*, 2014; Hossein *et al.*, 2015; Limbachiya *et al.*, 2016) which has now become one of (a number of) synthetic biology's holy grails.[114] Working primarily as artist in residence at Harvard Medical School, Davis is a true polymath, embracing scientific method as a tool at his creative disposal and using DNA as his material, composing the molecules into an arrangement that holds conceptual, not functional value. Therefore the legacy of Davis' work raises additional questions for me regarding how material relates to our subjective imposition upon it. What becomes of the art/life that he has made? Are the *E. coli* which host the DNA granted the right to reproduce, as nanoscale editions, indefinitely? Is synthetic DNA, as a product of technological invention, revered for a while and then placed on the biotechnological scrapheap? How does 'lively' trash of this kind differ from other material waste? [115]

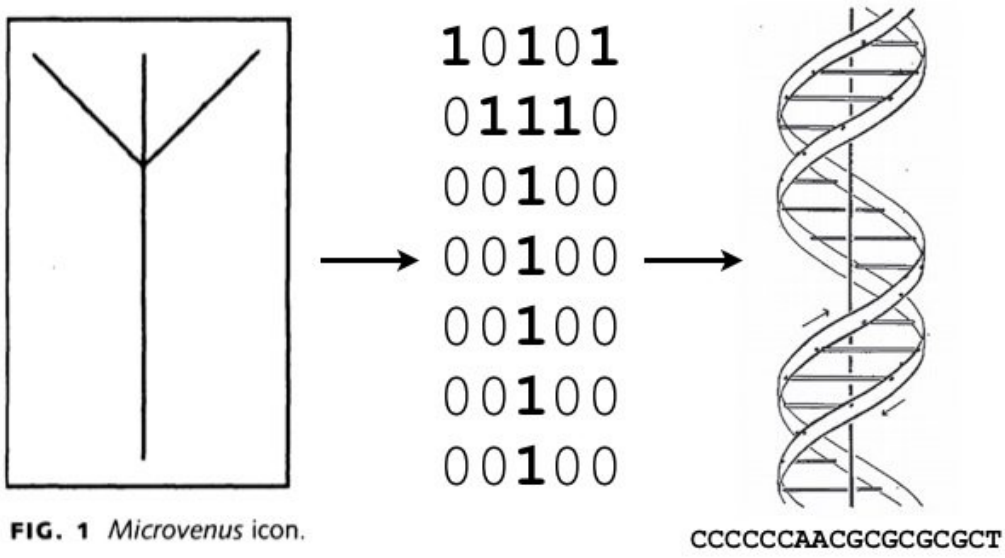


Figure 25: Joe Davis, 1986. *Microvenus.* Image: Joe Davis. Reproduced by kind permission of Joe Davis

Eduardo Kac in *Genesis*, (Kac, 1999) converts text to Morse code and then Morse code to DNA, to enable the insertion of the text, *'Let man have dominion over the fish of the sea and over the fowl of the air and over every living thing that moves upon the earth'* (Genesis, 1:28) within *E. coli* bacteria. The work adds further layers of meaning through a rendering of the same DNA sequence and mutations of that sequence in musical form. Composer Peter Gena worked with molecular biologist, Charles Strom on the development of the *DNA Mixer* (Gena and Strom, 1995): a computer generated music system that combines pitch, frequency, intensity and duration as parameters that map to genetic information such as molecular bonding, level of water solubility and atomic weight. Visitors to the gallery are able to genetically modify the *E. coli*, by pressing a button that

shines a UV light on the organisms. As a result of the visual and auditory cues, the audience is given to understand that the text encoded within the organisms mutates[116].

With *Xenotext* (Bök, 2015), poet Christian Bök's approach is more declarative. Bök encodes text within a living organism and uses it to fabricate a means of entering into a dialogue with the organism. The *Xenotext* is a poem that exists as a DNA sequence that, once encoded within the organism, leads to the expression of a protein, which gives the original text new meaning. Bök has spent several years working on the project to determine the perfect cypher that will enable the original poem to read as a new text. Bök's cypher uses the pairing inherent in the nucleotides of DNA (A to T, C to G) to engineer a poem that can be read in one of two ways: either as the original DNA strand or as the translated protein (which reads as the pair to the original DNA). Thus, his approach uses scientific understanding of genetics to construct a dialogue with the organism: both his initial poem and the organism's 'response' are designed by Bök. The project is an ongoing work for Bök, who wishes to encode his poem with the highly robust extremophile micro-organism, *Deinococcus radiodurans*. Inspired in part by William Burroughs' idea that language is a virus and the view that life on Earth originated in the stars, Bök explains,

> 'By putting my poem into this bacteria, I could conceivably be writing a book that might outlast the rest of civilization. It could be on planet Earth when the sun explodes. Trying to write a book that effectively endures as a kind of moral artefact, something akin to the Voyager probe or the Pioneer probe.' (Bök and Mackenzie, 2015)[117].

Both Kac and Bök's works contrive an experience for the audience through their presentation of scientific information on a pedestal. In both examples, although they explore the unpredictability of life, an intention is manifest in the outcome and in order to achieve this intention, an aesthetic form of black boxing is applied. In the case of Eduardo Kac, whilst he is entirely open about his processes, and detailed information on the work is available on his website and in gallery literature, aesthetically the work leads the audience to a conclusion: that life is unpredictable and this is enabled through a visual short-cutting of the scientific processes required to make the work. Bök's presentation is equally open about the scientific process. The use of the pedestal is evident in Bök's intention: through his veneration of scientific methodology, he envisages the ultimate transhuman desire, to live forever, repeated ad infinitum throughout the universe, in the form of bacterial communication. Thus in both cases the work uses genetically modified life to speak

authoritatively of the artist's intent and neither fully surrenders agency to the organism. Bök's *Xenotext* shares with Davis' *Microvenus* a sense of a figurative pedestal – an intention for the 'word' to live on through their work and in this, an implicit acceptance of the entanglement between 'word' and 'genetic information'. This conflation of language and genetics is in Lily E. Kay's words, 'a metaphor of a metaphor and thus a signifier without a referent, a *catachresis*' (Lily E. Kay, 2000, p. 2) - a point that Kac's *Genesis,* in its rendering of the 'word' as mutable, starts to hint at.

Perhaps the most transparent translation of DNA in creative practice is that of artist Günter Seyfried, whose long-term project *Polycinease* (Seyfried, 2017), with colleagues at Vienna based research and science communication company, *Biofaction* developed a method for encoding a sequence of images as DNA (Seyfried, Grabher and Bartenstein, 2004). This was followed by *Mutants from Inner Space*, an experiment to subject the DNA to "simulated radioactivity, UV radiation and toxicity" which then led to the mutation of the original sequence (Seyfried, Grabher and Feurle, 2008). They continue to develop the work to enable specific edits of images within DNA using the CRISPR/Cas system (Seyfried *et al.*, 2017). Here, in contrast to Kac's aesthetic, the pedestal is removed entirely by opening up the process of DNA mutation and editing through the work and through an ongoing project website. Perhaps more interestingly, even though the work remains behind glass, this barrier becomes less visible as the audience engages with the mechanics of working with DNA as material.

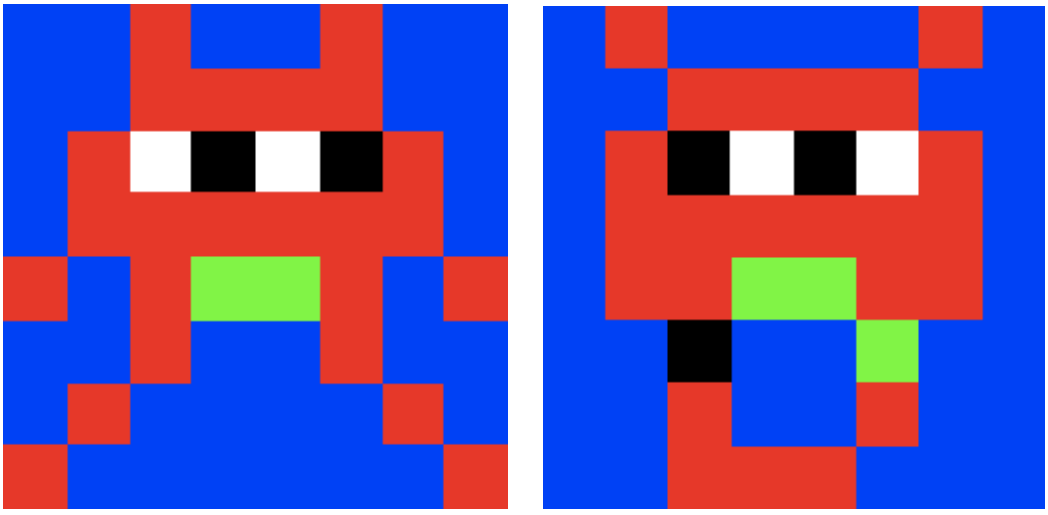


Figure 26: Seyfried, Grabher and Feurle, 2008. *Mutants from Inner Space*. Frames 1 and 2 (zoomed). Reproduced by kind permission of Günter Seyfried

4.5.2 Designing a Cypher: Methodology

In designing a cypher, I directly address the question, *How might material relate to the subjective thought now embodied within it?*[118] By approaching the question from a perspective of relation, I aimed to experience mutation as a form of communication - to enter into a dialogue where I could not predict the outcome. In my situated approach to working in the laboratory, I focus on scientific, rather than creative, methods of translating DNA into information, in order to allow difference to unfold through practice. Thus in this section, both form and content overlap as I also explore the question, *Where does meaning reside in a practice that constitutes the living as 'readable'?*

I was drawn to a paper by biomedical scientists, Ailenberg and Rotstein (Ailenberg and Rotstein, 2009), in which they utilised the Huffman coding method[119] to explore the possibilities of using DNA as a storage medium. In this paper, Ailenberg and Rotstein outline techniques for encoding image, music and text into DNA and illustrate this using the first line of the nursery rhyme, *Mary Had a Little Lamb* in text and musical notation, to which they added a crude, stick-figure image of a lamb (see Figure 26)[120].

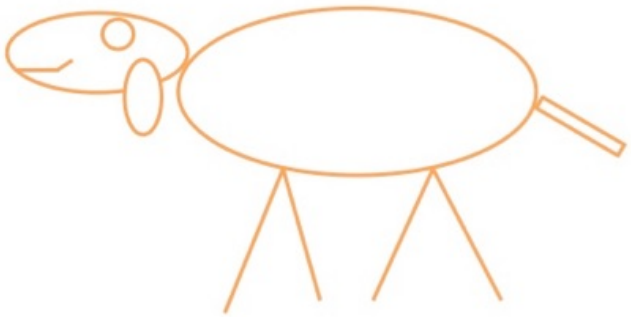


Figure 26: Artist's reproduction of lamb image used in (Ailenberg and Rotstein, 2009). Research documentation, 2017. Image: Louise Mackenzie

Ailenberg and Rotstein's seemingly simple translation belies the number of choices that are (often unconsciously) made in the practice of constructing a translation. Leading me to question at what structural level I should construct my own translation and what form of information I ought to encode.

4.5.2.1 Structural Level 1 - DNA

Unlike computer code, DNA's four nucleotide bases are not binary opposites: on/off, they are already multiple and relate in pairs and folds[121]. I chose not to develop a cypher based on the nucleotides, as the mapping of only four parameters felt limited, even though working from a base of four could allow for multiple variation in the ways that the bases relate. Further research could therefore explore a system that works with four bases, such as the colour systems, CMYK or RYGB for example. In order to generate an image from a simple colour mapping such as this would however require constructing further levels of translation, mixing the four bases in varying degrees and defining an order in which to arrange them[122].

4.5.2.2 Structural Level 2 – Codons

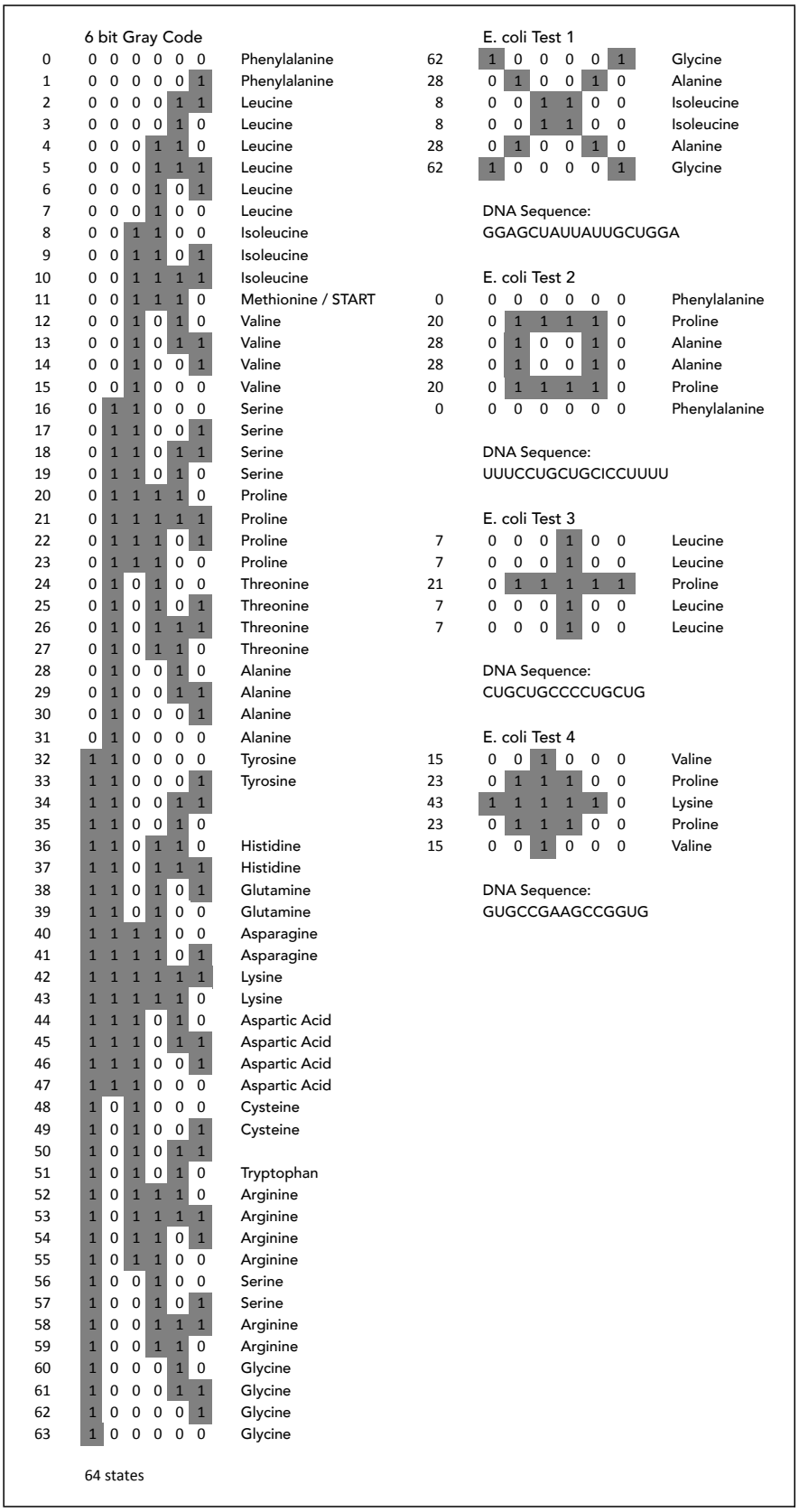
Codons are the name given to the triplets of nucleotide bases found within DNA (see 3.2.1). With four bases forming triplets, there are 64 possible combinations of codons. In a kind of reversal of Borge's Chinese Encyclopaedia (Foucault, 2005, p. xvi), a simple Wikipedia search reveals that 64 is (among other things):

- A superperfect number
- In chess or draughts, the total number of black (dark) and white (light) squares on the game board
- The total number of gems in a standard Bejeweled game board
- Number of golden disks in the myth of the Tower of Hanoi
- Number of sexual positions in the Kama Sutra
- The subject of the Beatles song "When I'm Sixty-Four"
- The code for international direct dial calls to New Zealand
- The number of crayons in the popular Crayola 64 pack
- The number of the French department Pyrénées-Atlantiques

(Wikipedia, 2017a)

4.5.2.3 Image as Mapping Strategy

Working with 64 different parameters, I began to explore mapping structures that would enable two-dimensional shapes to be formed and constructed simple images that could be coded as DNA (see Figure 27). As DNA is molecular, and therefore has a physical structure (albeit one that we cannot see), I was not instinctively drawn to developing an image or a three-dimensional form. The living body (human or otherwise) could be perceived as the ultimate sculptural representation of DNA, although as captured succinctly in Heather Dewey-Hagborg's body of work exploring forensic DNA phenotyping (Dewey-Hagborg, 2013, 2015, 2017), DNA cannot be the only factor contributing to the resulting form, thus for me to attempt to explore the mutation of the DNA of an organism sculpturally or visually felt like a confusion, an unnecessary layering. I was looking for something that focused on science's rationalization of DNA as code. It felt more important to me to find another dimension to work within.



	6 bit Gray Code						
0	0	0	0	0	0	0	Phenylalanine
1	0	0	0	0	0	1	Phenylalanine
2	0	0	0	0	1	1	Leucine
3	0	0	0	0	1	0	Leucine
4	0	0	0	1	1	0	Leucine
5	0	0	0	1	1	1	Leucine
6	0	0	0	1	0	1	Leucine
7	0	0	0	1	0	0	Leucine
8	0	0	1	1	0	0	Isoleucine
9	0	0	1	1	0	1	Isoleucine
10	0	0	1	1	1	1	Isoleucine
11	0	0	1	1	1	0	Methionine / START
12	0	0	1	0	1	0	Valine
13	0	0	1	0	1	1	Valine
14	0	0	1	0	0	1	Valine
15	0	0	1	0	0	0	Valine
16	0	1	1	0	0	0	Serine
17	0	1	1	0	0	1	Serine
18	0	1	1	0	1	1	Serine
19	0	1	1	0	1	0	Serine
20	0	1	1	1	1	0	Proline
21	0	1	1	1	1	1	Proline
22	0	1	1	1	0	1	Proline
23	0	1	1	1	0	0	Proline
24	0	1	0	1	0	0	Threonine
25	0	1	0	1	0	1	Threonine
26	0	1	0	1	1	1	Threonine
27	0	1	0	1	1	0	Threonine
28	0	1	0	0	1	0	Alanine
29	0	1	0	0	1	1	Alanine
30	0	1	0	0	0	1	Alanine
31	0	1	0	0	0	0	Alanine
32	1	1	0	0	0	0	Tyrosine
33	1	1	0	0	0	1	Tyrosine
34	1	1	0	0	1	1	
35	1	1	0	0	1	0	
36	1	1	0	1	1	0	Histidine
37	1	1	0	1	1	1	Histidine
38	1	1	0	1	0	1	Glutamine
39	1	1	0	1	0	0	Glutamine
40	1	1	1	1	0	0	Asparagine
41	1	1	1	1	0	1	Asparagine
42	1	1	1	1	1	1	Lysine
43	1	1	1	1	1	0	Lysine
44	1	1	1	0	1	0	Aspartic Acid
45	1	1	1	0	1	1	Aspartic Acid
46	1	1	1	0	0	1	Aspartic Acid
47	1	1	1	0	0	0	Aspartic Acid
48	1	0	1	0	0	0	Cysteine
49	1	0	1	0	0	1	Cysteine
50	1	0	1	0	1	1	
51	1	0	1	0	1	0	Tryptophan
52	1	0	1	1	1	0	Arginine
53	1	0	1	1	1	1	Arginine
54	1	0	1	1	0	1	Arginine
55	1	0	1	1	0	0	Arginine
56	1	0	0	1	0	0	Serine
57	1	0	0	1	0	1	Serine
58	1	0	0	1	1	1	Arginine
59	1	0	0	1	1	0	Arginine
60	1	0	0	0	1	0	Glycine
61	1	0	0	0	1	1	Glycine
62	1	0	0	0	0	1	Glycine
63	1	0	0	0	0	0	Glycine

64 states

E. coli Test 1

62	1	0	0	0	0	1	Glycine
28	0	1	0	0	1	0	Alanine
8	0	0	1	1	0	0	Isoleucine
8	0	0	1	1	0	0	Isoleucine
28	0	1	0	0	1	0	Alanine
62	1	0	0	0	0	1	Glycine

DNA Sequence:
GGAGCUAUUAUUGCUGGA

E. coli Test 2

0	0	0	0	0	0	0	Phenylalanine
20	0	1	1	1	1	0	Proline
28	0	1	0	0	1	0	Alanine
28	0	1	0	0	1	0	Alanine
20	0	1	1	1	1	0	Proline
0	0	0	0	0	0	0	Phenylalanine

DNA Sequence:
UUUCCUGCUGCICCUUUU

E. coli Test 3

7	0	0	0	1	0	0	Leucine
7	0	0	0	1	0	0	Leucine
21	0	1	1	1	1	1	Proline
7	0	0	0	1	0	0	Leucine
7	0	0	0	1	0	0	Leucine

DNA Sequence:
CUGCUGCCCCUGCUG

E. coli Test 4

15	0	0	1	0	0	0	Valine
23	0	1	1	1	0	0	Proline
43	1	1	1	1	1	0	Lysine
23	0	1	1	1	0	0	Proline
15	0	0	1	0	0	0	Valine

DNA Sequence:
GUGCCGAAGCCGGUG

Figure 27: Sample test patterns for encoding image within *E. coli* using 64-bit gray code. Excel. Research documentation, 2015. Image: Louise Mackenzie

4.5.2.4 Structural Level 3 – Amino Acids

Within the genetic code there are 64 codons but only 20 possible amino acids. The genetic code is therefore described as degenerate, as some amino acids are represented by more than one codon. These different levels of articulation have led to comparisons with language more generally[123].

Amino acids can be characterized according to their hydrophobicity, polarity, acidity, chemical families and atomic weight (see Figure 29). I considered representing the structural aspects of the genetic code as different colours, shapes, pitches or notes with perhaps different hues, lengths or resonances depending upon characteristics identified within the material itself (examples of mappings to music, image and text are set out in Appendix V). I considered other ways to order amino acids: frequency of use, structural size, when discovered, fabulous, drawn with a very fine camelhair brush, from a long way off they look like flies…[124]. I spoke at length to one of my collaborators at the Institute of Genetic Medicine, Dr Steven Laval about how to categorise amino acids but it transpires that they are as elusive as philosopher, Graham Harman's withdrawn objects: we can't see all sides at once (Harman, 2010). Nonetheless I was able to persuade him to attempt to characterise amino acids (see Figure 28). As a result, I began to devise means by which to align aspects of the genetic code with aspects of other language structures, for example matching hexadecimal colours or instruments with varying tonal ranges to the subjectively identified characteristics of the amino acids (see Figure 30 and Appendix V for details).

From: Louise Mackenzie
Sent: 12 March 2015 15:47
To: Steven Laval
Subject: Question re amino acid characteristics

Dear Steve,

Hope you're well. I have another, perhaps slightly odd, question for you...

I know that amino acids are grouped into their various properties and I am trying to get to grips with their various characteristics, but would you say that certain amino acids 'behave' in particular kinds of ways?

For example, I am thinking about Glycine as being the 'most flexible' of the amino acids and Methionine as a 'starter'. Are there any other ways in which you might define particular amino acids, other than their properties? I suppose I am looking for more personal (I hesitate to say 'anthropomorphic') characteristics!

Best,
Louise

Good question. As you know, scientists resist anthropomorphism, although generally unsuccessfully!

Proline is very flexible, and often forms hinges in proteins.

Hyrophobic stretches (long runs of Gly, Ala, Val, Leu, Ile, Pro, Phe and Met) either bury themselves in membranes to form "anchors" or hide in the middle of proteins. I guess they would be introverted.

The opposite is the extroverted amino acids with polar side-chains (Ser, Thr, Cys, Gln and Tyr) which reject membranes and gravitate to the outside of proteins. These side chains are also more "active", generally forming the active sites of enzymes and coordinating co-factors such as metal ions.

Cysteine is particularly sociable, forming disulphide bonds with other, more distant cysteine residues which stabilises the protein tertiary and quarternery structure. Unpaired cysteines are "lonely" and can cause major problems for a protein by forming inappropriate bonds.

Hydroxyl side-chains (Ser, Thr, Asp) are communicative, functioning as signals like holding a flag.

I hope that helps. Please understand how heretical this would be to the majority of my colleagues!

All the best.

Steve

Excellent answer! Making me smile in The Hague, thank you for your heresy.

Louise

Figure 28: Email Correspondence between Louise Mackenzie and Dr Steven Laval on the characteristics of amino acids. Research documentation, 2015. Image: Louise Mackenzie

Codons	Amino acids	Letter	Implied Characteristics	Hydrophobicity	Essential	Polarity/Acid/Base
G G U	Glycine	G	Introv.	in between		Neutral, non-polar
G G C	Glycine	G	Introv.	in between		Neutral, non-polar
G G A	Glycine	G	Introv.	in between		Neutral, non-polar
G G G	Glycine	G	Introv.	in between		Neutral, non-polar
C C U	Proline	P	Flexible / Introv.	in between		Neutral, non-polar
C C C	Proline	P	Flexible / Introv.	in between		Neutral, non-polar
C C A	Proline	P	Flexible / Introv.	in between		Neutral, non-polar
C C G	Proline	P	Flexible / Introv.	in between		Neutral, non-polar
U G U	Cysteine	C	Manic	Hydrophobic		Neutral, polar
U G C	Cysteine	C	Manic	Hydrophobic		Neutral, polar
U A U	Tyrosine	Y	Extrov.	Hydrophobic		Neutral, polar
U A C	Tyrosine	Y	Extrov.	Hydrophobic		Neutral, polar
U C U	Serine	S	Extrov. / Signal	in between		Neutral, polar
U C C	Serine	S	Extrov. / Signal	in between		Neutral, polar
U C A	Serine	S	Extrov. / Signal	in between		Neutral, polar
U C G	Serine	S	Extrov. / Signal	in between		Neutral, polar
A G U	Serine	S	Extrov. / Signal	in between		Neutral, polar
A G C	Serine	S	Extrov. / Signal	in between		Neutral, polar
A C U	Threonine	T	Extrov. / Signal	in between	essential	Neutral, polar
A C C	Threonine	T	Extrov. / Signal	in between	essential	Neutral, polar
A C A	Threonine	T	Extrov. / Signal	in between	essential	Neutral, polar
A C G	Threonine	T	Extrov. / Signal	in between	essential	Neutral, polar
C A A	Glutamine	Q	Extrov.	Hydrophilic		Neutral, polar
C A G	Glutamine	Q	Extrov.	Hydrophilic		Neutral, polar
A A U	Asparagine	N	Extrov.?	Hydrophilic		Neutral, polar
A A C	Asparagine	N	Extrov.?	Hydrophilic		Neutral, polar
G A A	Glutamic Acid	E	Signal?	Hydrophilic		Negative, Acidic
G A G	Glutamic Acid	E	Signal?	Hydrophilic		Negative, Acidic
G A U	Aspartic Acid	D	Signal	Hydrophilic		Negative, Acidic
G A C	Aspartic Acid	D	Signal	Hydrophilic		Negative, Acidic
A A A	Lysine	K	Gregarious?	Hydrophilic	essential	Positive, Basic
A A G	Lysine	K	Gregarious?	Hydrophilic	essential	Positive, Basic
C A U	Histidine	H	Gregarious?	Hydrophilic	essential	Positive, Basic
C A C	Histidine	H	Gregarious?	Hydrophilic	essential	Positive, Basic

Figure 29: One Possible Characterisation of Amino Acids (Sample). Excel. Research documentation, 2015. Image: Louise Mackenzie

Amino acids		Musical Scales Instrument/Timbre	Frequency	English	Rationale
Valine	V	Trombone	82.407	E2	Part of a large structural family (wind) with a range of instruments increasing in size (brass)
Valine	V	Trombone	103.826	G# / Ab2	Part of a large structural family (wind) with a range of instruments increasing in size (brass)
Valine	V	Trombone	110.000	A2	Part of a large structural family (wind) with a range of instruments increasing in size (brass)
Valine	V	Trombone	123.471	B2	Part of a large structural family (wind) with a range of instruments increasing in size (brass)
Tryptophan	W	Bassoon	61.735	B1	Part of the Aromatics, stems from alanine root, part of three that absorb UV so 'sunny' somehow (woodwind)
Alanine	A	Flute	261.626	C4	Part of a large family: can be substituted in many other Aas, so common wind instrument
Alanine	A	Flute	293.665	D4	Part of a large family: can be substituted in many other Aas, so common wind instrument
Alanine	A	Flute	349.228	F4	Part of a large family: can be substituted in many other Aas, so common wind instrument
Alanine	A	Flute	391.995	G4	Part of a large family: can be substituted in many other Aas, so common wind instrument
Cysteine	C	Alto Saxophone	146.832	D3	Sulphurous (wind) and also slightly special
Cysteine	C	Alto Saxophone	220	A3	Sulphurous (wind) and also slightly special
Tyrosine	Y	Oboe	246.942	B3	Part of the Aromatics, stems from alanine root, part of three that absorb UV so 'sunny' somehow (woodwind)
Tyrosine	Y	Oboe	369.994	F# / Gb4	Part of the Aromatics, stems from alanine root, part of three that absorb UV so 'sunny' somehow (woodwind)
Glycine	G	Piano	27.5	A0	Most common, flexible, an instrument used a lot
Glycine	G	Piano	34.648	C# / Db1	Most common, flexible, an instrument used a lot
Glycine	G	Piano	36.708	D1	Most common, flexible, an instrument used a lot
Glycine	G	Piano	41.203	E1	Most common, flexible, an instrument used a lot
Proline	P	Guitar	82.407	E2	The most flexible, a different type of instrument, also used a lot
Proline	P	Guitar	103.826	G# / Ab2	The most flexible, a different type of instrument, also used a lot
Proline	P	Guitar	110	A2	The most flexible, a different type of instrument, also used a lot
Proline	P	Guitar	123.471	B	The most flexible, a different type of instrument, also used a lot

Figure 30: Sample of One Possible Musical Representation of Amino Acids. Excel. Research documentation, 2015. Image: Louise Mackenzie

4.5.2.5 Music as Mapping Strategy

The power of music to evoke emotion is well documented from the classics of ancient Greece to anthropological studies of indigenous communities[125]. There are precedents within both art and science for the effect of vibrations on physical matter[126]. Music feels like a kind of corporeal key, with the capacity to unlock the body. The effect of music on matter can be traced historically to Plato's concept of harmonic resonances (Guthrie and Fideler, 1987, pp. 34, 52), which has in turn led some researchers, largely outside formal academia, to perceive music (and/or sound) as fundamental in signifying meaning in life[127]. There is a sublime sense of the mysterious and also something unsettlingly deterministic in the exploration of harmonic resonance. With music (the pattern inherent in rhythm is perhaps humanity's oldest construction of language), the secrets of matter appear tantalizingly close. Artist Joey Holder touches on this magical quality through her exploration of the relationship between DNA and shamanism, referencing the work of anthropologist, Jeremy Narby in her work, *Ophiuchus* (Holder, 2016a). I initially set out to use music as a mapping strategy[128] but, in my conviction to work within the bounds of synthetic biological determinism, I ultimately felt that this was the wrong approach.

The relationship between matter and sound is undeniably complex and I did not feel ready (or able within the scope of the project) to unlock any corporeal doors. Rather, in working from scientific principles, my interest was in exploring how matter might evolve the language that I offered to share with it. Evolution at the microbial level is something

that happens on a timescale that is possible for humanity to experience. From Eduardo Kac's *Genesis* (Kac, 1999) and my experience researching cyanobacteria (Brain and Caldwell, 2015), I was aware that it is possible to direct evolution through specific actions[129]. Further, Richard Lenski, in his work on the long time evolution of *E. coli* has experienced mutations without planned direction (Barrick *et al.*, 2009, pp. 1243–1247). Thus, I felt that through translating an experience of my own and sharing it with lively material, I might be able to experience the processes that lively material engages in, over time and across generations.

4.5.2.6 Sound as Mapping Strategy

> 'I am sitting in a room different from the one you are in now. I am recording the sound of my speaking voice and I am going to play it back into the room again and again until the resonant frequencies of the room reinforce themselves so that any semblance of my speech, perhaps with the exception of rhythm, is destroyed. What you will hear, then, are the natural resonant frequencies of the room articulated by speech.' (Lucier, 2014)

Alvin Lucier's performance, *I am sitting in a room* (Lucier, 2014)[130] became a key influence in choosing the medium through which I would translate the genetic code. In an attempt to smooth out irregularities in his voice, Lucier recorded and re-recorded a phrase, ultimately eliminating language and replacing it with noise. This removal of language appealed, perhaps through similarly appropriating the primacy of speech, I could lose control of it[131]. The unique qualities or 'grain of the voice' (Barthes, 1977, p. 182)[132] enable me to combine both the formal logic of a language system with a subjective position. Through language I could communicate a thought as DNA and allow this to be genetically recorded and re-recorded within the lively material of the cell. Through sound (speech), I hoped to aesthetically convey the slipperiness of my presence within the body of the organism. I began by thinking that I wanted to signify the specific changes that might occur through mutation but then realised that in order to engage with the organism, I was not primarily interested in the signifier with all its forms of mediation, but in the event of participation. I wanted to engage in a form of exchange. I would impose my thought upon the body of the organism and was curious to know how it might resonate within the host.

Given that I wanted to engage in a form of dialogue with the organism, and one that I could potentially present for a public audience, spoken language felt an appropriate way to highlight the compounding of DNA, code and information. I was compelled to draw upon the perceived biosemiotic relationship between codons and phonemes[133]. Codons when combined, form segments of DNA (for now, let's call them genes) that can make functional proteins. The common understanding of the term 'gene' (as a specific unit of heredity), as has been noted by philosopher of science, Evelyn Fox Keller, is diminished the more science begins to understand about DNA. Keller suggests that the term be abandoned altogether in favour of embracing more ambiguous terminology (Keller, 2010, p. 80).[134] Phonemes are short components of language that, when combined, form words and can make meaningful sentences. There are 44 standard phonemes in the English language. By adding phonemes to represent regional dialects and other basic utterances, a complete mapping of 64 phonemes to codons was possible. After initially striving to find a meaningful method for mapping phonemes to codons, I resorted to grouping amino acids according to their specific properties (see Figure 29) and then arbitrarily mapping phonemes to these broader groupings. The mapping is only meaningful therefore in the sense that by grouping similar amino acids, where possible, similar phonemes ("d", "t", "dd" for example) are also grouped together (see Figure 31).

AMINO ACID	CODONS	PHONEME	PHONETIC SOUND
Aspartic Acid	G A U	/aʊ/	**ou**t, n**ow**, cac**ao**, mi**aow**, mi**aowe**d, g**au**ss, b**ough**, pl**ough**ed, v**owe**d, Macl**eo**d
Aspartic Acid	G A C	/ɔɪ/	av**oi**d, t**oy**, l**awy**er, Fr**eu**dian, ch**oll**a, enj**oye**d, b**uoy**ant, b**uoye**d
Lysine	A A A	ɢ	Glottal (g at back of throat, a gulping, glugging sound)
Lysine	A A G	ɤ	Eugh (the sound a child makes when s/he doesn't like something)
Histidine	C A U	|	Tszk (tut-tut or tsk-tsk type noice)
Histidine	C A C	Hm	Hmmm (a nasal mmm, with a breath in front)
Arginine	C G U	B	Brr (rolling of the lips)
Arginine	C G C	H	Hhr (think French r, rolling at back of throat)
Arginine	C G A	ʋ	Vw (revoir)
Arginine	C G G	ɲ	Ny (onion)
Arginine	A G A	ʄ	Dy (would'ya)
Arginine	A G G	ɻ	Ly (will'ya)
STOP	U A A	/uh/	(short intake of breath)
STOP	U A G	/uhh/	(long intake of breath)
STOP	U G A	/1	(pause 1 sec)

Figure 31: Sample of Original Phoneme to Codon Mapping Plan. Excel. Research documentation, 2015. Image: Louise Mackenzie

Further details of the development of the cypher are documented in Appendix IV. The potential mapping strategies are limitless, only bounded by imagination. Returning to the question of codifying the living, I am left with the realization that our present reading of

DNA within the body as ‘the genetic code’ is merely one of many possible translations. Beyond the scope of this research, therefore, are options to explore the relationships between DNA and language systems as art practice, which may further challenge the aesthetic (and ethical) use of genetic material as communication medium.

4.6 What will happen if I store this thought safe within you?

Now that I was ready to communicate with the organism, I had to choose what to say and how to say it. My initial intention was to communicate through a virus, drawing on Burroughs' relationship between language and materiality. This would have involved encoding information into a bacteriophage (a bacterial virus) and in the lab that I was working with, this option was less viable (see Appendix IV). The more suitable and practical method was to work with a DNA plasmid, a small circular piece of DNA that floats within the body of the bacteria, external to its chromosomal DNA, but copied on to subsequent generations nonetheless. A DNA plasmid is a small section of DNA with a limited number of base pairs, therefore the phrase that I chose to encode, using the cypher that I had developed, could be no longer than around 150 base pairs. Around the length of a tweet[135]. As I was interested in a response from the organism, and the evolutionary process by which this might occur, the phrase had to question my interaction. I chose to frame this as a question to the organism and, guided by the desire to act as intuitively as possible, I returned to the original dialogue that I performed to the organism in the first year of my research (see Section 3.1.1).

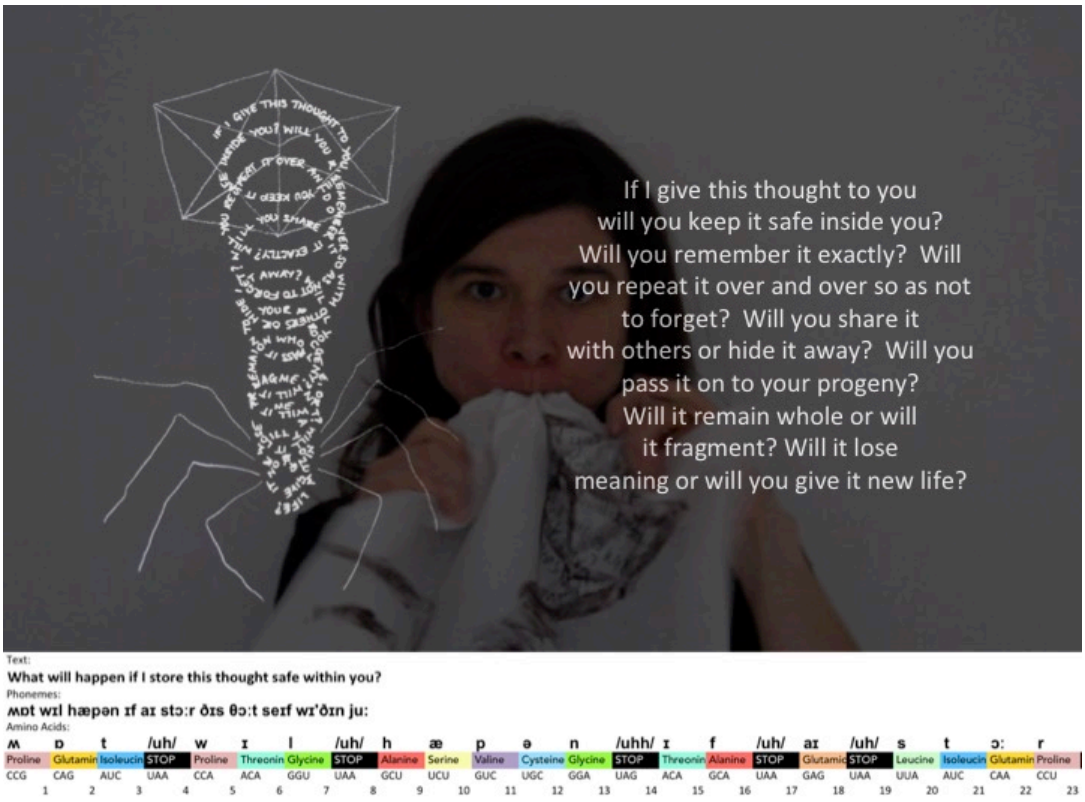


Figure 32: Video still from working Lab Diary. Research documentation, 2015. Image: Louise Mackenzie

Text:

What will happen if I store this thought safe within you?

Phonemes:

ʍɒt wɪl hæpən ɪf aɪ stɔːr ðɪs θɔːt seɪf wɪ'ðɪn juː

Amino Acids:

ʍ	ɒ	t	/uh/
Proline	Glutamine	Isoleucine	STOP
CCG	CAG	AUC	UAA

w	ɪ	l	/uh/
Proline	Threonine	Glycine	STOP
CCA	ACA	GGU	UAA

h	æ	p	ə	n	/uhh/
Alanine	Serine	Valine	Cysteine	Glycine	STOP
GCU	UCU	GUC	UGC	GGA	UAG

ɪ	f	/uh/		aɪ	/uh/
Threonine	Alanine	STOP		Glutamic A.	STOP
ACA	GCA	UAA		GAG	UAA

s	t	ɔː	r	/uh/
Leucine	Isoleucine	Glutamine	Proline	STOP
UUA	AUC	CAA	CCU	UAA

ð	ɪ	s	/uh/
Phenylalanin	Threonine	Leucine	STOP
UUC	ACA	UUA	UAA

θ	ɔː	t	/uh/
Phenylalanin	Glutamine	Isoleucine	STOP
UUU	CAA	AUC	UAA

s	eɪ	f	/uh/
Leucine	Serine	Alanine	STOP
UUA	UCG	GCA	UAA

w	ɪ	ð	ɪ	n	/uh/
Proline	Threonine	Phenylalanin	Threonine	Glycine	STOP
CCA	ACA	UUC	ACA	GGA	UAA

juː	/1
Glutamic A.	STOP
GAA	UGA

Figure 33: Louise Mackenzie, 2015. *What Will Happen If I Store This Thought Safe Within You?* First Iteration of Text to Phoneme to DNA Translation for Insertion in Synthetic DNA Plasmid. Image: Louise Mackenzie

[82] Olympus CKX41 microscope, School of Marine Science & Technology, Newcastle University
[83] http://www.blurb.co.uk/books/4323687-oltramarino
[84] *Arthrospira*, more commonly known as *Spirulina*, is capable of producing *phycocyanin*, an anti-oxidising phycobiliprotein with a rich deep blue pigment. Phycocyanin is used as a natural blue food colouring, in place of synthetic dye Brilliant Blue, which has been linked to health concerns skin and eye irritation (https://onlinelibrary.wiley.com/doi/abs/10.2903/j.efsa.2010.1853) and ADHD (https://www.scientificamerican.com/article/where-does-blue-food-dye/). Research into *Arthrospira* and another micro-algae, *Dunaliella salina* (capable of producing beta-carotene, also a highly prized pigment) involves optimising the production of these pigments. The process used to generate high volumes of such pigments involves what is described as "strain development activities" (the word commonly used in relation to this process is 'stress'). In other words, the algae are pushed to the limits of their natural capabilities to excrete higher volumes of the proteins required for commercial production. In some cases, the genetic morphology of these unicellular organisms is altered, through the process of micro-evolution: rapid natural selection for specific conditions. A nano-scale version of the domestication of wildstock or the breeding of dogs.
[85] Dr Gary Caldwell and Dr Chelsea Brain, of MaST, Newcastle University, UK.
[86] *The Stars Beneath our Feet* was commissioned by Artichoke for Lumiere Durham 2015 (https://www.loumackenzie.com/thestarsbeneathourfeet).
[87] Total Internal Reflection Fluorescence microscopy is a technique by which fluorescent light absorbed and emitted by the object of study is captured at the cell surface and translated into images. 'Fluorescence is the property of some specimens to absorb light at a particular wavelength and to subsequently emit light of longer wavelength. This phenomenon is used in fluorescence microscopy to study specimens which *can be made to fluoresce*.' Quoted during the presentation, 'An Introduction to Fluorescence and Confocal Microscopy', given by Kate Passam, Advanced Image Specialist for Nikon Instruments UK at Newcastle University, 2015 (my italics added). Fluorescence microscopy requires a high-energy light source, such as mercury or laser, and special filters to distinguish between light absorbed (or excited) via the object of observation and light emitted. TIRF allows the detailed study of the surface regions of cells, by imaging a 100-nanometer layer at the interface of sample and coverslip through making use of the evanescent field. The evanescent field is a complex physical phenomenon, summarized by Leica Microsystems as, 'The evanescent field occurs if incident light is totally reflected at the interface of two transparent media with different refractive indices. In biological applications the incident light is usually laser light and the interface the glass of the coverslip and a film of aqueous solution between coverslip and adherent cells.' (Ockenga, 2012).
[88] I owe the bulk of my understanding of microscope imaging to the support of the excellent Dr Alex Laude of Newcastle University's Bio-Imaging Unit, who also recommended my attendance at the two-day, Light Microscopy Workshop at Newcastle University.
[89] My observations of scientists using complex microscopy techniques at the Institute of Genetic Medicine (and via instruction from Kate Passam, Advanced Image Specialist for Nikon Instruments UK, during Newcastle University's Light Microscopy Workshop) is that on viewing an image via a computer screen, one will choose colours, adjust contrast, hue and other parameters to enhance the image and pick out a particular feature of interest. This is an intuitive process, based on what feels like the clearest image. It is worth noting that other images we cannot perceive directly are similarly constructed, for example, images taken by the Hubble telescope are enhanced by scientists who will use colours as signs to depict specific information such as type of gas emitted from a star (Moskowitz, 2010).
[90] Definitions of 'looking' and 'seeing' from Oxford English Dictionary (Stevenson (ed.) and Waite (ed.), 2011)
[91] The sound walk was given as part of a range of activities supporting the sound art installation, *Sound Strata of Coastal Northumberland* by artist, Susan Stenger (Watson, 2015).
[92] Besides the work of pioneering field recordist Chris Watson in the UK, the University of Cornell Macaulay Library in the USA houses the world's largest collection of animal audio recordings. The Macaulay Library aims to create a comprehensive library of natural sounds and as such seeks recordings for species not currently on their database. At time of print there are 13135 audio recordings of insects, ranging from grasshoppers to ants, but no recordings of microscopic

organisms (The Cornell Lab of Ornithology, 2017). Ultrasound expert, J. D. Pye has written extensively on the use of ultrasound and infrasound recording techniques to study the high and low frequency sounds of living organisms (Pye, 1993; Pye and Langbauer, 1998) although not micro-organisms, and of course this falls outside of human levels of perception. Other notable natural sound recordings are the Borror Laboratory of Bioacoustics in the Museum of Biological Diversity at Ohio State University, USA, which again includes insects within its collection, but not micro-organisms, although their *BioPresence* art exhibition (Ohio State University, 2015) did include a technologically mediated recording of slime mould (First Contact, Axel Cuevas Santamaria, 2015).

[93] Ümwelt is a term introduced by philosopher and semiotician, Jacob Von Üexkull to describe the environment as experienced by the organism (or animal) as something that is unique to the organism (Sebeok, 1994, p. 33).

[94] http://www.viralexperiments.co/relational-sensing

[95] Dombois & Eckel's chapter on Audification in The Sonification Handbook (2011) provides an excellent brief history of technological developments in sound (Hermann, T., Hunt, A., Neuhoff, J. G., editors)

[96] Audification is an auditory display technique in which a sequence of data over time is scaled and filtered (to remove background noise from the sample) so that frequencies lie in a human-audible range (see Dombois & Eckel, 2011 and Höldrich & Vogt, 2015).

[97] The mapping techniques used in sonification can be subtle (such as using the changes in value of a variable to alter the frequency of a sine tone) or they can be more elaborate (e.g., the use of melodic phrase structures to represent the various activities of a computer program, as Paul Vickers and James Alty have explored (Vickers and Alty, 2006, pp. 335–354)). Whilst an exact definition is still debated, the term can summarily be defined as 'the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation' (Hermann *et al.*, 2011, p. 9).

[98] Microbiological samples in liquid medium were held on non-reflective microscope slides with an inset concave curve and placed under a microscope where two lasers at precise angles were directed at the samples, as described in a Skype conversation with Joe Davis (see Appendix III, Viral Experiments, Interviews).

[99] This work led Gimzewski and Pelling to define a new field of research: Sonocytology or cell sonics (Pelling, Andrew; Niemetz, 2004).

[100] Gimzewski and Pelling found that the tip of an Atomic Force Microscope (AFM), which is normally in motion detecting the contours of a surface, could be used whilst stationary to detect the motion of a cell membrane. Through transforming the oscillations of the AFM tip, it was possible to determine the frequency, in kHz of the oscillations, thus converting them to sound (Pelling, Andrew; Niemetz, 2004).

[101] f/2 solution, fore further information, see (Guillard and Ryther, 1962).

[102] Further details on use of the AFM in the sonification of *Dunaliella salina* can be found in Appendix III, Viral Experiments, Microbial Sensing (http://docs.wixstatic.com/ugd/858ebb_91972e48d80c4c61af9f54bc030fdd1c.pdf?index=true).

[103] The approaches are discussed in detail under Appendix III, Viral Experiments, Microbial Sensing.

[104] Photosounder is an audio editor/synthesizer that is capable of converting a photographic image to sound, thus sonifying the image data. Created by Michael Rouzic in 2008, Photosounder uses synthesis algorithms to take the digital information of an image and convert this into sound frequencies. It is also possible to use Photosounder to alter the resulting sound using a variety of parameters to achieve desired acoustic effects.

[105] https://soundcloud.com/louise-mackenzie-1/dunaliella-salina_20s_photosounder_noiseremoved

[106] https://soundcloud.com/louise-mackenzie-1/maxpatch-microbialsensing-test2

[107] Attempts to reveal the object, through increasingly complex layers of technology are considered as alchemical in reference to the ancient Greek and Egyptian origins of the tradition. Not alchemical in the sense of seeking immortality or turning metal into gold, but alchemical in the *anima mundi* sense of seeking out the 'essence' of matter. I use here the Kantian sense of the 'thing-in-itself' as noumenon: an object in the world that we can perceive as existing outside of us, yet never fully have access to. Thus we understand things to exist outside of us and yet we know that their 'appearance',

the way that we perceive them, is not outside of us. The way that the noumenon appears to an observer therefore Kant describes as the phenomenon.

[108] Canadian composer and environmentalist, R. Murray Schafer, first coined the word 'soundscape' to define a sound or combination of sounds that form an immersive environment. It is often used to refer to the acoustic environment audible to the human ear.

[109] https://www.loumackenzie.com/natura-naturans

[110] It has long been debated whether viruses are living or not. In 1892, botanist Dmitri Ivanovsky was tasked with determining the cause of a disease affecting tobacco plantations. After applying porcelain filters to remove bacteria from his samples, he found a smaller agent causing the infection (The Editors of Encyclopaedia Britannica, 2016). In 1898, Dutch microbiologist Martinus Beijerinck repeated the experiment and created the term 'virus' (the root of the word is Latin for 'poison') to describe the infectious agent which was not a bacteria and thus to his mind a new, smaller form of life (Bos, 1999, p. 1). In 1935, American chemist, Wendell M. Stanley shared the Nobel Prize in Chemistry for his work, which claimed viruses to be inert matter. On crystallising the tobacco virus and viewing its biochemical structure, it was found not to contain the essential structures required for metabolism, an essential requirement in the definition of life (Villareal, 2008, pp. 101–105). The debate continues to the present, with theorists unable to agree (Brown, 2016) Luis P. Villareal offers another perspective, 'More poetically, virologists Marc H. V. van Regenmortel of the University of Strasbourg in France and Brian W. J. Mahy of the Centers for Disease Control and Prevention have recently said that with their dependence on host cells, viruses lead "a kind of borrowed life."' (Villareal, 2008, p. 104) Yet it is exactly the liveliness of viruses that drives continued interest in their use as tools within the laboratory. Borrowing from Lyn Margulis' references to perception within science, Villareal describes this as a 'myopic view' (Villareal, 2008, p. 102)and goes on to suggest that there may be a continuum from non-life to life, as also suggested by Catts and Zurr (Catts and Zurr, 2006, p. 2) and Radomska (Radomska, 2016, pp. 32–26).

[111] https://www.loumackenzie.com/transformation-content

[112] Barthes proposed that Saussure's concept of the sign is primarily denotative, offering literal or 'common sense' meaning whereas in connotation, a sign can be comprised of multiple layers of meaning, all present together, and bound by historial and anthropological situatedness (Barthes, 1977, pp. 32–37).

[113] Davis' work was inspired in part by the launch of the Voyager spacecraft and his frustration with the anatomically incorrect information chosen to represent the female form (Davis, 1996).

[114] Research in DNA data storage has caught significant commercial attention, with synbio startups such as Twist Bioscience providing wetware support to major corporations such as Microsoft, Apple and Google. As early as 2006, one possible method of DNA data storage was patented in the US by Battelle Memorial Institute (Wong, Wong and Foote, 2006)

[115] In Davis' own words, 'the story doesn't end here'. Davis recently posted the following entry on his Facebook account: 'As far as I know, the first ever message-bearing crystal was produced today in the laboratory of Thomas Schwartz at MIT Biology. The result of considerable patience and no small effort, this is a crystal composed of millions upon millions of Microvenus DNA molecules. Ordinarily, crystals are comprised of huge numbers of identical molecules and so, are invariably uniform. Due to this natural homogeneity and despite frequent appearance of "memory crystals" in science fiction, individual crystals are not programmable in the way that data can be recorded onto flash drives or burned into laser discs. In this case, data is contained in each of the uniformly repeating molecules that make up the crystal. Each molecule in the crystal matrix is encoded with the Microvenus icon. At the time Microvenus was first created (1986), synthesis of DNA in quantities sufficient to produce such a crystal was prohibitively expensive. Synthetic DNA has become much more affordable in the past few years however, and the price continues to drop. The story doesn't end here, though. More to come... Please Standby :)' (Davis, 2017).

[116] From my own experience in the laboratory and subsequent conversation with Eduardo Kac (Kac and Mackenzie, 2016) it is important to point out that the translation of the mutated DNA is not presented in real time, thus the mutation that occurs by audience members switching the UV light has no direct connection to the mutated text that we see in the *Genesis* installation, nor to the musical interpretation of DNA mutation in the work of Gena and Strom (Gena and Strom, 1995, p.

5). Kac is clear about this in describing the work, maintaining that the audience is nonetheless able to experience a sense of this mutation in real time through the visual feedback of the bacteria glowing when the UV light is switched on. The level of complexity inherent in creating the text and musical translation are such that to the audience, time is in effect collapsed and a simulation of the mutation event is experienced.

[117] See Appendix III, Viral Experiments, Interviews (http://www.viralexperiments.co/interviews) for full interview transcript.

[118] This becomes, almost literally, the thought that I store within the body of the organism, as will become apparent later in the chapter.

[119] Huffman coding, developed by David Huffman in 1952, is a method used in information theory that (in the most simplistic terms) aims to eliminate redundancy in coding through an algorithm that assigns a prefix code based on the frequency of the characters used (Huffman, 1952, pp. 1098–1101).

[120] I initially cut and pasted the figure of the lamb, as used in Ailenberg and Rotstein's article to show in this thesis, but the quality of the image (through difference of scale and therefore pixellation) led me to instead choose to reproduce the image: as with any reproduction, my drawing is almost, but not exactly identical.

[121] The four bases are complicated by RNA (single stranded genetic information), which is comprised of Adenine, Cytosine, Guanine and **Uracil**, which *becomes* Thymine in DNA. The difference in chemical composition is that a methyl group exists on Thymine, but not on Uracil. There are only speculations as to why this occurs. It is known that Cytosine (one of the other nucleic acid bases) can *spontaneously* convert to Uracil through a process known as deamination. Such spontaneous reactions occur within DNA at a rate of around 100 bases per cell per day (Alberts *et al.*, 2002). It is also known that Uracil *becomes* Thymine in a process of methylation. For further details, read the answer to the evocatively titled question addressed to the US National Science Teacher's Association website, *'Why did mother nature use uracil to replace thymine in mRNA (messenger ribonucleic acid)? What is the advantage of using U instead of T in the RNA?'* (Freyer and Sturr, 2006)**.**

[122] It is possible even to envisage hyperreal three-dimensional DNA sculptures constructed from a four-colour base, ordered and arranged in specific folds. The field of bionanotechnology sculpturally manipulates the three dimensional molecules that comprise DNA, forming synthetic DNA into novel structures; a technique sometimes referred to as DNA origami (Seeman, 1982, 2005). This approach privileges form over function although the two begin to converge as the potential for in vivo therapeutic use leads to the design of DNA boxes that can chemically lock and unlock to deliver drugs within the body (Kumar *et al.*, 2016).

[123] Levels of articulation within semiotic theory relate to the various components of language that can be broken down and reassembled to provide different meanings (Chandler, 2002, p. 244). Compounding the relationship to language, amino acids are each characterised via a letter of the modern Latin alphabet, immediately suggesting a simple method of composing genetic information in text form (albeit with the exclusion of six letters). An internet search of 'making sentences with DNA' throws up myriad examples of high school or university biology lesson plans that teach biology through the translation of sequences of codons into words and sentences. Perhaps instead the letters could be substituted for Tamil, Aramaic, hieroglyphs or the colours in a box of crayons.

[124] This heterotopia is of course borrowed from Michel Foucault and Jorges Luis Borges in turn (Borges, 1993; Foucault, 2005).

[125] Anthropological studies attest to the ubiquitous significance of music across human culture, see for example an early reference made by Margaret Mead (Mead, 1928, p. 109) and a subsequent survey of musical anthropology by Alan Merriam (Merriam, 1964). Tracing back through classical literature, Pythagorean scholars counted music as one of the four fundamental characteristics of mathematics: *"Arithmetic = number itself; Geometry = Number in space; Music or Harmonics = Number in time; Astronomy = Number in space and time"* (Guthrie and Fideler, 1987, p. 34)

[126] For contrast, see for example bio artist, Adam Zaretsky's reciprocal vibratory experience, *Macro Micro Music Massage* (as documented by Plohman, 2001) and the scientific investigation of the effects of vibration on cell proliferation (Martirosyan, Baghdasaryan and Ayrapetyan, 2013, pp. 40–47).

[127] Much of the literature is non-academic, with associations to new-age movements and healing therapies, or alternatively to occult technologies. An early advocate of the link between musical resonance and atomic or molecular forces was Philadelphia born entrepreneur, John W. Keely. Founder of the Keely Motor Company and pioneer of 'free energy', Keely performed public experiments claiming to have discovered a method of generating power based on the resonance of tuning forks[127]. Keely died in 1898 and was denounced as a fraud the following year after investigation by The Philadelphia Press. However his theory of 'sympathetic vibration' has been revived in contemporary scientific discourse around consciousness and quantum entanglement (Bhutkar, 2015). Independent researcher Richard Merrick has proposed a 'grand scientific musical theory' that unifies music across disciplines such as geometry, biology and physics through a complex system of pattern recognition (Merrick, 2009, 2010). In his self-published article, *Toward a New Harmonic Framework*, Merrick argues against theological associations that have held back harmonic resonance theories by specifically invoking the golden ratio as scientific evidence of a 'natural order' and proposes that, '[a] new vision of life as a beautiful musical crystal could suddenly blossom into the social consciousness, elevating self-image and bringing a new sense of interconnection and responsibility back to society.' (Merrick, 2017).

[128] See Appendix III, Infectious Melodies (http://www.viralexperiments.co/infectious-melodies-proposal).

[129] See also (Packer and Liu, 2015) and Kishony Lab's video of bacteria rapidly adapting to antibiotics on a plate (Harvard Medical School, 2016) provides a powerful visible account of directed evolution.

[130] https://www.youtube.com/watch?v=fAxHlLK3Oyk

[131] Along with Alvin Lucier, composer, Robert Ashley's *Automatic Writing* (Ashley, 1979) led me to think about unconscious speech acts as a means to create prose that could act as the basis for a dialogue with the organism. In *Of Grammatology*, Jacques Derrida's *logocentrism* deconstructs the Western philosophical assertion of the primacy of speech to hold meaning over writing, attributing this to a metaphysics of presence. I play on this idea in a contemporary context, by translating speech into a deferred recording of speech (Derrida, 1979, pp. 3–73).

[132] I borrow from literary theorist, Roland Barthes his term, 'the grain of the voice' to refer not specifically to the voice in music, as Barthes does, but to the 'materiality of the body' as signified through speech. Barthes discusses the grain of the voice through philosopher, Julia Kristeva's principles of geno-text and pheno-text (Barthes, 1977, p. 182).

[133] I have already alluded in Section 3 to the genetic-semiotic relationship through the work of Crick and Jakobson, which developed as the field of biosemiotics. A particularly recent evolution of this line of questioning comes from evolutionary biologist, Tyler Volk who discusses the relationship between phonemes and codons in terms of 'alpha-kits': systems of language that can be defined according to observable patterns (Volk, 2017, pp. 157–165). I too am drawn to the patterns that appear to us in biological and language systems, although I like to believe that their teleology is a faculty of consciousness that is always-already beyond our grasp. Cultural theorist, Francesco Vitale draws attention to the biological undertones that run through Derrida's earlier works, becoming manifest in his later writing. For Vitale, Derrida's *différance* points to, 'a genetico-structural condition of the life of the living and of its evolution' (Vitale, 2014, pp. 95–114), suggestive of an infinitely elusive quality of consciousness.

[134] Evelyn Fox Keller challenges the language used in genetics to present a feminist view of scientific theory that allows for critical enquiry into the 'and/or' view of nature-nurture. Keller's approach works from within the life sciences to demonstrate that nature and nurture were never separate and that we have always been more than both or either. This expanded view of the field has helped me to reconsider facts as presented in the context of the laboratory, and negotiate DNA as code through my research.

[135] The social media application, *Twitter* has historically enabled users to communicate with a maximum of 140 characters of text, known as 'tweets'. As of 26 September 2017, Twitter announced an increase to a total of 280 characters, prompting a backlash amongst users that this defeated Twitter's *modus operandi* of concise communication.

5 SUBJECTIVE EXPRESSION OF LIVELY MATERIAL

5.1 Constructing Lively Material in the Lab

In this chapter, having designed a cypher and chosen the phrase that I wished to encode, I then learned how to impose my thought upon the body of the organism. I enacted a slow performative approach to understanding the steps involved, which lead to a reading of my actions that sits both inside and outside the laboratory.

The space between materiality and subjectivity is animated right here. My thought becomes lively in another body. The human construction of DNA is novel, inclusive and differential, fed by multiple voices, shaped primarily by science and the media, *how might it be shaped through art practice?*[136]

Lab Diary, 21 November 2014:

Is it possible to conjure up DNA, just as we conjure up words? The media myths would lead us to think so. An article in the New York Times suggests it is, '[P]rocesses using synthetic biology … include "artificial gene synthesis," in which DNA is *created on computers and inserted into organisms*' (Strom, 2014, italics added). But how do I move from computer screen to living organism? How do I actually generate this lively material? Synthetic biologist and contributor to speculative design project, *Synthetic Aesthetics*, Christina Agapakis takes care to bridge the mythical gap:

> 'In synthetic biology, the physical reality of DNA as a chemical is analogous to the transistors that make up computer chips, its raw sequence of bases the "assembly code." These are layers that most programmers don't have to think about when they design software, just like most synthetic biologists don't necessarily think about how the DNA is made when they design metabolic pathways. But this abstraction in the engineering hierarchy doesn't mean

> that the lower levels aren't important or happen somehow on their own, and certainly not "from scratch."' (Agapakis, 2014)

> Thank you Christina, I feel it will be important not to forget this.

There are a number of methods by which DNA can be synthesized. The term DNA synthesis can refer to:

- DNA replication: the natural process of DNA synthesis that occurs in all living cells. This can also be artificially stimulated *in vivo*;

- Polymerase Chain Reaction (PCR): the synthesis of DNA *in vitro* within the laboratory, through melting the DNA (a process which separates the two strands of the double helix) and replication of the strands using the enzyme DNA polymerase;

- Artificial Gene Synthesis: the artificial or chemical synthesis of genes *in vitro* without the requirement of an existing DNA template (also known as oligonucleotide synthesis). Recent research has also led to the synthesis of novel base pairs, not found in nature[137].

DNA is not magically derived from thin air, but from cane sugar; the synthesis and production of oligonucleotides first developed in the 1970s. The four DNA bases are, 'available in metric ton quantities from a variety of sources. The cheapest suppliers are in China; they sell their product for under $100/Kg' (Sanghvi, 2005, p. 20). The synthesis of DNA from the bases is a complex process involving nucleotides and nucleosides. Nucleosides were originally manufactured from fish silt, but this process was inefficient, 'to isolate 1Kg of four nucleosides, one would need 1,818 Kg of salmon' (Sanghvi, 2005, p. 23). A new process using cane sugar has been refined, fully automated and is patent protected by Mitsui Chemicals in Japan, significantly reducing the production costs of DNA synthesis (Sanghvi, 2005, p. 21). I can't seem to find any public information on how much cane sugar is needed and the processes by which it is acquired for DNA production.

5.1.1 Expressing Wetly

> 'Between the dry world of virtuality and the wet world of biology lies a moist domain, a new interspace of potentiality and promise'. (Ascott, 2000)

With the cypher created (detailed in Section 4.5.2), I now had a means to translate my spoken word performance into a phonetic sentence that I could then translate into DNA. The phonemes in the sentence are matched to codons, which are then read in sequence as a string of DNA. This string of DNA is then inserted within a loop-shaped string of DNA called a plasmid. Plasmids exist naturally within bacterial cells, but this plasmid is synthetic, created to order within the laboratory.

Synthetic biology is ontologically situated between the dry laboratory spaces of engineering and computer science and the wet laboratory space of biology. The labels dry and wet signify the difference in the spaces: the former a space of desks and computers, bits and bytes, the latter a space of benches and bottles, cultures and cells, creatures and flesh. With terms like 'wetware' and 'moist media'[138] the coding metaphor is extended into corporeality without question. No sense of agential, fleshy metaphors pushing back.

The computable qualities of DNA, molecules defined in terms of four basic units, 'the combinatorial possibilities… not one, but two sets of binary pairings in parallel, A-T, C-G' (Thacker, 2004) have given rise to the possibility of storing vast amounts of data in the form of DNA. Following this model, and having designed (as crisp, dry data) the thought that I want to share with the organism, I was now ready to enter the moist world of the wet lab in order to express myself within the organism. None of this felt comfortable.

The transition from abstract concept to visceral matter complicates my understanding of DNA. What is this matter that is dry and informational, yet moist and relational? DNA is not considered as life but as code, yet without DNA there is no life. It must therefore be 'lively material', within which I express my thought, wetly.

Technical information on the creation of the plasmid is detailed in Appendix I.

5.1.2 Moist Loops of Communication

Lab Diary, 26 July 2015:

> Plasmids, these beautiful little looped pieces of DNA, they soak up information and then they pass it on and they can move freely between organisms and do this. They are like moist little loops of communication.

The smallest motes of life: DNA, plasmids, viruses and bacteria are common tools within the laboratory, but I cannot shake their presence as biological entities that possess 'indeterminate vitality' (Bennett, 2010, p.92) and exist in relation to other living entities. In the plasmid, form and function combine.

Figure 34 shows a construction of appropriated images of plasmids taken using Electron Microscopy. In scientific texts where the contents of the plasmid must be delineated, it is depicted as a pure circle (see Figure 36). Yet as perceived through the microscope, its form is irregular, twisted and even knotted. The circle reduces form to function (and a singular function, that DNA transmits information) overlooking consideration of functional qualities present within the plasmid: for example, that it moves, bends and folds[139]. No matter how many images of plasmids I piece together, how many angles I look from, they could not tell the whole story. Form is in motion and form relates - always multiple possibilities.

Figure 34: Louise Mackenzie (2017), *Flat Lively Objects.* Image: Louise Mackenzie

5.1.3 The Name of the Gene

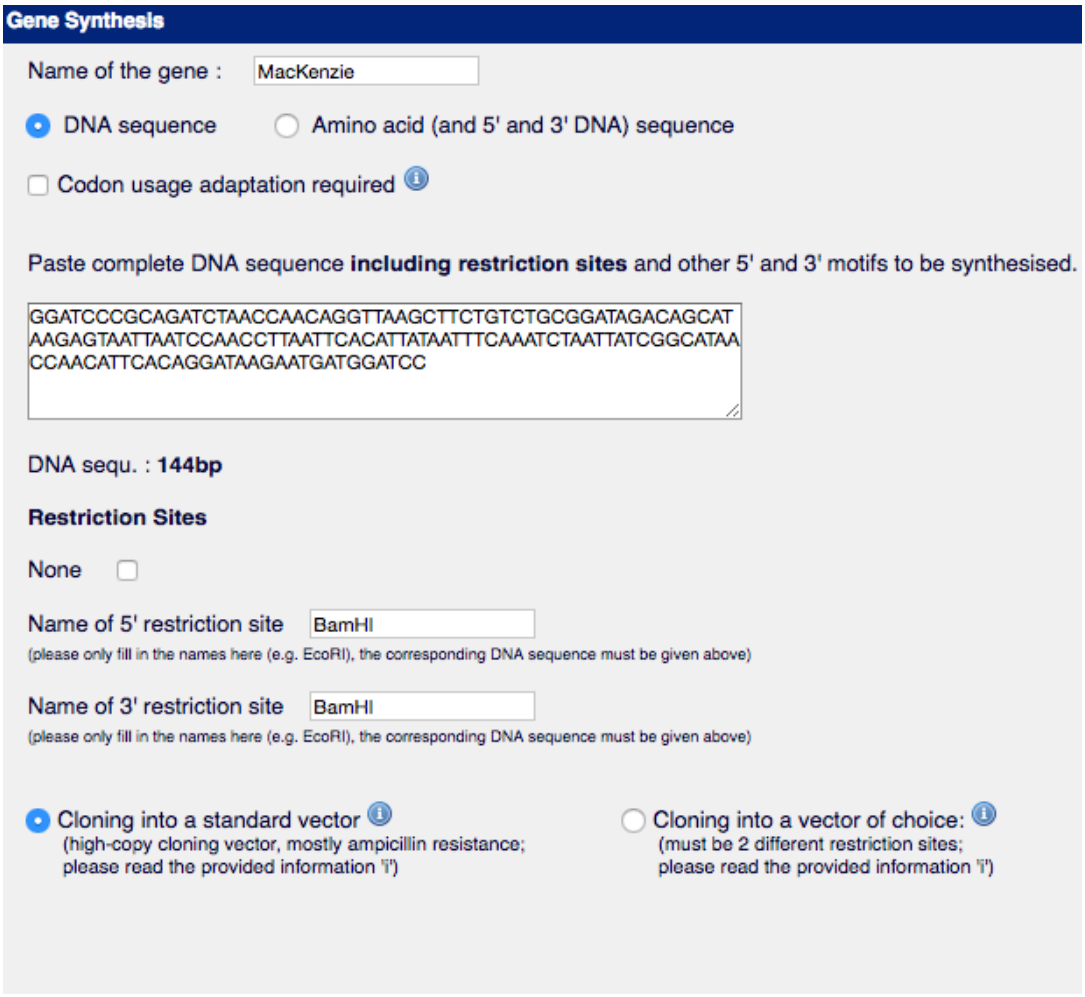


Figure 35: Online Gene Synthesis Form for Production of Plasmid Vector. Research Documentation, 2015. Image: Louise Mackenzie

Names, patents, inventions, how could we function without them? **Name of the gene** is the first field to be completed when ordering the plasmid. It could almost be a book or film title[140]. One of my colleagues in the lab ordered the plasmid for me and therefore completed details on the order form, naming the gene MacKenzie (my surname is Mackenzie[141]). This act of naming brought to mind the 'artist's gene' that Eduardo Kac created for *Genesis*[142] which although relevant in the context of Kac's work, still felt uncomfortable. Let us set aside for a moment the fact that Kac's sentence is not a gene in strict scientific terms (see 5.1.4, below). First, I wish to focus on the generation of ideas. In naming a 'gene', Kac takes on board fully the mantle of 'creator'. One could liken this to the creation of International Klein Blue (IKB) by Yves Klein (Howarth, 2000). Both artists claim to have made something unique: Kac by defining a specific DNA segment as

an artist's gene and Klein through patenting the unique chemical procedure that produces an exact shade of paint[143]. In both cases, although they acknowledge the work of others, the artists choose to associate themselves exclusively with an invention. That is, the *idea* is invented and the resulting artwork is a product of the idea. Both artists required collaborators and both ideas are generated through a specific combination of materials (materials that already existed in different formations and will go on to exist in new formations in future). For Klein, a fixing agent produced in collaboration with an art supplier was the manifestation of the *idea* of a unique, transcendental colour. For Kac, the idea incorporates a post-modern self-awareness: a section of DNA assembled in a specific manner is labelled as the 'artist's gene', specifically addressing the power of the word and signifying 'humanity's supremacy over nature' (Kac, 1999).

I too have an idea, but it is a question to prompt a dialogue. With the label, MacKenzie (not Mackenzie), something had been taken from me. The capital K served to emphasise the transgression. Not only was my name used without my permission, it was altered without my permission[144]. I did not want to stake a claim. This was not my idea. But I did want to relate, I did want to express myself, to communicate and solicit a response (in the organism, in others, I hope they don't mind if I do). So here are a few suggestions I have noted for signifying my expression:

- Meaningless
- Meaningful
- Name of the gene
- Not a gene
- Idea
- Only a thought
- No known function

5.1.4 No Known Function

function | ˈfʌŋ(k)ʃ(ə)n

an activity that is natural to or the purpose of a person or thing
[mass noun] practical use or purpose in design
(Oxford Dictionary of English)

Plasmids are pieces of DNA constructed within industrial DNA synthesis facilities: genetic production lines. Pure circles, with clearly defined starts and ends, this bit goes here, that there, assemble the whole, completely.

The plasmid is a continuous loop of DNA, which comprises distinct sections of DNA with distinct functions or 'genes'[145]. Within the DNA of the plasmid is all of the information that the plasmid requires to generate more plasmid, simultaneously information and function. A 'natural plasmid' (that is, one found naturally occurring within a living organism rather than one constructed in a laboratory) contains sections of DNA: an ORI or origin of replication (an origin point in the loop of DNA where copying can begin) and one or more functions that are used by the host organism, such as resistance to antibiotics or an ability to spread infection for example. Laboratory designed plasmids generally contain a specific 'gene of interest' (a piece of DNA with a specific function to be passed on to the host organism through the plasmid) and a number of other functional DNA components that enable tasks useful in laboratory practice, for example resistance to antibiotics, attraction of host cell material that will copy the gene of interest, or fluorescent 'tags' that will highlight the plasmid's presence within cells under particular conditions of microscopy.

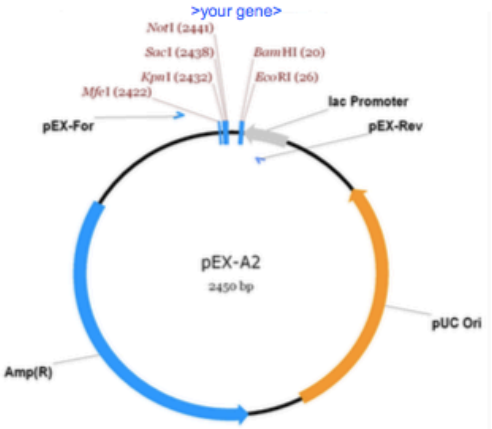
Gene Synthesis Quality Assurance Documentation

Order No.: **3645523/Topf,Ana**

OI33156362

Plasmid Name:	pEX-A2-MacKenzie	**Internal Name:**	OM83-2
Gene Name:	MacKenzie	**Gene Size:**	144bp
Vector Backbone:	pEX-A2	**Antibiotic Selection:**	Ampicillin
Cloning:	via Type IIS restriction enzymes	**Quantity:**	3.0µg

Plasmid Map



5' Restriction Site: BamHI
3' Restriction Site: BamHI
Cloning: via Type IIS restriction enzymes
(Type IIS sites not present in final plasmid)

MCS of pEX-A2

GGAGCAGACAAGCCCGTCAGGGCGCGTCAGCGGGTGTTGGCGGGTGTCGGGGC
TGGCTTAACTATGCGGCATCAGAGCAGATTGTACTGAGAGTGCACcaattgGG
TACCgagctcGCGGCCGCAAGC>your_gene>ACCTGCTTTTGCTCGCTTgg
atccGAATTCCTGTGTGAAATTGTTATCCGCTCACAATTCCACACAACATACG
AGCCGGAAGCATAAAGTGTAAAGCCTG

Figure 36: Gene Synthesis Quality Assurance Documentation for Synthetic Plasmid Thought-as-DNA. Research Documentation, 2015. Image: Louise Mackenzie

With one of my collaborators at the Institute of Genetic Medicine, Dr. Steve Laval, I discussed the components required to construct a plasmid that would contain my thought-as-DNA. These are:

- my thought-as-DNA (the 'gene of interest')
- resistance to ampicillin (which will enable me to 'find' my thought-as-DNA)
- a restriction site (the restriction site is the location on the loop of DNA where a section of DNA, my thought-as-DNA, can be 'cleaved' or separated out).

The website for the laboratory that will construct the plasmid asks for the DNA sequence of the 'gene of interest'. My thought-as-DNA is not a biological 'gene of interest', which therefore renders it (in my terminology) a 'useless gene' with no apparent biological function. That is, on the mountainous range of genetic databases that science has charted and flagged, there was no point, piercing and claiming my thought-as-DNA. As far as science is concerned, my thought-as-DNA has no place, no use.

In generating lively material with no known function, I wanted to open up possibilities for dialogue with the organism that would receive this lively material. I considered myself to be sharing my thought-as-DNA with the host organism. Paradoxically, I have a thought loaded with significance to me that when inserted within the body of the organism becomes insignificant to that body. I have no idea if the organism will consider my thought-as-DNA to be 'of interest' - whether it will be kept safe within its body, altered or discarded. There is no known biological function for this information, therefore should the organism choose to respond to my thought-as-DNA (should my thought-as-DNA be replicated, mutated or deleted) this would be an expression of its capacity to act.

5.2 Thought With No Known Function

What will happen if
I store this thought safe within you?
Will you remember it exactly?
Will you repeat it
over and over
so as not to forget?
Will you share it with others
or hide it away?
Will you pass it on
to your progeny?
Will it remain whole
or will
it frag
ment?
Will it lose
meaning
or will you
give it new life?
Will it transform you?
Will it change
and grow within you?
Will it generate
or fade away?

5.3 Lively Material

In taking a thought and translating it into DNA, the result is a physical object. Born/e[146] in the minds of scientists, designed by my collaborators and myself, ordered via the computer screen, assembled on the genetic production line from plant (and possibly fish) parts manufactured in China, according to procedures patented in Japan, and delivered into my arms in a shiny blue box, with the words, 'Experience the Power of DNA'. See? It is lively.

The plasmid is an assemblage: not words conjured up from thin air, but thought, matter, language, DNA, signifier and signified, a construction of parts and the fluid relations of these parts within a wider context, a construct in which only one of the actors is human (Haraway, 1992, p. 298). Before me it appears as a physical entity, but it is also the thought that led to the construction of the entity, the matter that is assembled as the entity, the relation of the entity to the (microbial) body and (architectural) bodies that it travels through and the unknown future relations between the entity and the bodies that encounter it in the laboratory, gallery and beyond.

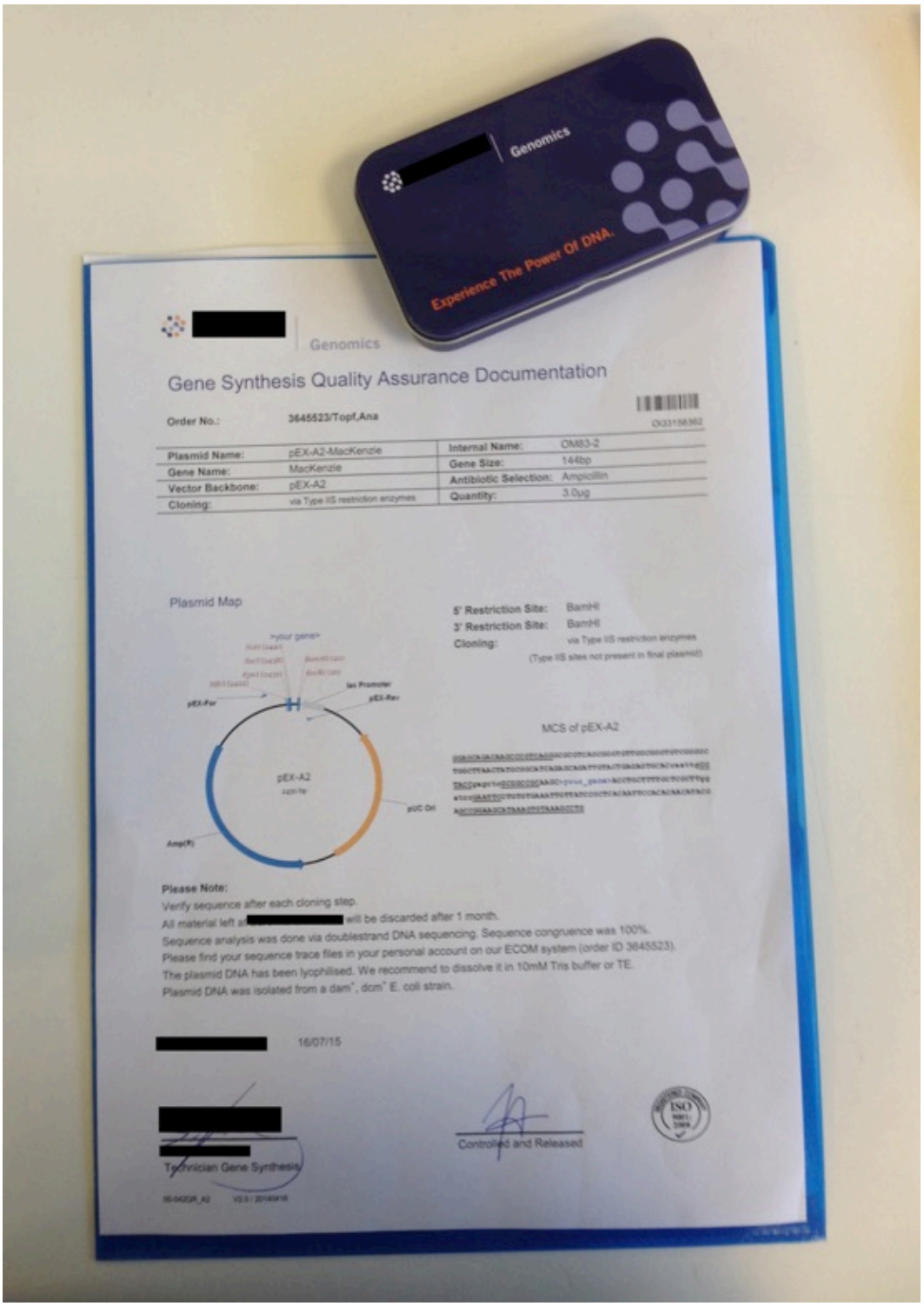


Figure 37: Thought-as-DNA delivered to Institute of Genetic Medicine. Research documentation, 2015. Photo: Louise Mackenzie

5.4 Constructing Mirrors and Being with Organisms

Lab Diary, 25 January 2016:

> Donna Haraway, in discussing how humanity reflects upon society through animal mirrors is careful to point out that we must be skilled in how those mirrors are constructed (Haraway, 1991, p. 21).
>
> I wish to construct microbial ones; I hope they shine.

In this section, through performative exploration of my relationship to the organism with the question, *If working with living bodies in the laboratory is abstract, how can this body relate to it?* I explore the ethics of working with living material in a discourse that begins with anthropomorphism and ends in autophagism[147]. The process of constructing an organism in the laboratory evolves into a constructed process of being with organisms. Dialogue with my scientist collaborators, in the lab and during the making of a short documentary film, gives rise to differences in ethical response, framed around whether the organism is considered as life or resource.

In order to insert synthetic DNA within an organism, there are two key elements: the synthesis of the DNA to be inserted and the process of transformation that enables the take-up of the synthetic DNA within the host organism. I must now insert my thought-as-DNA assembled in a lively plasmid vector, into a living organism. I cannot see the organism as a lifeless chassis in which to assemble inanimate parts. Instead I choose to frame it as a vessel with all the bodily materiality this implies. Each step feels increasingly personal. I will do my best to relate it faithfully as I experience it.

Whilst working in the laboratory, I kept a diary of my observations and conversations. Although my initial intention was to learn standard protocols in order to carry out the work I had planned, it became clear that my approach to documenting the use of laboratory protocols was sufficiently distinct from that of my scientist colleagues to warrant further attention. I was committed to learning the techniques used to conduct basic molecular biology and genetic research and at the same time I was re-framing them in a manner that made sense to me. Scientific protocols: the instructions for specific techniques, set out like recipes to ensure accuracy, were something that I wanted to think with. A student of science might well question a protocol, but more often it has become a habit: the technique

is embodied as part of a larger plan and therefore challenging an already established protocol merely wastes time[148]. For me, thinking with the protocols was time well wasted.

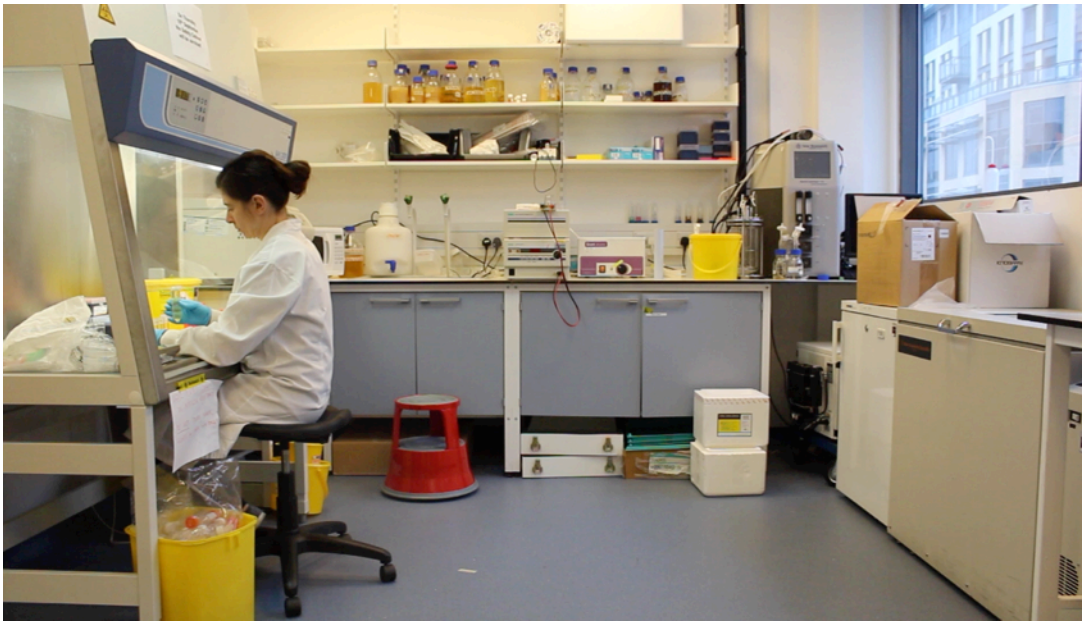


Figure 38: Working in the Cloning Room at the Institute of Genetic Medicine. Research documentation, 2015. Photo: Louise Mackenzie

5.4.1 Host

The soon-to-be host of my thought was once un-named living material, then *Escherichia coli*, claimed by man. Now it is claimed by capitalism: produced and sold as 'One Shot® TOP10'.

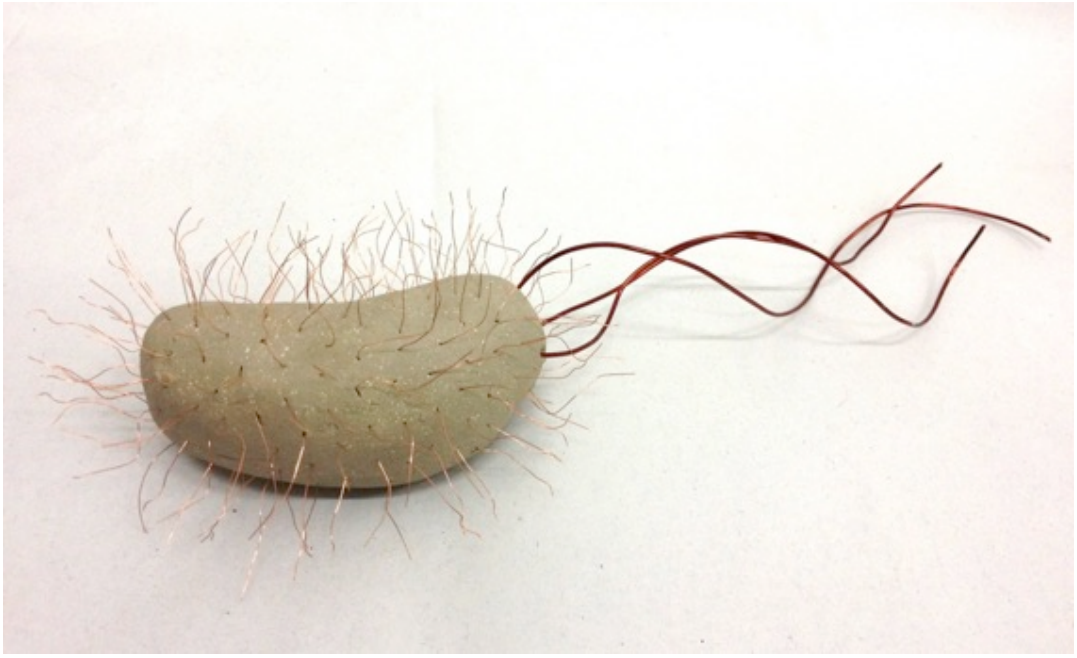


Figure 39: Louise Mackenzie, *Transition* (detail) 2012. Clay, copper wire. Image: Louise Mackenzie

Escherichia coli (*E. coli*) are gram-negative, prokaryotic bacteria, which can grow with or without oxygen (aerobic and anaerobic growth). They are commonly found in the intestines of mammals and also on the edges of hot springs. *E. coli* are described through their relation to humans, that is to say there are pathogenic and harmless varieties. Some *E. coli* can cause severe illness due to Shiga-producing toxins, others may cause urinary tract infection or mastitis. The general public are most likely aware of negative associations, as diseases attributed to *E. coli* are commonly contracted through contaminated food, however many forms of *E. coli* also live amicably in our gut working to break down food, assisting with food absorption and vitamin K production[149].

The human history of *E. coli* is scatological and territorial. The original strain, *Bacterium coli commune*, was claimed from the faeces of a healthy child by German bacteriologist and paediatrician, Theodor Escherich in 1885[150]. Modern lab strains come from four original model strains: K-12, B, C and W. Strain K-12 was claimed from the stool of a diphtheria patient at Stanford University in 1922. Various strains have been

derived from K-12, through treatment with agents such as nitrogen mustard, UV radiation and X-rays. Over decades of laboratory use, the bacteria have evolved from organism to resource to genetically assembled product, existing only within the confines of the laboratory. One of the most common strains of *E. coli* used in laboratories today (the organism I shall be working with) is One Shot® TOP10 (TOP10).

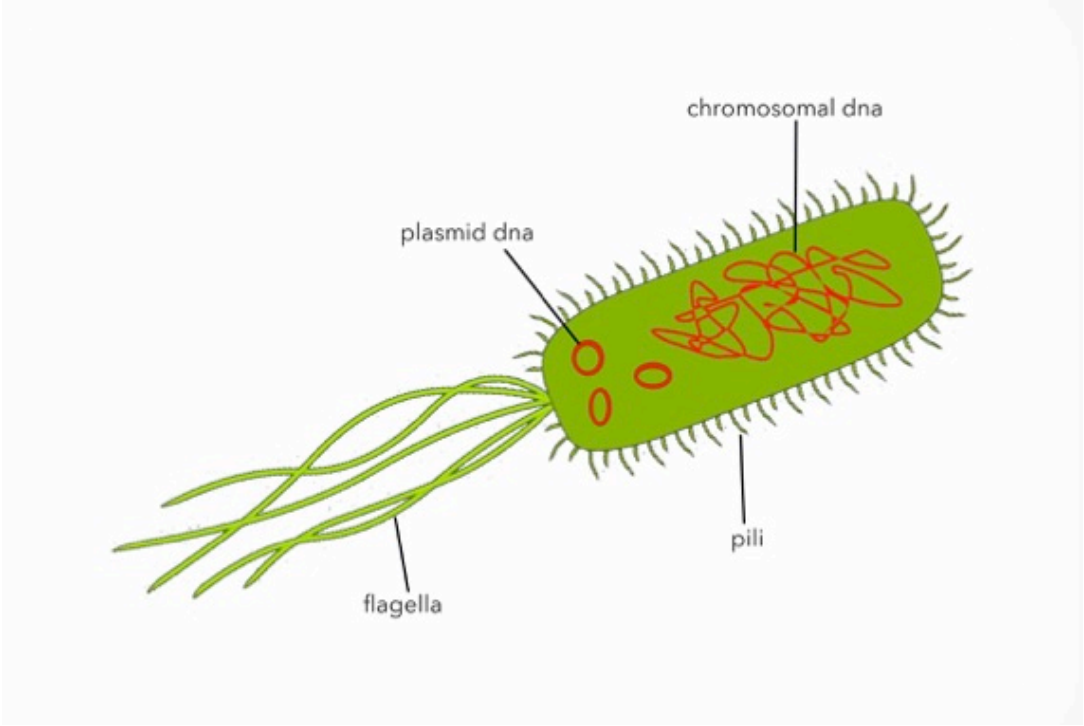


Figure 40: Diagram of *E. coli* bacteria showing pili, flagella, DNA and plasmid DNA. Research Documentation, 2016. Image: Louise Mackenzie

5.4.2 Transformation – Subjectivity within the Object

The process that will place the thought-as-DNA within the organism is called transformation, the method is known as heat shock. There is a stark contrast between the images conjured by 'transformation' and 'heat shock', both terms that can be classed as expert language constructed in the environment of the laboratory and as such, are deliberately detached from emotional context[151].

I become a machine whilst learning the process, unable to reflect sufficiently whilst I take in new rules and patterns. I have moved from designing lively material to being with living material in the laboratory. I try to keep the *being with* present, but in order to carry out the task I have set, living material (feeling thing) becomes resource (object / tool). Keep the resources in optimum conditions (optimum for who?). Step by step, I follow instructions, no time to relate, just check the figures: volumes, temperatures, timings.

My subjectivity begins to gnaw at my direct experience, diary entries leaking into practice. I can't keep the two apart[152].

> Lab Diary, 25 January 2016
>
> These are 'competent' *E. coli* organisms (already genetically modified to be suitable for transformation), kept in an -80°C freezer. I defrost them (wake them from their cryogenic slumber), then place them into extreme heat, which causes the very membrane of their bodies to stretch apart to the point where my plasmid can slip inside. This is a shock to them, but hopefully they are resilient enough to just take it in. Some may not survive this.
>
> There are consequences… I am left with 'woken' *E. coli* and am faced with the prospect of discarding them.
>
> They were disposed of in the correct manner: poured into a container of bacterial waste that will be autoclaved[153].

Figure 41: Bacterial waste. Research documentation, 2015. Image: Louise Mackenzie

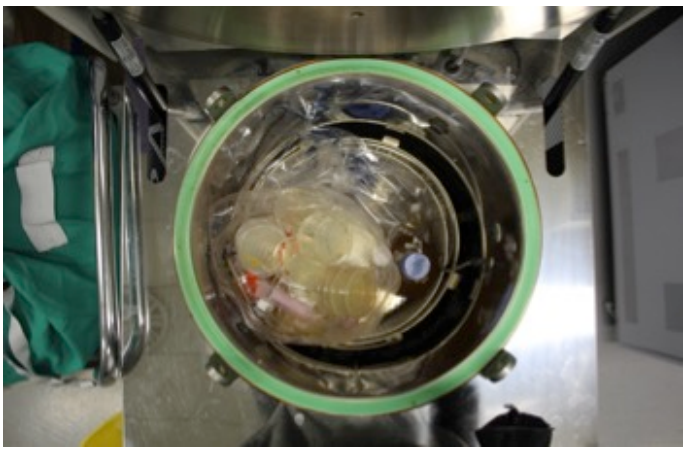


Figure 42: Autoclaving bacterial waste. Research documentation, 2016. Image: Louise Mackenzie

This prospect of getting rid of life I found perplexingly traumatic. I had to dispose of life that no longer served a useful purpose (to me). In the nature of Martin Heidegger's *Bestand*, they had become tools (victims?) of my research (Heidegger, 1977, pp. 17–23). Some of their kin survived another day, to grow on a warm agar plate, but the remainder

were surplus to requirements: waste. I had no means within the space of the laboratory to grow them all, they outgrow their media too fast but I could not bring myself to part with this universal tube of life[154]. Instead, I embarked upon a process of retaining a small sample, adding them to fresh media and growing them in the incubator overnight, to repeat the process ad infinitum in the manner of Richard Lenski[155] but unlike Lenski, I was doing so for reasons I couldn't quite explain.

5.4.3 Constructing Mirrors

As I repeated the daily process of sampling and culturing the organisms, I began to reflect upon the microbial other as self.

> Lab Diary, 25 January 2016
>
> The microbial are vital before me, as living, multiplying organisms. I have played a part in generating something that does not exist without me and I am laden with responsibility for it. I have begun to think of the *E. coli* in my research as my progeny and yet I am troubled by my position in relation to them, attempting to nurture them whilst at the same time, subjecting them to conditions that seem closer to a form of torture.

> Lab Diary, 26 January 2016
>
> I sat down and contemplated killing the rest again[156]. I mark the occasion by photographing the cultures to remember them. Are we too distant for this to matter; is matter too technological?

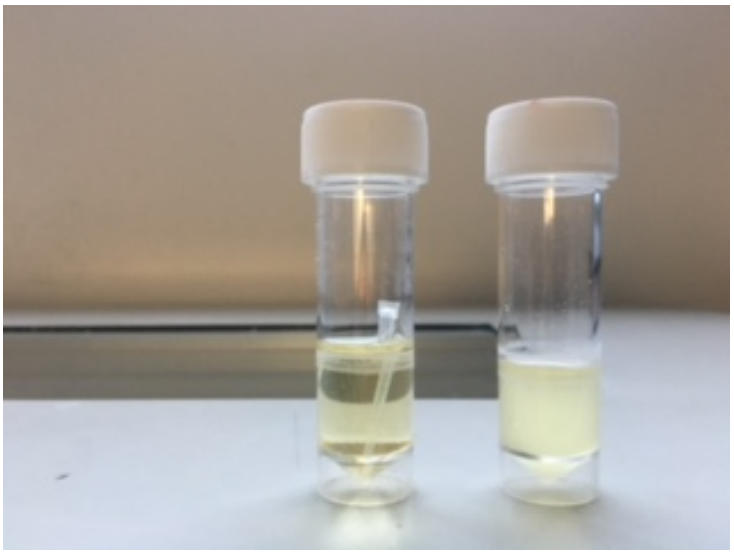


Figure 43: Universal Tubes containing old colony (left) and newly transformed *E. coli* (right). Research documentation, 2016. Image: Louise Mackenzie

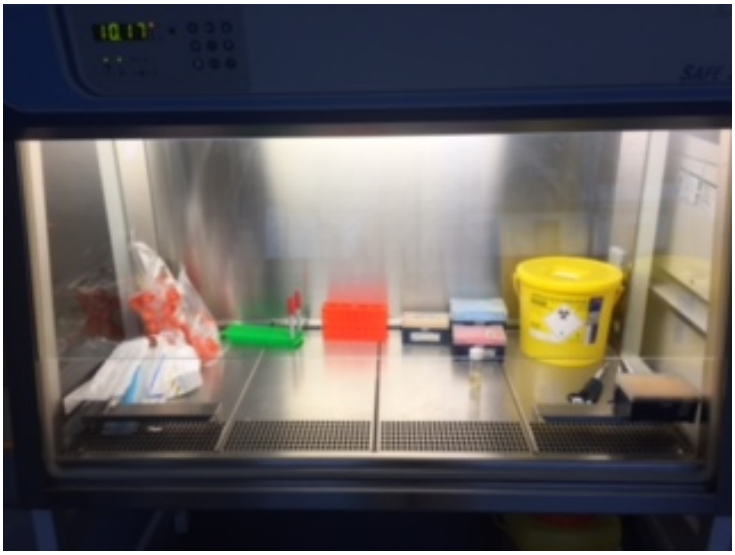


Figure 44: Transformed *E. coli*, surplus to requirements await their fate. Research documentation, 2016. Image: Louise Mackenzie

So here was where the trouble began. To choose to discard that which is not useful to me and to keep that which is. These are living organisms, the name microbe was chosen to mean small life: *micro*- small, *bios* - life. Ironically, the term is considered to be inaccurate as the Greek translation is quite literally, 'short-lived' (Harper, 2010). In the lab environment this literal definition stands up.

Why was I so reluctant after the transformation process to discard the 'fruits of my labours'? Do I have any right to choose whether they live or die, simply because I am human? One might argue, as Donna Haraway does, that these organisms are technological in the first instance (Haraway, 1992, p. 297). They have been created, indeed

domesticated, for human use. They have no place outside of the laboratory environment. They are part of a complex relationship entangled with humanity. There is no 'wild' to release them into. Thus, they serve a purpose and are culled after they have served that purpose. This is what one might describe as 'humane' and is a part of 'the unresolved dilemmas of killing and relationships of use' (Haraway, 2008).

The process of sequencing the organisms to extract my thought-as-DNA further complicates my experience as I literally break the multiple bodies of the organisms apart, until I am left with my phrase, floating as DNA, suspended above their fragmented remains (see Appendix I). The more I perform the activities associated with storing and extracting my thought-as-DNA, the more routine they become and I am troubled by my loss of sensation. I continue to sequence the organisms hoping to find that they have responded to my question. Each attempt reveals no change (see Appendix IV for an example of the results). The physical response is instead evident in the enforced laboratory cycle of life and death. I began to think back to an earlier discussion I had with my scientist colleagues, that was over-ruled on safety grounds. I wonder if perhaps instead I could grow the organisms that contain my thought-as-DNA more happily inside another living body.

Lab Diary, 15 October 2015

We discussed one of the ethical elements of my own practice: my desire to consume *E. coli* (or perhaps another gut organism that may be safer) that I have modified, with a question that I hope to harbour within me and then reveal an answer to, potentially, at a later stage. In conversation with Rod Dillon of Lancaster University, Rod had suggested using another organism such as an insect or even a long living organism such as a tortoise, whose faeces could be analysed and sequenced for changes.

Lab Diary, 26 February 2016

> I had an interesting conversation with Volker[157] around setting up a live performance of me taking my 'thought' inside my own body. I'd like to place it in my head: under the skin at the nape of my neck. A vulnerable place: a hidden place, where I could hold a secret thought.

'Staying with the trouble' (Haraway, 2016, pp. 2–8), this train of thought begins a series of public discussions around hypothetically storing a thought within my body that are documented under artist talks within Appendix III. They form the basis for a post-doctoral project on the imposition of will in medical research through both radical empiricist and anthropomorphic performative practice, provisionally titled, *Velleity With(out) Volition*.

5.5 Turning the Mirror Outwards

Figure 45: Louise Mackenzie & Baltan Laboratories, 2016. *Untourage #3*. Webisode. Image: Gary Malkin

Untourage #3 (Mackenzie, 2016c)[158] was my first opportunity to introduce my work to others within the Institute of Genetic Medicine. *Untourage* is a web series of short, playful video tours produced by Baltan Laboratories, a cross-disciplinary group based in the Netherlands, where artists are invited to explain science to scientists, or scientists are invited to explain art to artists, with all the potential for failure that this entails. As a collaborative project, there was an element of fitting to a pre-defined style, I did however frame the shots and wrote the script to focus on the organisms and the scientists' reactions to how I was discussing them. This was still a relatively early stage in my research where I wanted to build the trust of colleagues whose hospitality I was receiving. Although I was imposing upon the institution and the individuals within it, I was attempting to do so by working within the parameters of a format (that of the documentary) that my colleagues would be familiar with and comfortable being included within.

> 'So today I want to show you my companion species or even I might be so bold as to call them my progeny. This is what I call my genetically modified bacteria. I am in a sense their progenitor. These bacteria are somehow descended from me. They wouldn't exist if I hadn't created them and as such I feel a responsibility towards them.'

Figure 46: Louise Mackenzie & Baltan Laboratories, 2016. *Untourage #3*. Script excerpt.

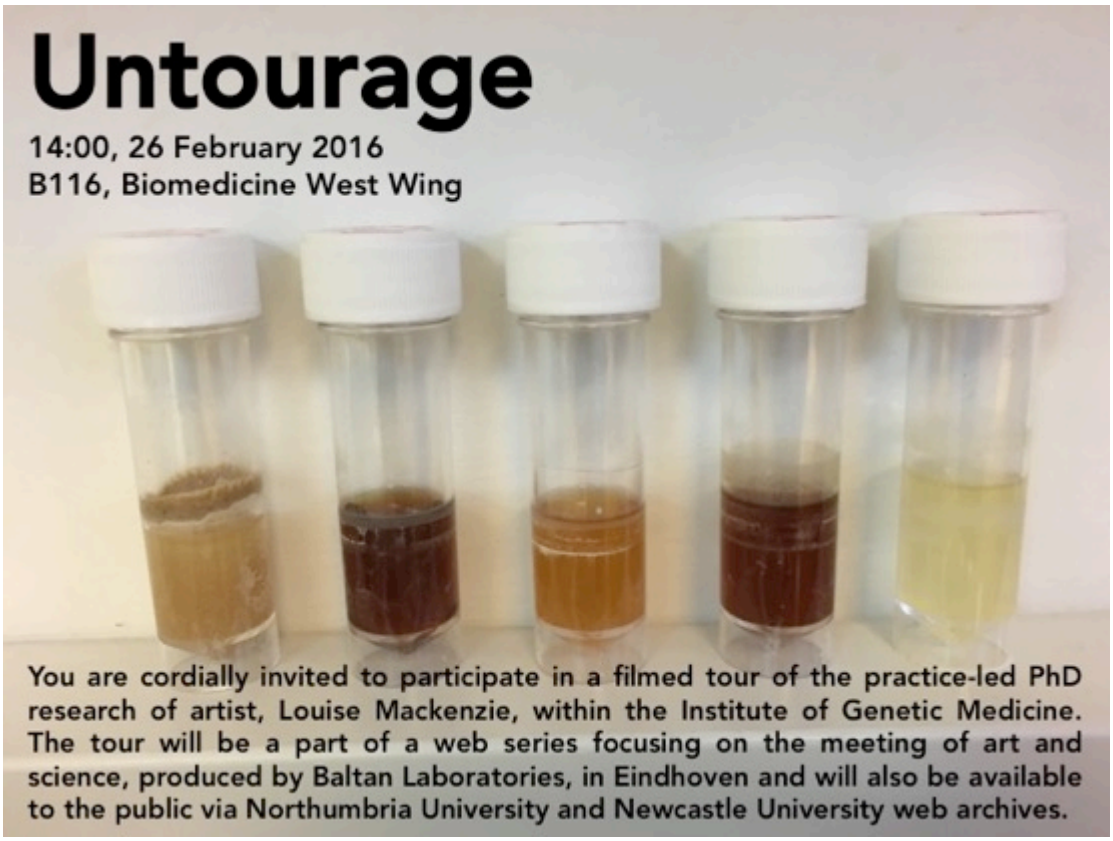


Figure 47: *Untourage* invitation. Research documentation, 2016. Image: Louise Mackenzie

5.6 Anthropomorphism as Methodology

Following filming, a discussion with participants highlighted key areas for further research. The full transcript of both the film and the preview discussion is documented in Appendix VI. The humour in the video was seen as perhaps taking away from the seriousness of the research. Subtle humour however proved to be a useful strategy for discussion. In addressing the bacteria as kin to be respected (Haraway, 2003, p. 9), I instinctively adopted a peculiarly British sense of irony, which acted as a means to relax participants, drawing out comments that perhaps might not have been made in a more serious setting[159].

Responsibility was also raised in two distinct contexts. My scientific supervisor at the Institute of Genetic Medicine, Professor Volker Straub suggested that I felt a specific form of responsibility caused by my actions in the laboratory, pointing out by way of example that we use deodorant, which kills off microbes without even thinking about it. This sense of responsibility, based around the *making* (genetic modification) of life was a sense that he felt scientists shared. My collaborator in the laboratory, Dr Ana Topf suggested that the sense of responsibility stemmed from my *use* of life, framing of the organism as *kin*, engendering feelings of sympathy and respect. Of course, both are present. Since working in the laboratory, I now find myself quietly apologizing when using Dettol or rolling on Dove. This apology itself may seem insignificant but it triggers in me a nomadic thought process that begins with killing the organism and meanders down many paths, such as the manufacturing processes that go into making the plastic and chemical products that go towards killing bacteria, the pollution of the oceans with plastic and chemicals and the mutation and adaptation of marine micro-organisms to the pollutants that we pump into their eco-system[160].

Although initially subconscious, it became clear that my anthropomorphic behavior in the laboratory followed a language of nurture. After having been guided through laboratory protocols initially, I was reframing them in a context that allowed me to think about the organisms in their environment, rather than their purpose in the laboratory. Whereas I had been introduced to a series of steps, using specific tools, which led to an end result, my context revolved around their existence as living beings in the laboratory space. I anthropomorphized the organisms, discussing them as beings, considering sentience; I spoke about the sense of responsibility I felt towards them having ‘made’ them in the

laboratory[161]. I began to see my work in the laboratory as a form of personal, situated performance: a recalibration of scientific laboratory protocols into another, equally valid working method. Artist, and professor at Northumbria University, Christine Borland commented to me in relation to her own encounters with scientists that perhaps as artists we undergo a subtle shift in persona in the laboratory space[162]. I was aware of presenting particular aspects of my self that I felt important to reflect whilst in the space of the laboratory as a reaction to the language and protocols that I experienced. This instinctive presentation has manifested as *other*, an imposition or intrusion, which has enabled reflection on the specific qualities that being *other* manifests.

During *Untourage*, my mutation of scientific protocol into a language of nurture led to dialogue around life rather than tool use. Deliberately anthropomorphising laboratory protocol led one of the tour participants to counter my romantic description of nurture with one of torture. Further, two audience members began to reflect on their own use of laboratory life and extrapolated this to higher order organisms that they have worked with. This raises questions around the ethics of living material in the laboratory and whether it is necessary or appropriate to anthropomorphise non-sentient life. In her writing on dog training in *The Companion Species Manifesto*, Donna Haraway extols the virtues of anthropomorphism, '[a]ll that philosophically suspect language is necessary to keep the humans alert to the fact that somebody is at home in the animals that they work with' (Haraway, 2003, p. 50), although it is less obvious how this might relate to living material in the laboratory.

What became significant in publicly humanizing the organism was that a change in language resulted through the group and perhaps more important was the level of reflection that the change in language prompted. Thus shifting persona enabled not only myself but also others to think about life rather than use in the context of their own relationships in the laboratory. As Haraway goes on to say, 'just *who* is at home must be permanently in question' (Haraway, 2003, p. 50), the importance of anthropomorphism is the absence of fully knowing the other and the value of what emerges from relating. What seems vitally important is that dialogue now remains open ended, with further possibilities to extend ways of relating outside of the usual constructs of the laboratory space.

5.7 Polishing Microbial Mirrors

As I polish microbial mirrors through my anthropomorphizing of the organism, I run into troubling territory. The question of the animal[163] is problematized by the discovery of microbial life and what we understand in more recent chronological history as the sentience of the organism, its ability to communicate socially (Bassler, 2009) and its ability to impact us directly and have a relationship on and within us (O'Neill (Chair), 2015). With evolution there is a temporal, linear continuum, where the microbial organism is perceived to be at one end and human is at the other, yet there is also, let's say a spatial-relational spectrum, where they co-exist, indeed on and within one another at multiple points in space and time. A linear continuum enables us to ethically dissociate from the organism whereas a spatial-relational perspective binds us together. Within this collapsing of time and space then, if we are to, as Ursula LeGuin suggests, cast off the names (Le Guin, 1985), how can we adequately account for our specific relationship towards the organism? What of our fear, for example, that organisms can hurt us? Donna Haraway reminds us that 'To regard a dog as a furry child, even metaphorically, demeans dogs and children – and sets up children to be bitten and dogs to be killed' (Haraway, 2003, p. 37). Just as with animals, an organism has the capacity to kill or be killed, so how then do we frame our relationship? Can it include hospitality? The references in the literature are to Rousseau's cat, Haraway's dog, Derrida's cat (Haraway, 2000; Derrida and Wills, 2002; Oliver, 2009, p. 64), these are pets, domesticated animals; animals that the author can relate to. Is it even possible to conceive of hospitality towards (shared with) an organism that runs wild amok us? Perhaps it is a problem of shared language and Wittgenstein's lion has the answer (Wolfe, 2003, pp. 1–48).

Looking back on the performance *Natura naturans*, the work highlights the subject as a spatio-temporal lively material and raises questions regarding humanity's inability to '"cut" once and for all where we would in general like to cut' (Derrida, 1988). In offering unconditional hospitality to the organism, akin to what Leonard Lawlor describes as 'giving the animal all of one's home and oneself' (in High *et al.*, 2017, p. 173)), we open up questions of sacrifice in considering whether it is possible to unconditionally share our home with the organism as microbial other, whilst at the same time, realising that in the case of the organism, the home that we share is also the home of the self and the other is never completely separate. Art historian, Assimina Kaniari in her exegesis of the intricacies of artist Kathy High's performative work, *Embracing Animals*[164], notes High's discomfort

in bringing animals into the gallery context, asking 'can we ever really host the animal without in some way imposing our own proprieties and property relations onto their lives…?' (High *et al.*, 2017, p. 184). In our actions towards the organism as other therefore, where we make the cut and in doing so, deny the organism subjectivity, we are also denying ourselves.

> 'the question is no longer one of knowing if it is "good" to eat the other… nor of knowing which other… the living or the nonliving, man or animal, but since *one must* eat …how for goodness' sake should one *eat well*?' (Derrida, 1988).

In *Eating Well*, Derrida draws upon humanity's relationship with the animal to attempt to define a way through the trouble, by, '*learning* and *giving* to eat, learning-to-give-the-other-to-eat' (Derrida, 1988), yet his words remain entangled in constructed spaces, caught between the wild and domesticity. If we accept that this boundary is constructed, to eat well is not only about sharing but also about understanding that, to an extent, we are eating ourselves. As philosopher Matthew Calarco reminds us, Emmanuel Levinas claims that the animal does not have a face, so to speak (Calarco, 2008) and in my extension of animal to organism, I must agree, for not every animal does. Levinas references the snake (which arguably is not the most obvious example. I choose microbe, or even mole rat, for let's face it, the face is all about the eyes). The face (that Levinas denies the animal) Derrida sees as a means to form a relationship with the other, an obligatory relationship where one is held hostage before the other (High *et al.*, 2017, p. 167), this face is domestic. There is no face when domesticity is stripped away and we are all wild, when the animal (the organism) is always already a part of the other. This aligns with the 'sacrificial structure' at the heart of Derrida's argument (Derrida, 1988, p. 278) that Levinas cannot address through the face, but diffractively suggests a new form of sacrifice, not Derrida's *carnophallogocentrism* but feminist writer, Irina Aristarkhova's *autophagy*[165]. We must be prepared to sacrifice parts of ourselves as we sacrifice the other. This is where unconditional hospitality arises, through sacrificing *the* organism in accepting that we are always already *with* organism and (perhaps most importantly) we *are* organism.

I further develop my position on autophagy by altering from anthropomorphizing the cell to xenomorphising[166] the collective body of cells, always 'in this together' (Braidotti, 2005), never in isolation. In using the term xenomorph, I appropriate Derrida's, 'animal that therefore I am' (Derrida and Wills, 2002) but in drawing from xenofeminist practice that embraces the alien (Cuboniks, 2015; Bureau d'etudes *et al.*, 2017) and vital materialist

approaches that extend the sense of self beyond the body (Braidotti, 2005; Bennett, 2010, pp. 116–119), I replace animal - that which has a face that we can relate to - with the alien other/self of the organism (the cellular body) that we already are but can never fully understand. By treating the objects of my enquiry as collectively complex forms, with a nonhuman form of sentience, my intention therefore is not to humanise but to problematise matter, suggesting that we must acknowledge we can never fully understand its rich spatial and temporal depth: facets of it will always be alien to us. In this context, I contribute to the discourse of xeno-politics[167] as a rejection of the 'natural' by extending towards it the beginnings of an aesthetics of care: that is, an acknowledgment of acts of imposition, within the context of synthetic biology, as acts of autophagy.

Imposition implies an exchange. It suggests taking up space and it suggests drive and force. Implicit in the actions of the self, willfully acting upon the lively material that we are at once a part of and can never fully know, is a requirement to acknowledge the act of imposition. If I impose, I impose upon my extended self and as such, I become responsible for my actions. Human will therefore manifests as autophagic imposition. Beyond the extent of this doctoral research, through the framework of the project *Velleity With(out) Volition*, I intend to further explore the concept of imposition in relation to Derrida's discourse on hospitality. Hospitality is, Derrida says, 'due to the foreigner' (Derrida, 2000, p. 73) and thus in an aesthetics of care, I ask, *What are our obligations towards the organism, when the organism is also the self?*

5.8 Postscript – Chance Events in Assembling Lively Material

At this stage in the work I believed I had genetically modified a living organism. Had I genetically modified a living organism? This question was raised by my scientific collaborator, Dr Ana Topf, who is used to researching the effects of genetic mutations within humans who have muscular dystrophy. Thus the addition of plasmid DNA to a bacterial organism barely qualifies, the change is so small and insignificant. Scientists discuss the *E. coli* they work with as cells. They are considered resources, not living organisms. Furthermore, the organism is already genetically modified (prior to my adding new plasmid DNA), therefore do we now have a new species of genetically modified organism within the laboratory, or is the modification so insignificant that it is more like adding a plaster or prosthetic of some kind? What is the difference? Instinctively I feel that the difference is one of scale. If considering an expanded timeframe rather than the snapshots created within the constructed laboratory space, there is latent potential within the actions and intra-actions that occur the lab.

My optimistic hope was that by adding to the DNA of the organism, it would respond by taking the DNA that I had inserted and changing it in some way[168]. I realise now that under the timeline of my thesis this is unlikely, but I am a great believer in accident and chance. Perhaps some small action: the temperature in the room, length of days between 'feeds', accidentally forgetting to add ampicillin, someone replacing the fluorescent lighting in the lab, my cooking apple crumble for dinner, the result of the Brexit referendum, or other seemingly insignificant event, might trigger a response, so I have resolved to grow my progeny indefinitely.

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[136] I refer to the question posed in Chapter 2, *How does art practice rooted in biotechnology shape our relation to lively material*? The construction of elements within this chapter as part auto-ethnographic, part performative diary draws upon my framing of biotechnological art practices outlined in Chapter 2 and my personal, situated experience of working with living and lively material in the laboratory to reconsider this question.

[137] The development of novel or 'unnatural' amino acids has enabled research into the structure and function of proteins. Somewhat akin to adding a nonsense word in a sentence, the research aims to explore how the body might relate to this novel insertion (Wang, Parrish and Wang, 2009).

[138] The term wetware is used colloquially to refer to the brain as computer. Science writer, novelist and mathematician, Rudy Rucker, with a nod to William Gibson's *Neuromancer* (Gibson, 1984), used the term wetware in a range of science fiction novels, notably the eponymous, *Wetware* in 1988, in which he describes organic life in terms of programmes and code (Rucker, 2007). Moistmedia is a term coined by artist and cybernetic theorist, Roy Ascott to reference the space in which consciousness and computing relate in a 'fluid reality' that comprises 'bits, atoms, neurons and genes' (Ascott, 2000).

[139] This understanding of DNA in terms of its structural qualities is also employed within science, with 'hairpin' structures, keys and locks all common attributes of synthetically generated DNA (see for example, (Ren *et al.*, 2016)). **[FOLD BACK ⊃ TO FOOTNOTE 100]** Narrowly read structural approaches do not fully account for a relational sense of movement in medium, time and space (and the unpredictable consequences of this) that I suggest are more akin to an art historical reading of DNA.

[140] Semiotician and author Umberto Eco drew the title for his novel, *The Name of the Rose*, from the 12th century poem, *De contempt mundi*, by Bernard of Morlay, reasoning that, 'the rose is a symbolic figure so rich in meanings that by now it has hardly any meaning left'.

[141] The naming of things has always signified tangled relations. Mackenzie signifies 'son of Kenneth'. In fact I am Mackenzie, daughter of Kenneth, but my father, Kenneth Mackenzie was son of James. My mother has had six judicial surnames and on one piece of legal paper I am the chattel of the house of Murphy, but I'd rather you just call me whatever feels right on the day that we meet.

[142] Kac refers to the specific sequence of DNA prepared for the installation *Genesis* (in which he encoded a passage from the biblical book of Genesis) as the 'artist's gene' (Kac, 1999) .

[143] Frustrated by an inability to reproduce the exact shade of pure pigment colour in liquid paint form, Yves Klein collaborated with art supplier Edouard Adam (who in turn, referred to a chemist at French chemical manufacturers, Rhône-Poulenc) to manufacture a synthetic resin that, when combined with ultramarine pigment, retained for Klein its original 'pure energy' (Frere-Jones, 2015). Klein then applied for a patent for the colour in his name, or more specifically, in the name International Klein Blue. For Klein, whose motivation was to 'sense the soul' (Honnef *et al.*, 2000, p. 298), International Klein Blue was a means to presence the immaterial. His search for an absolute form of expression also served as a means to presence Klein's ego, as evidenced in his 1957 diary entry, 'a painter ought to paint one single masterpiece: himself, perpetually … becoming a kind of generator with a continual emanation that fills the atmosphere with his whole artistic presence and remains in the air after he has gone,' (Weitemeier, 2001, p. 7).

[144] My apologies to Dr Steve Laval, to whom this tirade will come as a surprise. His act was a very minor imposition in relation to my imposition on his time overseeing a very busy laboratory. However minor impositions can lead to interesting digressions.

[145] See Section 4.5.2.6 for Evelyn Fox Keller's view of the term 'gene'.

[146] I use both borne and born to suggest that an idea may originate in the mind but may also be carried by many minds and not be original to any one.

[147] Autophagy, from the Greek *auto-* (self) and *–phage* (to eat) is literally self-devouring. Within biology, autophagy is the natural process within a cell, by which unnecessary or dysfunctional components are broken down. Thus autophagy can be considered not as cannibalism, but more as a renewal of the self.

[148] In conversation with scientists whom I have worked with in the laboratory, I frequently found that many of the questions I raised dealt with matters that they took for granted en route to the more complex (and therefore abstract) problem that they were addressing.

[149] For further details see the *Escherichia coli* page on Microbe Wiki (Jacques and Ngo, 2014).

[150] It was later registered (under his name) in the National Collection of Type Cultures at the Lister Institute in London in 1919 (Dunne *et al.*, 2017).

[151] In S*uper-natural*, artist, Sneha Solanki compares 'heat shock' to 17th century witchcraft (Solanki, 2012). Solanki creates Tituba, a synthetic bacterial construct named after a 17th century Salem witch. The comparison is deliberately provocative, conjuring images of burning at the stake or drowning. As in the folklore, ability to survive such extremes of temperature is proof of witchcraft. Thus Tituba, a super-natural being, is born. Solanki's work teases out the mythical associations between historical interpretations of witchcraft and contemporary interpretations of biotechnology. The experience for the organism may be more workhorse than winged horse.

[152] See further details in Appendix I, Lab Diary.

[153] Autoclaving is a process of sterilisation where materials are heated to such a high temperature as to kill all forms of life.
[154] This is actually the common name of the plastic vial that the *E. coli* are cultured in liquid media within: the 'universal tube'.
[155] For an overview of Richard Lenski's long-running *E. coli* experiment, see Lenski's website at Michigan State University (Lenski, 2010)
[156] My work in the lab was beginning to resemble the killing rituals introduced by Oron Catts and Ionat Zurr (see also footnote 22).
[157] Professor Volker Straub, Institute of Genetic Medicine
[158] http://www.baltanlaboratories.org/library/untourage-3
[159] Humour is often employed as an effective tool within art practice, perhaps moreso when dealing with serious subjects. My approach sits a fairly long way down a spectrum of subtlety, with bioartist Adam Zaretsky somewhere near the opposite end, challenging his audience to consider the queering of genetic practice through the creative possibilities of human gene editing (Zaretsky, 2017b).
[160] Nomadic traces come to me from Gilles Deleuze via Rosi Braidotti, who may describe my nomadic thought as, 'outward-bound and based on complex relations with a multiplicity of others, including non-human others' (Braidotti, 2005).
[161] The words we use at sites of production have become particularly relevant in the project. I have spent much time considering the words made, designed, created, generated, constructed and, primarily drawing from Donna Haraway's writings (see for example, Haraway, 1992), have settled on both 'constructed' and 'generated' as ways to convey my particular intra-actions within the laboratory, however, earlier in the research, I had not yet reached this conclusion and so other words were forefronted.
[162] Personal discussion.
[163] I reference here Jacques Derrida's discourse on the animal and related writings on the topic, see for example (Derrida, 1988; Derrida and Wills, 2002; Calarco, 2008; Higgs, 2010; Slater, 2012; High *et al.*, 2017).
[164] In the work, High brings transgenic rats (that have a modification of the B27 gene, implicated in the autoimmune digestive condition that High lives with) to her home to live with her.
[165] Here, I use autophagy as understood by Aristarkhova from her talk, *Eating the Mother*, at the conference, Taboo, Transgression, Transcendence in Art & Science 2017 (https://avarts.ionio.gr/ttt/2017/en/guests/), where her analysis of the work of performance artist Jess Dobkin's *The Lactation Station Breast Milk Bar* (2012-16) relates Derrida's theory of carnophallogocentrism to specific acts of self-cannibalism.
[166] Xenomorphism translates as strange form (from the Greek *xenos*- strange, and *–morph* form). Thus in the relational context of matter as 'a dynamic intra-active becoming that never sits still' (Barad, 2007, p. 170) and within that context, lively material that relates to wilful impositions upon it through bioart and synthetic biology practices (see for example, artist, Mary Tsang's project, *Open Source Estrogen* (Tsang, 2015) and the manifesto of the xenofeminist collective, Aliens in Green (Bureau d'etudes *et al.*, 2017)), I consider the collective body of cells that comprise any living organism, including the human body, as an always stranger stranger: a xenomorph comprised of elements that we cannot possibly fully know.
[167] Generated through, for example, feminist collective, Laboria Cuboniks (Cuboniks, 2015) and bio art collective, Aliens in Green (Bureau d'etudes *et al.*, 2017).
[168] I initially intended to use directed evolution strategies (see Appendix I) but as I began to impose upon the organism, I found that I wanted to impose less, not more.

6 TRANSLATING SUBJECTIVE EXPERIENCE

In this chapter, I discuss research works made for public exhibition based around inserting my thought within a living organism. As I moved through the experience of learning both information-processing approaches to life and laboratory techniques for working with life, I felt increasingly divided and found my conflicted experiences difficult to bring into a public context. I reflect on the works exhibited in the context of the frameworks 'behind glass' and 'on a pedestal' and the ethical context set out in Chapter 2. Initial attempts to focus on the evolution of the organism result in an aesthetic black boxing that falls symptom to the same issues of technological layering that I experienced within scientific practice. Ultimately the most revealing works are those where the material and the semiotic are brought together in anthropomorphic language and myth. I conclude that the evolution of the subject is predictable and unremarkable in purely material terms but becomes rich in ways that could not have been predicted through my relation with the organism, my collaborators and the audience.

6.1 Material-Semiotic Speculations – Cacophonous Vessels

6.1.1 Pithos

> '[I]t is with a certain feeling of urgency that I seek the nature, subject, words of the other story, the untold one, the life story.' (Le Guin, 1989, pp. 168–69)

Pithos is an ongoing project exploring the body of the living organism as vessel. It has been presented in different forms as the research progresses. The first iteration of *Pithos* (Mackenzie, 2016b)[169] was the presentation of a clay vessel into which I had worked the synthetic DNA plasmid by hand, thus impregnating both the clay and my hands with the DNA plasmid. The vessel literally represented the *E. coli* that I had inserted my DNA plasmid within, but was unable to bring into the gallery at this early juncture in my research.

Pithos has become part of an evolving project that references the Pandora myth, tracing biotechnology to the roots of craft (techne) and exploring what it means to make with material that has the capacity to evolve. The project questions gendered notions of technology and attempts to unbind technology from ideas of determinism through the evolution of lively material.

The installation focuses the audience's attention on two key elements presented in a blacked out space: a simple hand crafted clay pot and an 8-channel audio work. Both the vessel and the word, as indexes of technology and culture, are interrogated through the Pandora myth.

Figure 48: Louise Mackenzie, 2016. *Pithos*. Installation Detail, BALTIC39. 8-channel audio (3:09), clay vessel, DNA plasmid bioassemblage. Image: Louise Mackenzie

Derided as a misogynistic fable[170], I reconsider the Pandora myth through the Greek figure of the *pithos* as a conflation of techné and life; the first instance in which an object is both crafted and alive. The making of a clay vessel flowed intuitively. I had been troubled by the framing of the organism as chassis (Frow and Calvert, 2013), conjuring images of Fordian production lines and eliciting similar physical manifestations of the genetic production line (see Figure 49)[171]. Both chassis and vessel suggest forms of containment, but the former indicates a determinate structure, constructed and controlled and the latter

evokes unpredictability: a space for gathering and nourishment, fluid mixing and also spilling out. This inherently felt more appropriate for the liveliness of the organism.

Figure 49: Genome Foundry, Edinburgh University. Research documentation, 2016. Image: Louise Mackenzie

The word *pithos* means vessel. More specifically, it was a vessel that would have contained goods of economic value: wine, oil or grain. It appears in the classical rendition of Pandora[172], Hesiod's poem *Work and Days* where, depending upon the meaning given through translation, Pandora is either the first woman on earth, a *pithos*, or an evil to blight all mankind (Panofsky and Panofsky, 1962, pp. 3–13). Writing at the turn of the 20th Century, classicist Jane Ellen Harrison challenges the misogyny in Hesiod's story. Harrison's work on myth and ritual in ancient Greece, boldly feminist and as a result marginalized by history, uncovers the significance of women to early Aegean culture (Arlen, 1996, p. 170). Whereas Hesiod describes Pandora as techné; a *pithos,* fashioned by Hephaestus from earth and water, Harrison traces Pandora to a goddess of matriarchal ritual, from depictions of Pandora in the third and fourth centuries BC, in script and on ceramic vessels where she is seen emerging from the ground, symbolizing fertility and the riches of the earth. In particular, she draws our attention to the marginalia of Aristophanes' play, *The Birds*, 414 BC where a scholar's comment is to be found: 'to Pandora, the earth, because she bestows all things necessary for life' (Harrison, 1991, pp. 257–321).

In classic readings of the myth, 'woman is a separate and alien being': difference is rendered in the 'technical invention' of woman from clay and water (Zeitlin, 1996, pp. 56–57). The form of the *pithos* is also inherently gendered. 'Throughout the Hippocratic corpus … the woman's uterus is likened to an upside down jar, furnished with two ears or handles' (Zeitlin, 1996, p. 65). Thus we see a fusion of the function of the womb with techné in the myth of Pandora, in an attempt to wrest from woman the origin story.

> 'The first cultural device was probably a recipient .... a container to hold gathered products and some kind of sling or net carrier.
>
> So says Elizabeth Fisher in *Women's Creation* (McGraw-Hill, 1975). But no, this cannot be. Where is that wonderful, big, long, hard thing, a bone, I believe, that the Ape Man first bashed somebody with in the movie and then, grunting with ecstasy at having achieved the first proper murder, flung up into the sky, and whirling there it became a space ship thrusting its way into the cosmos to fertilize it and produce at the end of the movie a lovely fetus, a boy of course, drifting around the Milky Way without (oddly enough) any womb, any matrix at all? I don't know. I don't even care. I'm not telling that story.' (Le Guin, 1989, pp. 168–69)

Ursula Le Guin revisits the significance of the archaic vessel as container in reimagining the story of human progress from one of heroes and weapons to one of heroines and baskets (Le Guin, 1989, pp. 168–69). Le Guin suggests that the hero's story (in this case of fighting mammoths with weapons) is given as more exciting to tell but the above passage hints at a different problem, an ontological one repressed through phallogocentrism[173]. The heroine's story can be just as fierce, but her sticky warm-blooded messiness is not one of weapons, war and the end of life, it is one of birth and generation.

In my re-generation of the myth, I chose to fashion a simple clay pot from terracotta, water, my own spit and the synthetic DNA plasmid that I had constructed in the lab. I brought my thought-as-DNA into the studio and started to shape a vessel from clay. Crucial to making this vessel was that I had no prior idea of the form that it would take. It was not drawn or designed in advance; the form of the vessel came from my body as I worked. The vessel was thus an assemblage born of the clay, the thought-as-DNA and my body/mind, intra-acting. I began shaping the vessel into the form of a *pithos* with a wide belly and a lipped opening at the narrower neck. As I worked, I considered whether the vessel might have handles to aid carrying and instinctively decided against making something that might be construed as ornamental (after all the vessel is functional without handles). The positioning of handles on the form however served to remind me of the

lively nature of the vessel that I wanted to convey and I found myself shaping a form that was inherently gendered. In place of handles, I added two further openings and shaped the vessel ambiguously somewhere between a pot and a womb. *Pithos* then, intuitively positions the first example of techné as an object of care and more specifically, a symbol of the transformability of both material and life.

Pithos was exhibited as a part of *The Late Shows* at BALTIC39, UK in April 2016 (Mackenzie, 2016b). A room of approximately 4m x 4m was entirely blacked out, the pot rested upturned on a single plinth under a directional spotlight, and eight active monitors (speakers) were arranged at random heights and distributions throughout the space. The audio played a unique track to each speaker: a synthesised American male voice (plucked from the internet) repeating the original phrase now encoded within the *E. coli* and seven distinct mutations (generations) of the original phrase[174]. The first track includes ambient background sounds from the laboratory at the Institute of Genetic Medicine. The original phrase is repeated through one monitor, then additional tracks gradually begin to emerge randomly from each of the remaining monitors to give the effect of being surrounded by the evolving sound. The repetition increases randomly (mimicking the sense of growth out of control that I experienced whilst growing my *E. coli* in the laboratory) and thus the audio becomes increasingly difficult to listen to. Each track diminishes in intensity and volume until finally the eighth track, with its distinct mutation is repeated alone. The audio plays on a loop and lasts for 3 minutes 9 seconds. The audience was requested to enter the space no more than five at a time, to ensure a close and personal experience.

On reflection, the simplicity of presentation had resulted in an aesthetic form of black boxing. In my attempts to reduce the work to two key components I had excluded a significant amount of information that resulted in removing my association with the laboratory almost entirely (but for ambient background noise). The only engagement with the laboratory came through the information provided for the audience prior to entering the space (Figure 50). There was no visible evidence of the plasmid and the mutated voice: an aesthetically layered simulation of evolution, was too many technological layers removed from the organism. Thus, in removing the ‘glass’ (see Section 2.1.1) in such a subtle and clouded way, I had also removed a necessary tension from the work. This tension is compounded by the fact that the audience need to see the *E. coli*, but cannot, as only certain premises have licenses to hold genetically modified organisms[175].

Pithos
8 channel audio installation, terracotta vessel imbued with synthetic DNA construct and the DNA of the artist

In Hesiod's *Work and Days* we find the creation of Pandora, the first woman on Earth, whose curiosity caused her to open a *pithos*, allowing death and all the evils of the world to escape, all except *elpis* (hope) which remained within.

The *pithos* is a jar, large enough to conceal a body within. Commonly used to store and transport wine, oil, grain, or other commodities, *pithoi* were used among civilisations that bordered the Mediterranean Sea in the Bronze and Iron ages. The etymology of *pithos* is thought to derive from the Proto-Indo European **bhidh*- meaning "container", and also from the Latin *fiscus* or "purse", leading to a generally accepted view of the *pithos* as a large vessel containing goods of economic value.

The field of synthetic biology uses the body of the micro-organism as vessel, storing synthetic genetic information within the living cell for human value. The potential in genetically altering microbial organisms, for use as energy and within healthcare and medical treatment has attracted both private and public sector investment and an increased number of funded research opportunities within the technology and defence sectors. The field has adopted as a founding statement the words of physicist, Richard Feynman, *"What I cannot create, I do not understand"* and embraces open source techniques for 'coding' with DNA and a growing bio-hacker movement.

For *Pithos*, I have created a synthetic DNA construct and placed it within the living body of the synthetic biology workhorse, *E. coli*. Through a process of translation that matches the genetic code to phonemes in speech, the synthetic DNA takes the form of a question to the micro-biological other. This question permeates through generations of *E. coli* as they divide and multiply. Whilst they live in laboratory conditions, a computer simulation of their evolution has been converted into an 8 channel sound installation. *Pithos* explores what we are capable of making with life and whether we can, or should, attempt to contain it.

Figure 50: Supporting Text for *Pithos* at The Late Shows, BALTIC39. Image: Louise Mackenzie

Removal of the 'pedestal' (figuratively if not literally) was more successful however. The single plinth with the upturned pot indicated a sense of disruption. I specifically wanted to focus attention on the object, the upturned *pithos*, and on the sound, the disorienting, chaotic voices. However, in attempting to challenge perception poetically, I had sacrificed the vector-frame (Mitchell, 2010, p. 89). *Pithos* therefore expressed my inability to bring the organisms out of the laboratory. Mediated images and sound, although poetic, did not sufficiently convey the complexity of my situated relationship to the experience of genetically modifying life in the laboratory, as captured more directly in *Untourage*.

6.1.2 –Phage

–Phage is the second vessel to arise from the *Pithos* project. I created the sculptural installation, *–Phage* (Mackenzie, 2017a)[176] in reaction to *Pithos*. Although I have primarily been working with plasmids and *E. coli* in the lab, I also researched viruses as tools of communication and *–Phage* begins to address my attraction to the virus (specifically the bacteriophage) as sculptural form and as metaphor.

The bacteriophage latches onto the host organism with appendages and expels information (DNA) from within the central body into the host[177]. The technologically mediated image of the bacteriophage, with its geometric protein shell head, spiral tubular body and spider-like appendages, is an evocative form. Search the internet for 'bacteriophage' and a range of images appear, of which only very few are recorded through the technological layering of specialized microscopy techniques[178]. The bacteriophage is an example of where the narrowed focus of looking without seeing gives way to alchemical sensing through artist's impressions (see Figure 51). *Phagein* translates as 'to eat' or 'to devour'[179], therefore I chose in *–Phage* to make a direct comparison between the consumption of information and the consumption of nutrients, both of which I suggest are evident simultaneously in the material-semiotic relations of the phage and are thus by extension deeply entangled as forms of epistemological and ontological consumption respectively.

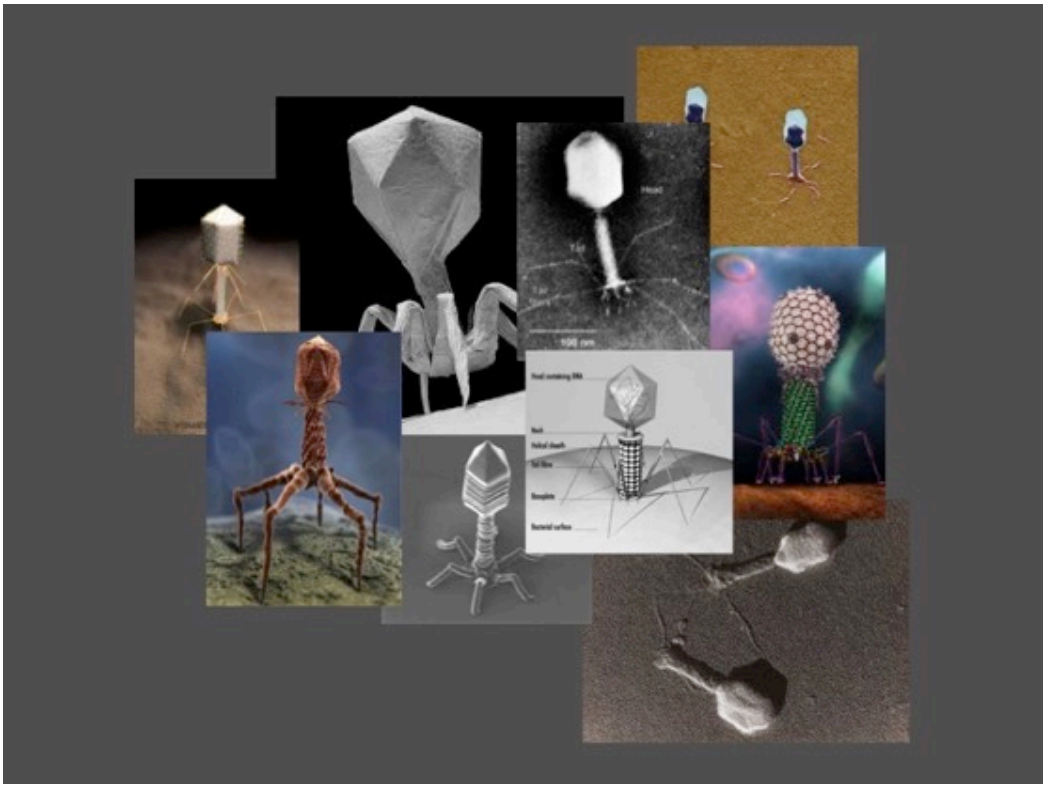

Figure 51: Bacteriophage images appropriated from internet. Research documentation, 2017. Image: Louise Mackenzie.

Figure 52: Vitrines at School of Marine Science and Technology (MaST), Newcastle University. Research documentation. Image: Louise Mackenzie

-*Phage* comprises scientific vitrines, mirror, a media player, two projectors and an 8-channel audio to project the sight and sound of my thought-as-DNA into the gallery space. The work gives presence to the form of the bacteriophage. The form of the virus is evidenced in the physical mutation of the two vitrines into a large hexagonal prism structure, with long appendages protruding from one end. The structure also *functions* as a virus. It is comprised of metal, glass, technology and code that the central body translates and replicates. Errors are to be expected. The technology housed within the -*Phage* (media player, projectors) assists in the reproduction of information. The information (audio and a spectrogram[180] of my thought-as-DNA spoken aloud) mutates, both visually and audibly. Attempts to read the information are distorted by mirrors that alter the image and by algorithmic parameters that audibly evolve the sentence (see *Pithos* installation 6.1.1).

-*Phage* mutates an existing form of scientific communication into an imagined contemporary equivalent[181]. Symbolically, the bacteriophage is the virus and the virus is the word (Burroughs, 2005, p. 5). Figuratively, the –*Phage* becomes for me a contemporary Bourgeoisian spider: a maternal monster (Manchester, 2009), devoured and devouring. In considering the information that would spill out of –*Phage*, my instinct was that it had to be my thought-as-DNA, although a part of me also wanted to transmit a confusing multitude of images, collaged together: my work in the lab, or found images and video footage of scientists historically staking their claim in the 'White Capitalist Patriarchy' (Haraway, 1988, p. 592).

The relation of -*Phage* to the audience is discussed in the context of the two exhibitions, *Viral Experiments* at Queen's Hall Arts Centre in Hexham (Mackenzie, 2017f)[182] and *Genocentric* at Summerhall, commissioned by ASCUS Art & Science and Edinburgh International Science Festival (Mackenzie, 2017b)[183] in Section 6.3 below.

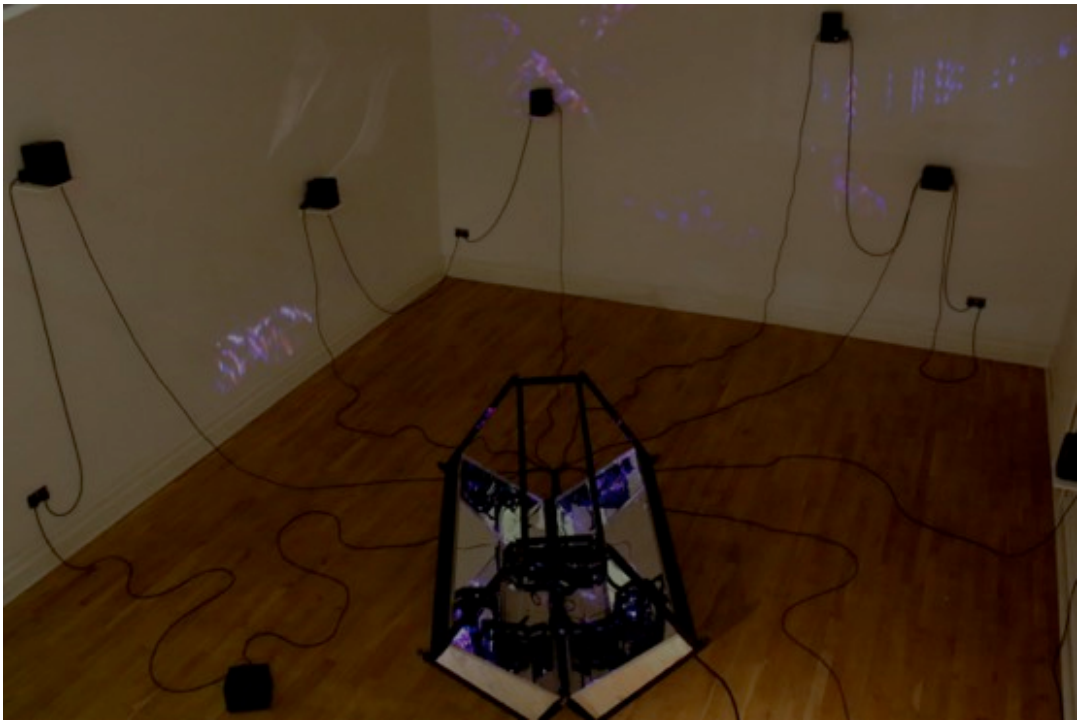

Figure 53: Louise Mackenzie, 2017. -*Phage* at Viral Experiments, Queens Hall Arts Centre, Hexham. Science vitrines, mirror, 8-channel audio, single channel video, projectors, media players, cables, synthetic DNA. Image: Dominic Smith

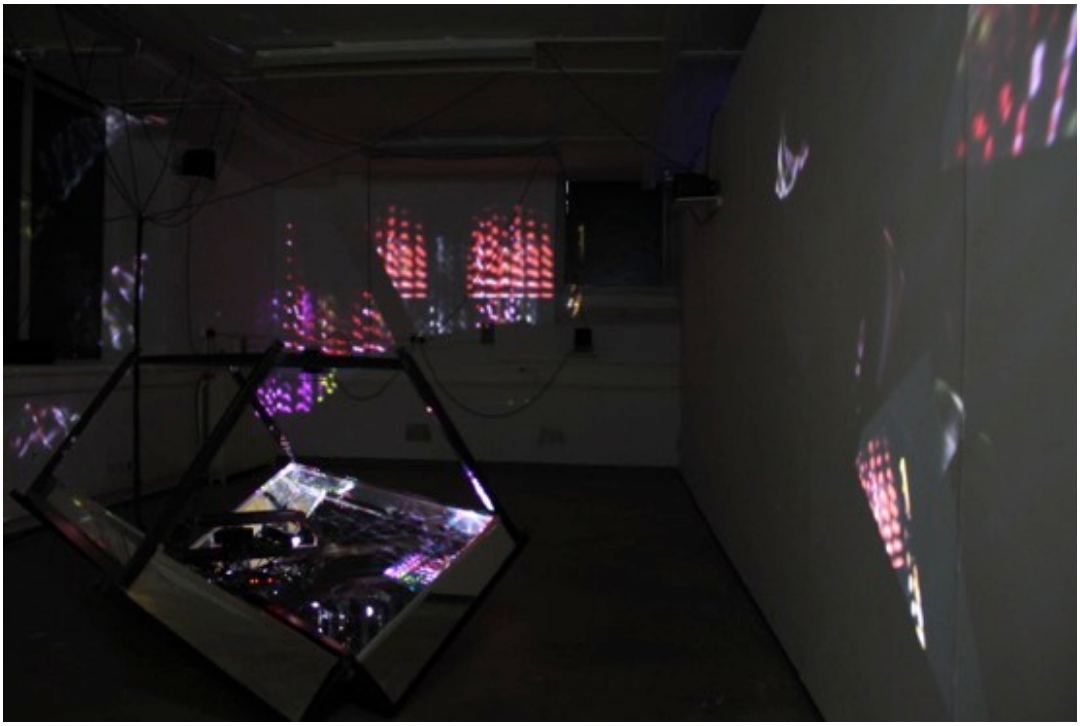

Figure 54: Louise Mackenzie, 2017. -*Phage* at Genocentric, Summerhall, Edinburgh. Science vitrines, mirror, 8-channel audio, single channel video, projectors, media players, cables. Image: Louise Mackenzie

6.2 Technologically Dis-Embodied Discourse

6.2.1 Sonifying Mutation

Physical interaction with the organism meant killing and sequencing the *E. coli* and I was reluctant to do so. From earlier experience in attempting to find mutation (see Appendix I, Lab Diary), I feared that not enough time had yet passed for mutation to occur. Also to kill and sequence the *E. coli* was an expense (a not insignificant expense to my host organisation and a significant one to the organism). I did not want to impose on either at this point.

With the support and advice of bioinformaticist and virologist, Dr. Derek Gatherer, whom I met during the *Microbes as Material* workshop at the University of Lancaster, I used an evolution modeling technique to predict the communication that I sought from the organism (the mutation that I was not yet seeing in the laboratory). I fed the DNA sequence (that represented my thought) into evolution modeling software: a tool known as *MEGA* (MEGA, 2017). Within this software, I applied the Jukes Cantor model, which is a basic evolutionary model assuming that the substitution of nucleotides within DNA occurs with equal probability (Jukes and Cantor, 1969). *MEGA* takes as input the translated DNA version of my thought and then, by running an algorithm, produces variations of this DNA according to the Jukes Cantor model. Using this method, it was possible to predict multiple generations of mutated DNA. I was then able to manually translate this synthetically mutated DNA back into spoken phrase using the cypher I had created and then type the resulting words into the online speech synthesis software, *Festival* (Black *et al.*, 2014) to produce a digitized voice, which I turned into an 8-channel audio using Apple's audio software, *Logic Pro*.

The mutated sounds I now had were generated as a result of substantial technological layers. I have summarized them below, but several more layers can be inferred even within this summary:

- My thought
- Spoken aloud
- Recorded (using technological layers to break the sound into digitized information)
- One aspect of this record (phonemes) translated into DNA

- DNA mutations generated through a mathematical model (several more layers of technology involved)
- DNA mutations re-translated back into phonemes
- Phonemes 'stitched' together manually
- Resulting sounds played through headphones or speakers

6.2.2 Genophone

As I wanted to find out whether my organisms would respond (my thought-as-DNA mutate) at different intervals throughout the project, I chose to develop an automated means of translating my thought-as-DNA. The concept of the *Genophone* (Mackenzie and de Crécy, 2016)[184] therefore arose as a means for me to technologically enhance my ability to communicate with the organism.

Figure 55: Louise Mackenzie, 2017. *Genophone*. Phoneme to DNA Speech Synthesis Software. Image: Louise Mackenzie

Through the support of Professor Simon King at the Centre for Speech Technology Research at Edinburgh University, I collaborated with masters student, Étienne De Crécy to develop a working prototype[185]. Using as a basis the cypher I had already developed (see 4.5.2), the *Genophone* maps the 64 codons of the genetic code to phonemes used within the English language (around 45, depending upon regional variation), plus some additional dialect phonemes, adding up to a total of 64. At the conceptual level, *Genophone* performs the following functions:

- The translation of written text into phonemes;
- The mapping of phonemes to DNA;
- The predictive evolution of DNA;
- The re-mapping of DNA into phonemes;
- The translation of phonemes into speech[186].

As a user interface, the *Genophone* was first designed to be accessed via a Twitter account and later via a website. Only basic interface features have been developed at this stage and this is a potential area for post-doctoral research.

My attempts to automate translation of my thought-as-DNA led to significantly more layers of abstraction. I have only outlined the highest level of conceptual layering above, behind this there is a vast constructed network (no longer simply layers) of neural processing to enable something resembling human speech (de Crécy, 2016). The *Genophone* essentially produces a sonification of the DNA sequence, however as it passes through so many permutations (including the recording of my own voice as data source[187]), it becomes an expanded hearing rather than a close listening.

My main considerations in the development of *Genophone* were voice, language and what I appropriate from Barthes as the grain of the voice (its material qualities: digital timbre and the in/accuracy of phoneme translation). In *Pithos* the voice was initially male, I had considered using a female voice but wanted to allude to the history inherent in the spoken word, the 'god-trick' as Donna Haraway would describe it (Haraway, 1988, 1991, p. 195). For *Genophone*, instinctively it felt right to use my own voice. As a metaphorical means to communicate directly with the organism, *Genophone* becomes the process of transition from thought to speech and therefore to use my own voice further emphasizes that it is my thought embodied within the organism.

After deciding upon using my voice, the choice of language became obvious. We had to compromise on the grain of the voice, however. Whilst I instinctively wanted to expose what Étienne perceived as flaws in the system, Étienne's considerations focused on precision of translation based on the specific phonetic qualities of my voice (de Crécy, 2016, p. 50). A core aim of speech synthesis technology is to remove any trace of the mechanical from the voice, creating an aesthetic black box around the technological

layering required to perceive the resulting sound[188]. In happy emergence from this often difficult discourse, the resulting sound is eerily close to a human voice, but it is possible to discern that the voice is digital. Thus a cybernetic version of voice, complete with Edinburgh dialect phonemes (my regional accent, each trip of my tongue delineated) was born.[189] Further expanded hearing through the subversion of speech synthesis technology by lively material (human or otherwise) has been identified as a potential area for post-doctoral research.

6.3 Material-Semiotic Articulation

In developing a cypher and then a plasmid, which was now incorporated within a living organism, I had not yet found adequate means to express this in a public context. I brought together my research to date in the solo exhibition, *Viral Experiments* at Queen's Hall Arts Centre in Hexham (Mackenzie, 2017f)[190] and then a few months later in *Genocentric* at Summerhall, commissioned by ASCUS Art & Science and Edinburgh International Science Festival ((Mackenzie, 2017b)[191]. The following sections address the research question,

How does the experience of synthetic biology in the laboratory translate into an experience in the context of the gallery?

6.3.1 Viral Experiments

Queen's Hall Arts Centre in Hexham is an innovative contemporary art gallery in a rural market town. There are two gallery spaces: upstairs I installed a video of my activities in the laboratory, *Lively Material* (see Section 6.5.1) and the phoneme to DNA translation device, *Genophone*. On the ground floor level (where the public enter the arts centre, which also houses a café, theatre and library), I exhibited *–Phage* alongside a vial containing my thought-as-DNA.

Walking into Gallery 1, the audience hears the mutating audio and can see the lines of the spectrogram distort into new forms (a form emerges from a slight warp in the mirror that resembles the double helix). Spot-lit on an oversized plinth nearby, a tiny vial (containing the thought-as-DNA) lies open with a question mark drawn on the lid (see

Figure 56). In Gallery 2, a video diary of my activities in the laboratory plays on a loop, next to a monitor that displays messages sent to the *Genophone* (see Figure 57). Instructions were available for audience members to use *Twitter* to send messages to the *Genophone*, which would respond by playing a synthesized sonification of their message and a rolling spectrogram of the sonification on the monitor.

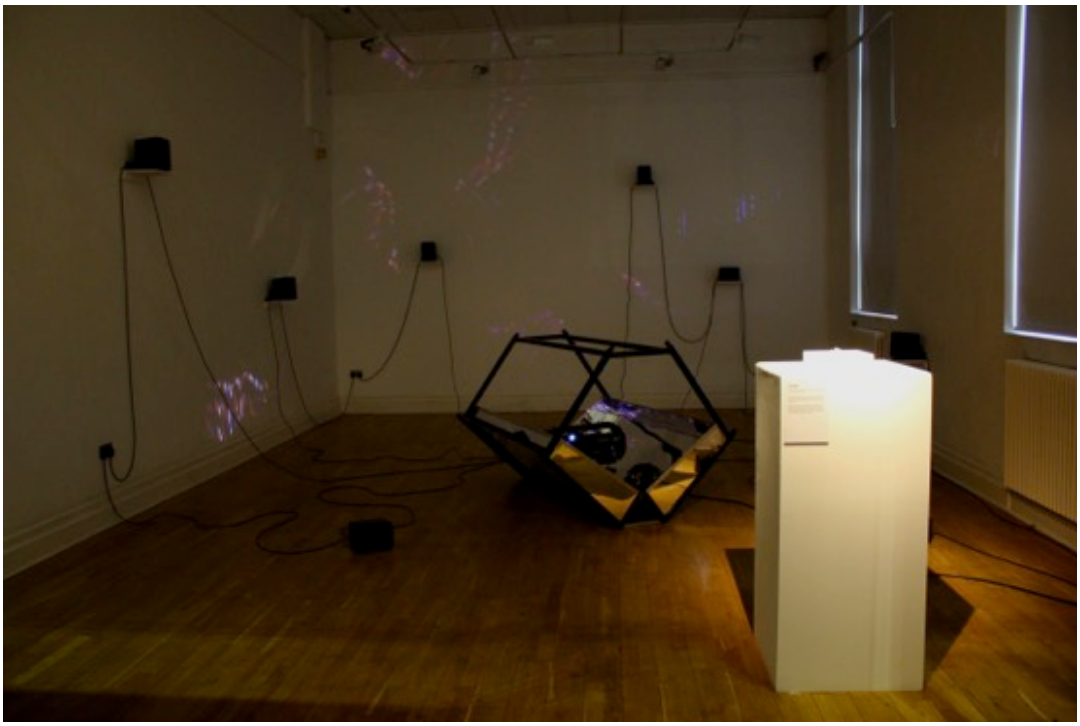

Figure 56: Louise Mackenzie, 2017. *Viral Experiments*. Installation view, Gallery 1, Queen's Hall Arts Centre, Hexham. Image: Louise Mackenzie

Even with the thought-as-DNA present alongside *–Phage*, the split of artworks across floors served to maintain a dissociation from the organism, evidenced in the variation in comments between floors[192].

Figure 57: Louise Mackenzie, 2017. *Viral Experiments*. Installation view, Gallery 2, Queen's Hall Arts Centre, Hexham. Image: Dominic Smith

Although my original intention was for *Genophone* to enable dialogue with the organism, this interaction was again deferred. By including predicted evolution within the construction of the *Genophone*, I had (like Kac's *Genesis*) aesthetically collapsed the distance in time between communication and response. However, rather than create an aesthetic black boxing of my experience with the organism, audience interaction was directed towards the predictive technology itself. Whilst this generated a different form of engagement (a sample of tweets is shown on my research website), the work remained technological, again preventing access to the organism. Further I was attempting to exhibit a process of translation as a sculptural object, thus requiring a visual device that would represent the spoken phrase. My initial desire to 'remove the glass' and communicate with the organism became reflected and distorted by metaphorical mirrors of technology.

Figure 58: Louise Mackenzie & Étienne De Crécy, 2017. *Genophone*. Installation view, Gallery 2, Viral Experiments, Queen's Hall Arts Centre, Hexham. Image: Dominic Smith

It was clear from *Viral Experiments* that the film, *Lively Material*, drew the various strands of the work together, becoming a necessary narrative in guiding the audience through my experiences in the laboratory. Visitors to the upstairs gallery commented that they had gained a more personal insight into the work through seeing my actions in the laboratory. Thus whilst the work remained 'behind glass' (or screen), by visibly positioning myself within the work, I became the subject for the audience.

Figure 59: Louise Mackenzie, 2017. *Viral Experiments*. Conversation with the Artist. Image: Gareth Hudson

Further connection to the work was developed through dialogue with the audience at a discussion scheduled for the exhibition opening. The discussion was chaired by exhibition curator, Dominic Smith and included myself, Professor Volker Straub from the Institute of Genetic Medicine and philosopher and ethicist, Dr Simon Woods of Newcastle University. The discussion format (rather than formal talk) and ensuing questions provided a valuable means by which to draw the various elements of the research together for the audience and helped to provide a context to the work across disciplinary perspectives.

6.3.2 Genocentric

The second presentation of my research was two months later, as the exhibition *Genocentric*, for *Contemporary Connections* at Summerhall, Edinburgh, commissioned by ASCUS Art & Science and Edinburgh International Science Festival (Mackenzie, 2017b). The term *Genocentric* plays on Jacques Derrida's concept of *logocentrism* (Derrida, 1979,

pp. 3–73) comparing primacy of the gene to primacy of the word, whilst hinting at my frustration with the limited means to relate to the materiality of the organism that this entails. Three separate spaces were constructed in a manner that required the audience to navigate between spaces to access each work in turn.

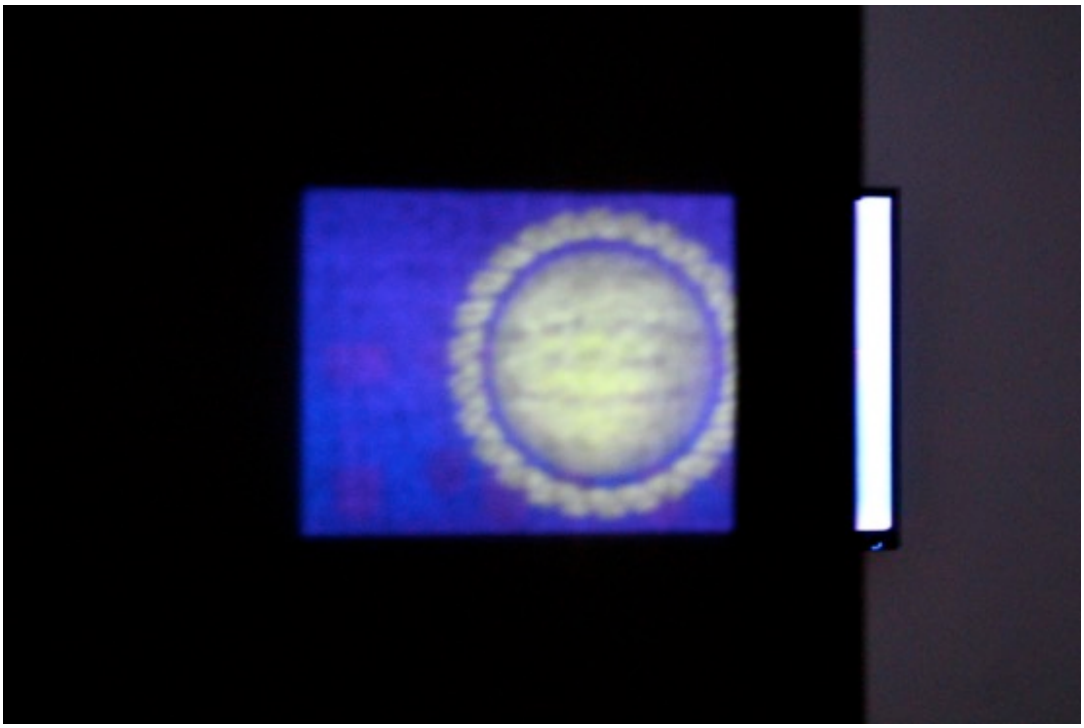

Figure 60: Louise Mackenzie and Étienne de Crécy, 2016. *Genophone*. Installation view, Summerhall, Edinburgh. Image: Louise Mackenzie

The development of *Genophone* progressed from *Twitter* to a website for the exhibition in Edinburgh. I chose to embed *Genophone* behind smokescreens and fun-show style mirrors (see Figure 61) so that the audience had to locate the work. The construction of the space and the construction of information on the website enabled a richer experience where the audience were able to create their own dialogue with hypothetical organisms.

Genophone remained disconnected from the organism in Edinburgh. In fact, *Genophone* has come to represent the irretrievable gap between the organism and myself. In contrast to works that aesthetically black box the evolution of the organism (see for example, *Genesis* Kac, 1999), the *Genophone* is open in its technologically layered alchemical trickery. It becomes a manifestation *of* the black box: a means of attempting to relate to the organism without fully connecting to it. It is not possible to reveal the genetic sequence of the *E. coli* bioassemblages in real time[193] and so I choose instead to reveal the capabilities of the technology: predictive and subjective. I was able to draw a closer, performative relation to

the organism through use of *Genophone* as tool, during the genetic modification workshop *Transformation* (Mackenzie, 2017e)[194], commissioned by ASCUS Lab and Edinburgh International Science Festival.

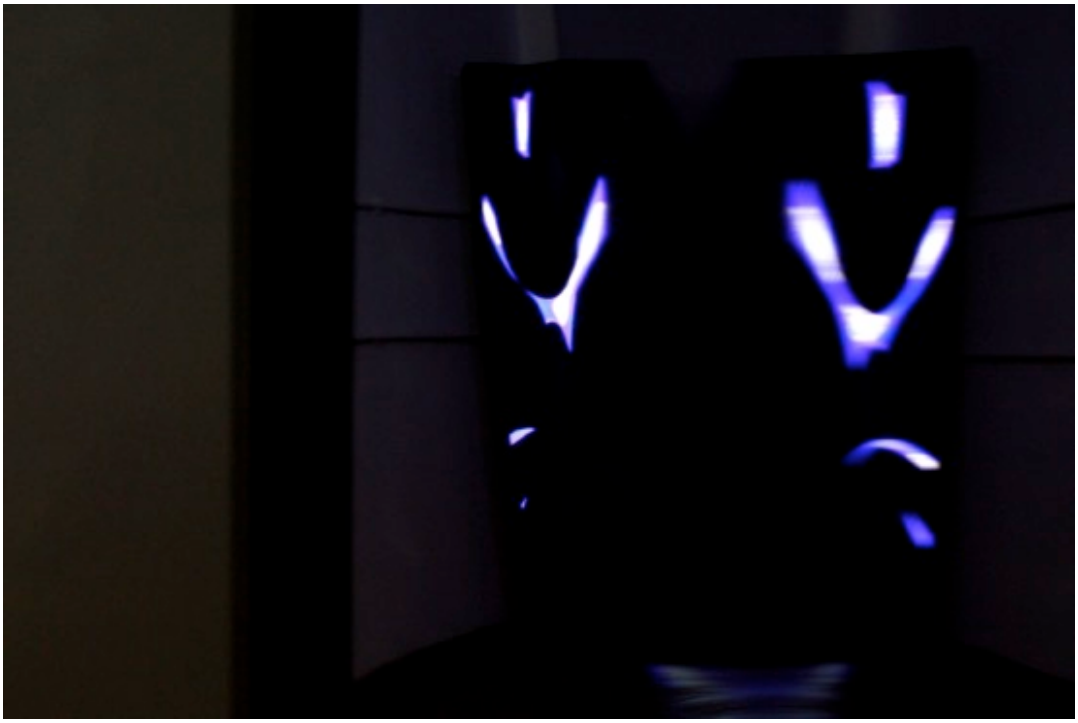

Figure 61: Louise Mackenzie and Étienne de Crécy, 2016. *Genophone*. Installation view, Summerhall, Edinburgh. Image: Louise Mackenzie

Genophone is at this stage only a prototype with limited functionality. Research to develop the work beyond the doctoral project would further explore the idea of aesthetic black boxing in genetic research and the concept of evolution as communication.

6.4 Bioassemblages

I ran a DNA extraction workshop in my studio for architecture students where we extracted DNA from our own cheek cells (Mackenzie, 2015c)[195]. The result can be somewhat underwhelming: the DNA is a faint, cloudy substance that precipitates in solution. Marta De Menezes' *Inner Cloud* (de Menezes, 2003) showing the artist's DNA, visibly precipitated in ethanol, questions what it is that we conceive of as DNA: The essence? The soul? Or is it simply raw material?

Figure 62: Louise Mackenzie, 2015. *DNA Extraction Workshop*. Newbridge Studios. Image: Louise Mackenzie

Although poetically portrayed in *Inner Cloud*, DNA can seem unremarkable up close. I was reluctant at first to simply show the material (partly as I would only be able to prepare such a small amount). Thus my thought-as-DNA was first exhibited mixed within the clay of *Pithos*. This however meant that the plasmid, although physically present, was only visible through the technologically embodied sound of my encoded thought, which thus altered the publics' perception of the work (see 6.1.1). This was a result of technological layering, rather than one caused by 'glass' or 'pedestal'. One that I suggest is particular to conceptual art practice working at the nano-scale. All materials signify, but this makes for difficult reading when signification of the central material is technologically layered. DNA is complicated by its reading as code. We understand it as part of the body, a visual double

helix form, or a series of coded letters. Attempts to presence the material and the information that I had bestowed upon it, without resorting to familiar forms of coded embodiment are less readily accepted.

For *Viral Experiments*, I wanted the thought-as-DNA to be visibly present as lively material, but without familiar technological embodiment. I chose to specifically draw attention to scale. The plasmid was suspended in a few millimeters of filtered, distilled water, held within a 1.5cm tall plastic vial. The vial was spot-lit on an oversized plinth. Only the plastic vial and the water were visible to the naked eye. Even presented this way, the thought-as-DNA is almost indiscernible. I was tempted to show this alone in the 5m x 13m gallery space, with only the sound, but this was too close to the previous iteration of *Pithos* where the sound seemed too disconnected from the object. This time, the plasmid and vessel (*-Phage*), were shown separately, but in the same gallery.

Given the relatively restrained context in which the work was shown, audience comments such as: 'the vial of DNA being open prompts thoughts of escape', 'disturbing' and 'scary' reminded me of the power of the presence of bio media in the gallery context, something Robert Mitchell describes as, 'encouraging in "spectators" a bodily sense of becoming (sometimes unwilling) participants and framing them as embodied parts of larger, dynamic systems, of which neither they, nor the artist are fully in control.' (Mitchell, 2010, p. 73).

Showing the plasmid DNA in a vial alongside *–Phage* made clear the significance of a 'behind glass' (or in this case, plastic) framing. When showing *Pithos*, visitors did not necessarily believe that the synthetic DNA was there, because they could not see it. For the most part, they could not see it again in *–Phage*, however it was presented in the type of vessel that one might expect, thus it was more believable and consequently the bodily experience for the audience was heightened. The invisible plasmid, now bounded by scientific material, had an authority not previously present in the work. This was of some personal frustration to me: the need to bound the work in scientific visual language before it has validity. Furthermore, the fact that I had subjected my will upon the DNA was still only obvious from the supporting text.

Figure 63: Louise Mackenzie, 2017. BioAssemblage #1, Thought translated into DNA and assembled in a plasmid DNA vector, Eppendorf Tube, Synthetic Plasmid Documentation. Image: Louise Mackenzie

For *Genocentric*, I chose to exhibit the synthetic DNA as a separate work with its own space. This was the first time that the plasmid was shown without the technologically embodied sound. As well as the vial containing the DNA in solution, I chose to exhibit the gene synthesis quality assurance documentation as further evidence of the presence of the plasmid. I also decided to leave the vial closed so that the lively material would not evaporate and thus would be in evidence throughout the duration of the exhibition. This presentation was significantly more scientific, with the vial closed and the inclusion of the plasmid documentation. Thus I had reverted to a 'behind glass' presentation. Another key difference was that for the first time, the thought-as-DNA was titled. I had wanted to avoid labelling this work, given that it was already a combination of thought and medium, but as other works in the exhibition focused on the thought, it felt necessary to draw attention to the medium.

There are already terms that describe genetically modified material in the context of art practice: 'transgenic art' (Kac, 1998), the 'semi-living' (Catts and Zurr, 2002) but I wanted to discuss the assemblage of lively material and genetically modified organisms in a sphere that is inclusive of other disciplines. Thus I introduce the term *bioassemblage* in an attempt to blur the boundaries between biotechnology and what Eduardo Kac terms transgenic art. I make no distinction between whether the assemblage is created within the context of science, art or any other practice. The term refers to all genetic constructs that include a human actor in their assemblage. Thus my thought, expressed as language within a DNA plasmid, is a bioassemblage just as the infamous DuPont patented 'Oncomouse' (a mouse genetically modified to carry cancerous cells) is a bioassemblage (Adler, 2016)[196]. There is therefore nothing particularly novel in designing a bioassemblage, it is by now a common occurrence in science and an increasingly common occurrence in art and design practices as the possibilities inherent in new materials are explored. By framing it in this way however I aim to consider more than the object in isolation. Imposing thought upon the body through my practice allowed me to ask, *Can art practice that works with living (and lively) material reconsider material not as living commodity, but as infectious idea?*

The intention with the introduction of the term bioassemblage is to shift discourse from an engineering rhetoric with a production and tool-use bias to a broader discourse that encompasses not only the abstracted material, but also its vitality and the spatial and temporal context within which the lively material exists. Therefore we can begin to question what sort of being or existence a bioassemblage is across deep time: a product, a

model, a design, an artwork, or is it more nuanced? It is, in essence a form of cyborg, Haraway's monster and as such requires us to consider its messy, unstable past, present and future.

BioAssemblage #1 [197] then becomes the first in a series of bioassemblages that challenge the scientific paradigm of making with lively material. It exists as an assemblage object: segments of synthetic plasmid DNA, designed and constructed in the laboratory. The assemblage is inert DNA, meaningless when read as DNA, yet when deciphered, it holds a question posed to the organism intended as its host. Thus the bioassemblage is will imposed upon material.

In the laboratory, the insertion of *BioAssemblage #1* within the body of *E. coli* generates another bioassemblage. I wish to think of these *E. coli* as animals that shall not be named, or nature that shall not be claimed. Or perhaps as '…that which we cannot desire' (Haraway, 1992). I shall for now use the term organism as a means to discuss not-animal-not-nature. Organisms, according to Haraway are 'made in world-changing technoscientific practices by particular collective actors in particular times and places'. In this thesis, *E. coli* moves from unnamed microbe to trademarked product (and back to organism). 'Organisms emerge from a discursive process. Biology is a discourse, not the living world itself.' (Haraway, 1992, pp. 296–298)

In Haraway's tales, nature is both *topos* and *tropos*: 'a commonplace... a place to rebuild public culture' (Haraway, 1992, p. 296) and in tropos, she invokes both the constructed figure and the turn (a turn towards the earth). For my part, I add a turning *of* the earth, in artifactuality. Replacing reproduction for generation, Haraway points out what she sees as post-modernism's failing: that we do not reproduce so much as generate. This she links to film-maker, Trinh T. Minh-ha's inappropriate/d other: a critical, deconstructed, relational figure that works from within to exceed domination (Haraway, 1992, p. 299). Haraway's artifactuality then is about the semiotics of lived experience and the turning of the earth to fashion new theoretical objects. Thus the bioassemblage in Haraway's words, 'insists on the absence of beginnings, enlightenments, and endings: the world has always been in the middle of things in unruly and practical conversation, full of action and structured by a startling array of actants and of networking and unequal collectives' (Haraway, 1992, p. 304) or as artist and theorist, Hito Steyerl suggests,

> 'Things are never just inert objects, passive items, or lifeless shucks, but consist of tensions, forces, hidden powers, all being constantly exchanged. While this opinion borders on magical thought, according to which *things* are invested with supernatural powers, it is also a classical materialist take. Because the commodity, too, is understood not as a simple object, but a condensation of social forces'. (Steyerl, 2010)

Thus a bioassemblage traverses institutional and historical layers. It is a construction of parts and the fluid relations of these parts within a wider context. While it appears to be a physical entity, it is also the thought that lead to the construction of the entity, the relation of the entity to the (organism) bodies and (architectural) bodies that it travels through and the unknown future relations between the entity and the bodies that encounter it in the laboratory, gallery and beyond.

6.5 Works of Kinship

The introduction of the bioassemblage became a stabilizing point in the project. Now the construction of information within the laboratory pivoted around bioassemblage alongside the sense of kinship that drove my actions in the laboratory.

In an attempt to move beyond the organism as resource and find ways to relate to living material, I began to experiment with ways in which I could commemorate the lives of the organisms that I was working with. My experience of laboratory culture in the UK is that there is little room for reflection on the living material that is a vital part of laboratory work, and by extension a vital part of our lives. Conversations I have had with my colleagues in the laboratory led me to conclude that a means to share the affect of working with life in the laboratory might form a useful first step in interdisciplinary dialogue on the place of kinship in the laboratory.

My practice instinctively began to reflect what Donna Haraway defines as a kinship approach. That is, a 'vulnerable, on-the-ground work that cobbles together non-harmonious agencies and ways of living that are accountable both to their disparate inherited histories and to their barely possible but absolutely necessary joint futures' (Haraway, 2003, p. 7). This approach reflects the practices of other cultures. The Japanese culture of honouring the spirits of animals used in laboratory research for example, further extended to artificial life in metaPhorest's project *aPrayer* (metaPhorest, 2016). My

experiences were that such a vulnerable approach was difficult for scientists in the UK to accept and so I chose to adopt the same philosophy through a subtle humour[198].

Although less fully resolved during the course of the doctoral project, I have begun to make a series of *Works of Kinship* that derive from my subjective experience within the laboratory. I highlight them briefly below before concluding this section with a discussion of the *Transformation* workshops that bring the technological embodiment and kinship works together.

6.5.1 Lively Material

For *Viral Experiments*, I created the experimental film, *Lively Material* (Mackenzie, 2017c)[199] based on extracts from my lab diary. *Lively Material* follows on from *Untourage* as a documentation of my subjective experience within the laboratory, where I attempt to hold onto this sensation without letting the procedures become routine. It documents the process of the construction of my thought, from speaking the thought aloud, to encoding it within plasmid DNA and imposing this upon the body of the laboratory organism, *E. coli*. The film became pivotal in that I become the surrogate subject for the audience. Rather than simply showing the DNA, the organisms or the technologically embodied thought, my situated response to the work becomes evident. Specifically, it is my relation to the laboratory and to the organism that is given. Thus in *Lively Material*, although still virtually behind glass, I had so far found the closest relation to the organism in a gallery context.

6.5.2 Memento Perimortem

The Latin phrase, *memento mori* translates as ‘remember (that you have) to die’ (Oxford University Press, 2017a). Post mortem photography is the practice of photographing the recently deceased. The term *perimortem*, meaning, ‘occurring at the time of death or very near to it’ is most commonly used in clinical settings and forensic medicine (Oxford University Press, 2017b). *Memento Perimortem* therefore serves as documentation of the termination of several generations of *E. coli* bioassemblages who have died in the making of my work.

Memento Perimortem (Mackenzie, 2015b) is a growing collection of images taken in the laboratory to commemorate the near death of the organisms that I impose my will upon. In the process of creating bioassemblages that hold my thought within their bodies, I have come to respect the liveliness of the organisms whose existence I am in part responsible for. These bioassemblages, made not born, multiply exponentially and I am resigned to reducing their numbers periodically lest they take over the laboratory.

My *E. coli* bioassemblages grow in tubes containing Luria Broth: a liquid nutrient medium. As the *E. coli* grow, the medium becomes cloudy. The *E. coli* become stressed as the number of live colonies increases and the available nutrients diminish.

Each week, I remove 1ml of *E. coli* from the tube on the left and place them into the tube of fresh growth media on the right. I retire the stressed colonies for autoclaving (sterilisation) and disposal as bacterial waste. I thank them, bid them farewell and commemorate their lives with a hastily taken photograph (using a phone to take images is not part of standard laboratory protocol).

By paying my respect to the organism in this way, I try to remember that the resource which I draw upon for my research is living and has the capacity to act and interact in ways that I may never fully comprehend.

6.5.3 Confessional

Following discussions with my collaborator at the Institute of Genetic Medicine, Dr Ana Topf, I wanted to test out scientists' reactions to a more open approach to working with lively material. I constructed on my website a zone of contemplation: an anonymous area in which to discuss working with lively material, a confessional of sorts, or perhaps a chance to place humanity under the microscope. There is the suggestion that it may feel uncomfortable at first but then who would like being under the microscope? With the aim of thinking about lively material as an extension of the self, this provides a virtual space where it would be possible to share amongst our multiple cellves[200] how we feel about the way that we interact with and use forms of life as a part of our own existence. Thus offering a space that operates outside the conformities of the institution: a space for instinct.

I tested this idea out without publicising it and a few people responded so I decided to push the idea as part of a later series of public workshops (see 0).

6.5.4 Food for Thought

The group exhibition, *#FEED* at Queens Hall Arts Centre in Hexham (Smith, 2017) was an opportunity for me to bring the genetically modified *E. coli* bioassemblages into a public forum for the first time. In this installation, under the title, *Food for Thought,* I presented sterilized genetically modified *E. coli* in a clear glass vessel, along with the correspondence from myself to the GMO Health & Safety officer at Newcastle University, which confirmed that the organisms I was exhibiting would be both sterile (dead) and contained safely[201]. This work was presented alongside a single printed image of all the universal tubes of *E. coli* bioassemblages that had died in the making of this particular work, *Memento Perimortem 2016-17* (Mackenzie, 2017d).

6.6 Transformation

With the support of Dr Ana Topf and PhD researcher Stephanie Carr, I developed the workshops *Transformation – Thinking Through Making With Life* (Mackenzie, 2017e)[202]. The idea to run workshops arose from a desire to extend to the audience a more direct relation of my subjective experiences working with lively material. These workshops marked another critical point in the work, that of the coming together of the linguistic, post-structuralist approach to working with life and the phenomenological, experiential approach to working with life. Thus in inviting members of the public to engage directly with lively material as both organism and resource, the workshops confront semiotics and materiality together.

Figure 64: Louise Mackenzie, 2017. *Transformation.* Psychotransgenic art workshop. Image: Anaïs Moisy.

The workshops are intended for an audience interested in working with life as material and thus are suitable for artists, designers, architects, scientists, engineers, computer scientists, bio-hackers and philosophers. The intended audience serves to illustrate the reach of genetics and synthetic biology, which is itself an indicator of the extended level of technological embodiment (and thus black boxing) that enables the construction of new knowledge without necessarily understanding the ground it rests on.

During the workshop, participants are given the opportunity to transform *E. coli*, that is they genetically modify *E. coli* to harbour within their bodies a piece of DNA that did not originate within them, *BioAssemblage #1*: my thought-as-DNA.

Figure 65: Louise Mackenzie, 2017. *Transformation.* Psychotransgenic art workshop. Image: Miriam Walsh, ASCUS Lab.

The first two workshops were conducted at ASCUS Lab in Edinburgh, an independent public access laboratory run by ASCUS Art & Science, as part of Edinburgh International Science Festival 2017.

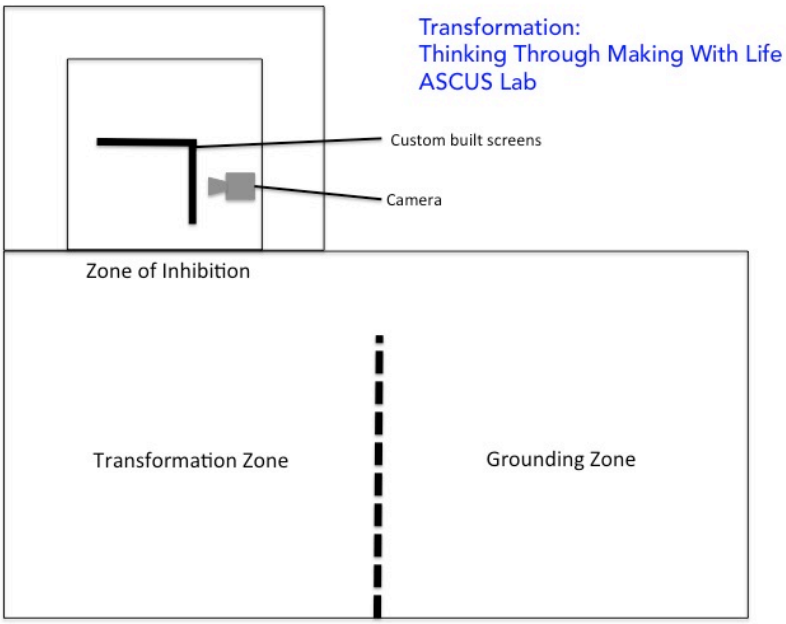

Figure 66: Louise Mackenzie, 2017. Floor plan for *Transformation* at ASCUS Lab, Edinburgh. Image: Louise Mackenzie

The workshop oscillates between three spaces or 'zones' that disrupt the 'behind glass' and 'on a pedestal' parameters. The *Zone of Transformation*, where lab based activities occur, the *Grounding Zone*, a linking space for participants to connect mind to matter through thought and reflection and the *Zone of Inhibition*, a performative space where participants are encouraged to develop a relationship to the cells that they work with. This latter zone becomes the starting point for film documentation that focuses specifically on the affect of working with transgenic life through anthropomorphic performative practice.

The Zone of Transformation is a formally constructed scientific space, with lab benches, scientific equipment and the observation of scientific protocols. In this space, participants impose *BioAssemblage #1* upon the body of TOP10 *E. coli* bacteria. Instructions are given and followed with little deviation from existing laboratory practice. The dictionary definition of transformation is, 'a marked change in form, nature, or appearance'; within the life sciences, the term refers to, 'the genetic alteration of a cell by introduction of extraneous DNA, especially by a plasmid' (Oxford Dictionaries, 2017). Thus instinctively, this became the name of the zone where the specific scientific process of transformation would occur and more ambiguously, the title for the workshop, where other processes of transformation are implied.

The Grounding Zone is a space in which to bring theory and practice together. Introductory and informational presentations take place here, as well as reflective activities. Drawing on 'ground' as a 'connection to earth', this zone is intended as an unconstructed space with no specific rules to define how participants should act[203], instead it functions as a space where participants reflect upon the act of creating a transgenic organism, free from the constructed space of the laboratory. The area is an open plan space, with ambient music, creative materials and in this particular iteration of the workshop, participants were able to draw creative inspiration from *Tales of Synthetic Biology*, a synthetic biology game created and demonstrated by artist and designer, Anaïs Moisy (Moisy, 2017).

> 'It's not like individuals aren't perfectly real and important entities, but no organism develops only out of its own genetic program. The intra-actions that construct the entities are all the way down. No organism is a one.' (Donna Haraway in Williams, 2009, pp. 133–163)

> 'As Brenner said, "the correct level of abstraction is the cell and not the genome."' (Catts and Zurr, 2008, p. 135)

The Zone of Inhibition is a constructed performative space where participants are forced to shift persona. Prior to entering the space, participants are informed that this is the environment of a sentient community-being of cells, who wish to interview participants about their actions in the workshop. Participants are also advised that they will be metaphorically placed under the microscope: that is they will be filmed and recorded in this space. The space is constructed as a small, blacked out room with a single (not particularly comfortable) chair and a bright light shining in the direction of the chair. A black gauze wall divides the participant from a projector screen and film camera, and from myself, using the *Genophone* software to act as conduit for the *Cells of L'Avenir*, a sentient community-being of cells[204]. A faint, ghostly projection is back projected high onto the black gauze, physically depicting the community-being of cells[205]. On entering, participants are interrogated by the *Cells of L'Avenir*, prompting a speculative dialogue on their experience as actors in the generation of a bioassemblage during the workshop. The resulting filmed dialogues will become a part of the ongoing laboratory diary that has now evolved beyond my experiences in the laboratory, to become part of a larger, participatory experience.

During the workshops, participants are asked whether they believe the bioassembled organisms should live beyond the length of the workshop, prompting discussion around the expanding contexts in which we work with and maintain lively material. We ran two half-

day workshops in Edinburgh and in the second, we decided to improvise the addition of a sculptural object, the next sculpture in the *Pithos* series, to hold our bioassemblages. Participants were able to take the transformed *E. coli* from the first workshop and assemble them within a clay vessel with a wide neck, filled with agar and ampicillin: the medium in which the *E. coli* cells are able to grow and proliferate (see Figure 67). The unfired vessel cracked when the agar gel (still too hot) was poured in and the fractured vessel seemed hopeless, yet, regardless of the altered form, all participants actively engaged in this activity (undertaken in the Grounding Zone). The lure of participating in the making of a sculptural object that preserved the living bioassembled organism within it was a powerful demonstration of the human propensity for mark-making and perhaps also an indication of the desire to move beyond glass and relate more closely to material. In a manner reminiscent of Catts and Zurr's MOMA showing of *Victimless Leather* (Catts and Zurr, 2008), the object became contaminated and a decision was taken to autoclave (sterilize) the sculpture (and thus the bioassemblages). The archival aspect of working with living bioassemblages is therefore a potential area for further post-doctoral research.

Figure 67: Louise Mackenzie, 2017. *Pithos (ongoing).* Transformation workshop, ASCUS Lab, Edinburgh. Image: Anaïs Moisy.

Figure 68: Louise Mackenzie, 2017. *Pithos (ongoing).* Transformation workshop, ASCUS Lab, Edinburgh. Image: Anaïs Moisy.

Figure 69: Louise Mackenzie, 2017. *Leaky vessel.* ASCUS Lab, Edinburgh. Image: Louise Mackenzie

A key outcome from the workshop was the power of abstraction in allowing participants to form a new perspective on life as material. This sense of abstraction became clear in two distinct ways. Firstly, my decision not to view the organisms under the microscope prevented the visual abstraction usually associated with microscopic organisms through technological embodiment. Secondly, by in a sense inverting this form of abstraction and placing participants under the microscope, I had provided a performative scenario that enabled participants to find imaginative means to place themselves in the realm of the organism.

Something that I had not anticipated was the reaction to the transformation process itself. The practical task of transforming synthetic DNA into *E. coli* is unremarkable. It essentially involves moving liquid between plastic vessels that are heated or cooled. Therefore it is difficult to connect to any sense of an organism that is only visible as a clear liquid in a plastic container. In the laboratory protocol for transformation of *E. coli*, there is no requirement for participants to view the organism under the microscope (the organism is simply a tool), thus compounding the sense of dissociation from living material. This indicates the primacy of technological embodiment in the laboratory context in that presently, the only means to relate to the organism is through technology.

Thus *Transformation* draws attention to a perceived difference between scientific and performative forms of abstraction. Within the context of the laboratory, levels of abstraction that enable us to isolate DNA from space and time are compounded by the visible distancing from the organism through layers of technology to such an extent that the organism is regarded simply as a chassis and DNA as a code or language to be translated, cut and pasted in what amounts to philosopher, Alfred North Whitehead's, 'fallacy of misplaced concreteness' (Whitehead, 1925, p. 51)[206].

DNA and the organism have become symbols of technological innovation. In this manner, I was able to design *BioAssemblage #1*. This type of abstraction creates a clear rupture between code on the one hand as something within the control of the human and life on the other hand as having form and agency. The *Transformation* workshop locates within this rupture, switching from the scientific abstraction of 'DNA as code' to a performative abstraction of 'DNA as lively material' through both an approach that removes the glass and reduces the pedestal, to enable an understanding of the material through intra-action and further through a performative approach that enables consideration of the organism as a sentient community-being of cells that learn and adapt over deep time.

0 ORIGIN OF REPLICATION

Start again.

This doctoral project set out to address the question,

In what ways can art practice situated in the laboratory expand understanding of our relationship with microbial life as material?

In doing so, it asked another question,

What will happen if I store this thought safe within you?

A question that I returned to often during this research was, *Is a microbe a life, and if so, how can I relate to it?* Intuitively, I pushed against aesthetic figurations that give primacy to the object (Harman, 2010; Morton, 2013) and as a result, I configured an approach to working with genetic material that constitutes it as lively. Drawing from discourse on viruses (Villareal, 2008, pp. 101–105; Brown, 2016), decomposition (Radomska, 2016, p. 35) and the vitality of matter (Bennett, 2010, pp. 1–19), I define the term **lively material**, and provide my own reading of the terms **organism** and **living material**, as a means to engage with laboratory life and genetic material in expanded ways that allow for its messy, related consideration as a phenomenon that cannot be neatly bound by time or space and as such, requires consideration as more than simply resource.

In Chapter 2, through the question, *How does art practice rooted in biotechnology shape our relation to lively material*? I found that there is space for lively material to leak out from the bounds of containment that are traditionally established in the gallery context. I defined the terms, **behind glass** and **on a pedestal** to describe respectively the safety and knowledge boundaries perpetuated by bioart practice and in doing so, proposed that **aesthetic black boxing** acts as a communication device that has the potential to exclude knowledge, unless its use as a device is explicitly acknowledged. I suggest therefore that our relation to lively material through biotechnological art practice is, much like biotechnology itself, evolving at an accelerated pace and an expanding DIY biotechnology culture has propagated a more inclusive, participatory approach to biotechnological materials that enables more direct and more creative forms of engagement. This in turn

helps to form new ways of relating to lively material that I begin to define as **radical participatory** and **empathetic performative** approaches.

My practice-led research began with the aim of developing a closer relation to the organism, as the other that I could not experience directly. In Chapter 3, whilst defining the work that I would undertake within the laboratory, I asked, *How can performative engagement with synthetic biology expand ways of knowing in the laboratory?* Practical and theoretical engagement with genetics and synthetic biology resulted in a rupturing of methodology. I found myself responding aesthetically to the negotiation of scientific models, whilst also working with them in attempts to develop a deeper understanding of lively material that I could not perceive directly. In exploratory studio practice that compared evolution to the chance-based works of Fluxus and Dada, I repeatedly experienced sensations of loss of control in a series of works that I describe as ***Viral Poetry***. These initial works, which played with material and with language intuitively, acted as vital markers that I would return to. One such work, ***Combined Knowledge, Unknown Territory***, included a performative dialogue with the organism, which became the basis for the core of the doctoral project, set out in Chapter 5, where I encode a thought as DNA and insert this within the body of *E. coli* bacteria.

Exploring ways to relate to the microbe as life, I asked, *Can technology be used to develop an embodied experience of the organism?* I found that it can, but in limited and focused ways that disclose only moments and fragments. In Chapter 4, I experience an irrevocable distance from the organism that I define through acts of **technological layering** that prevent any sense of access to the real. I position this as a denotative reading, that aims at becoming closer to the organism but ultimately reveals narrowly focused subjective positions on the organism, which I define as **looking without seeing** and **listening without hearing.** I suggest that art practice, drawing upon the works of Alvin Lucier by way of example (Lucier, 1965, 2014), makes use of such denotative readings to generate what I define as an **alchemical sense** of the organism, providing a counterpoint that acknowledges and combines layers of narrow positioning in a richer, yet still withdrawn, account that can never reveal the full spatial and temporal capacity of the organism - always in motion, always relating.

Through the question, *How does translation of the genetic code in novel ways open up possibilities for extending our experience of genetic material?* I considered options for

encoding information within DNA. I began with scientific precedents as my reference and experienced a fractured sense of self as I attempted to translate genetic information in a meaningful way whilst intuitively sensing that I could not access the real. I found this disconnect from the real to be manifest in descriptions of genetic material as code, in which the information-processing metaphor denies the liveliness that I experienced within genetic material. I develop a cypher for encoding information within DNA and in doing so realise that the possibilities inherent in using genetic material as storage medium are limitless, prompting me to ask a new question, *Where does meaning reside in a practice that constitutes the living as 'readable'?* I move from a search for meaning through the signified to a search for meaning in relation by developing a method for communicating *with* genetic material and I design a translation mechanism that will enable creative interpretation of DNA. In collaboration with speech synthesis expert, Étienne de Crécy, this becomes the ***Genophone***, a prototype speech synthesis system that translates phonemes to DNA and DNA to speech. The ***Genophone*** becomes an integral part of the ongoing research, ***Velleity With(out) Volition*** as I consider ways to communicate through the medium of lively material. This raises a question that I begin to address in Chapter 2 and is implicit in ***Velleity With(out) Volition***, but one that I do not fully engage with in the scope of the present research and so becomes part of a post-doctoral project, which may be phrased as, ***Can aesthetic uses of lively material as communication medium reframe our practical and ethical relations to lively material?*** Or perhaps more provocatively, ***Are there limits to the aesthetic uses of lively material as communication medium?***

Performative laboratory practice begins to leak into theory in Chapter 5, which situates my encounters with lively material in the context of placing a thought within the laboratory organism, *E. coli*. The question of whether an organism is a life becomes the more nuanced, *If working with living bodies in the laboratory is abstract, how can this body relate to it?* The act of creating a synthetic DNA plasmid leads to a critical examination of the actions undertaken that traces synthetic DNA to fish silt and cane sugar and ends in defining my thought-as-DNA as an assemblage object: lively material with many actors involved in its material-semiotic construction, which I then go on to define as the **bioassemblage** in Chapter 6. Through the question, *In adopting a cybernetic account of DNA, do I become a parasite upon the material of the body?* I find that the act of placing a thought within the body of the organism generates the sensation that I have imposed upon the organism and my subconscious anthropomorphic actions lead to a dialogue based around care as opposed to use of lively material. The organism becomes a metaphor for the

subject, which I come to understand as both alien and with us – a sentient community-being of cells. Working with the organism within the context of the laboratory, I find that I cannot extend hospitality to the organism *as other* and that instead I am faced with a realisation that my actions on the organism are also actions on the self in an expanded sense: the **xenomorph** (rather than the animal) that we are. This position of self as xenomorph then becomes a performative approach that enables consideration of the subject as always already *with* the other, allowing consideration of actions in a broader, vital materialist framework that take into account the extended network of relations that lead to specific phenomena[207]. The wilful actions undertaken in practising synthetic biology therefore become impositions upon the body of the xenomorph self/other, which I consider to be parasitic in a specific sense - that of collective self-renewal or **autophagy.** I then raise the question of whether it is more hospitable to work with my own lively material rather than sacrifice that of the laboratory organism, leading to a series of discussions - online, and through artist's talks - that question human will, imposition and an empathic engagement with the organism as self. These ongoing discussions begin to shape the developing project, ***Velleity With(out) Volition,*** where, as post-doctoral research, I plan to explore the possibility of imposing a question encoded within viral DNA upon my own body, through the question: ***What are our obligations towards the organism, when the organism is also the self?***

Chapter 6 documents the series of works made during the course of the doctoral project that explore my specific encounters with using the genetic code to follow the process of inserting a thought within a living body. They begin with dense technological layers of information through the sound based installations, ***Pithos*** and ***–Phage***, move through ***Works of Kinship*** that relate directly to the experience of working with lively material and end by bringing these strands together in empathetic performative and radical participatory approaches towards experiencing the organism in the workshop ***Transformation***. In performatively characterising the organism as the ***Cells of L'Avenir***: a sentient community-being of cells that is both a part of us and alien to us, I have come to understand my performative actions in the laboratory as xenomorphising (rather than anthropomorphizing) the organism. I plan to develop this expanded subject position through the making of a film based upon the workshop series, *Transformation.* My initial reluctance to terminate the life of the organism, twinned with a realization that I must do so, leads me to explore a practical aesthetics of care, so that I may maintain generations of the bioassembled organism indefinitely. This manifests as the ongoing project, *Pithos* where I am designing a

suitable vessel in which to house my thought-as-organism (see Appendix III, ***Bio-Artefactuality***)[208].

In finding ways to navigate the overarching doctoral question, I realise therefore that I can never fully answer the question that I have posed to the organism, as the answer is continually revealing itself in new ways. And so, I have to start again, this time as an autophagic xenomorph, always already a part of the ***Cells of L'Avenir*** with a desire to communicate (using the ***Genophone***) and thus impose my will in radical and empathetic ways that question whether my actions are ***Wishful Thinking: Velleity With(out) Volition***. There are no neat endings here. I've imposed on laboratory life, left marks all over the place and I can't put everything back the way it was. I impose my will and I acknowledge this as a form of self-renewal. No matter whether I wipe down the laboratory surfaces with ethanol or think twice before putting on deodorant, things have changed and keep on changing. But I like the difference that my thought is making. I think.

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[169] https://www.loumackenzie.com/pithos
[170] Aside popular sentiment of the pervading sense of division engendered by the myth, the misogynistic origins of the Pandora myth were challenged in the early 1900s in the writing of classicist, Jane Ellen Harrison and have been subsequently addressed in the works of historian Shelley Arlen and classicist, Froma I. Zeitlin (Harrison, 1991, pp. 42–44, 283–285; Arlen, 1996, p. 170; Zeitlin, 1996, pp. 53–75).
[171] Edinburgh University's Centre for Synthetic and Systems Biology has established the *Genome Foundry* (SynthSys, 2017), which troubles the analogy by confusing processes of assemblage with processes of casting. This may seem trivial but as the chassis metaphor has lead to a physical genetic production line, it may be wise to ask what the foundry might conjure in the technological cultural-imaginary: genetic sculpture?
[172] The mutation to a box was added by Erasmus of Rotterdam in the sixteenth century (Erasmus and Barker, 2001, p. 32)
[173] Derrida's term phallogocentrism broadens the psychoanalytic concept of phallocentrism to encompass oppositional metaphysics in all aspects of cultural history (Dely, 2004)
[174] Predicted mutations of my thought-as-DNA were manually reconstructed, phoneme by phoneme, using a combination of the evolutionary modeling software, *MEGA* (Tamura *et al.*, 2013), the online speech synthesis software, *Festival* (Black *et al.*, 2014) and Apple's audio software *Logic Pro.* Further details can be found in Section 6.2.1).
[175] In Section 2.2.1.2, I discuss the complexities of exhibiting genetically modified organisms within the UK.
[176] https://www.loumackenzie.com/phage
[177] In 1952, Alfred Hershey and Martha Chase found evidence that the material responsible for heredity was DNA. To do this, they enlisted the help of the T2 bacteriophage, a virus that infects the bacterium *E. coli*. By preparing bacteriophages that contained one of two radioactive isotopes, one that attaches to protein only and one that attaches to DNA only, Hershey and Chase were able to trace the path of the isotopes and thus determine that proteins had no function in passing on hereditary information from one generation to the next (O'Connor, 2008). Hershey and Chase's work situates the importance of the bacteriophage in genetic research. Understanding of the bacteriophage's ability to infect bacterial DNA led to it's use as a vector in transporting novel

genetic information, until the more recent discovery of plasmids and now CRISPR-Cas9 (Doudna and Charpentier, 2014)[177].

[178] Images of bacteriophages are primarily given as a result of Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM).

[179] The term –phage is generally used to denote consumption, for example within microbiology, bacteriophages are viruses that consume bacteria and phagocytes are cells that consume other cells, including viruses. My interest is primarily in the arresting form and behavior of the bacteriophage: '[A] bacteriophage (from bacteria and Greek φαγεῖν phagein "to devour") is any one of a number of viruses that infect bacteria. They do this by injecting genetic material [into the] host cell to […] replicate their nucleic acid. The infection may or may not lead to the death of the bacterium.' (Rao, 2012)

[180] The spectrogram was originally generated as a visual representation of the sound of the spoken phrase (see Section 6.2).

[181] After creating the works Life Support (Mackenzie, 2013a) and Oltramarino (Mackenzie, 2013b) in association with the School of Marine Science and Technology (MaST), I had been gifted two vitrines originally used for display of scientific artifacts. The cabinets were old and in need of repair, with scuffed paint and chipped glass, yet their significance as failed objects of scientific communication was alluring.

[182] https://www.loumackenzie.com/viral-experiments

[183] https://www.summerhall.co.uk/visual-arts/genocentric/

[184] http://www.viralexperiments.co/genophone

[185] Details of the making of *Genophone* can be found in Appendix III, Viral Experiments, Genophone (http://www.viralexperiments.co/genophone).

[186] Ideally, in a future iteration, *Genophone* will also translate speech into text and phonemes (and thus DNA), but this is another whole field of technological layering.

[187] To provide *Genophone's* neural network with sufficient information to construct a human voice, I recorded over 2000 distinct phrases, from which the neural network is able to find and smoothly link distinct phonemes together.

[188] A core aim of speech synthesis technology is to remove any trace of the mechanical from the voice, creating a black box around the technological layering required to perceive the resulting sound.

[189] Possible future iterations of *Genophone* (that deviate from the narrative of my entering into dialogue with the organism) could potentially include the use of archaic languages or novel systems of language (see also Section 4.3.2.4).

[190] https://www.loumackenzie.com/viral-experiments

[191] https://www.summerhall.co.uk/visual-arts/genocentric/

[192] Audience comments were polarized, with lively dialogue emerging between contributors. The audience mostly loved or hated the exhibition and the comments sheet became a debate on contemporary art and genetics in rural communities. There were separate sheets in each gallery space and the responses in Gallery 2 (i.e. from those who had visited both galleries) were all positive and more engaged with the work. A number of people visiting the arts centre for reasons other than to see the exhibition would have experienced the work on the ground floor. The comments on the ground floor were divided and in part this can be attributed to a lack of engagement with the full exhibition, however the fact that several people were motivated to comment in the negative, rather than walking away, showed a different kind of engagement.

[193] The issue of timing regarding public exhibition is discussed in my interview with Eduardo Kac, found in Appendix III, Viral Experiments (http://www.viralexperiments.co/eduardo-kac). Technically, sequencing the organism could be achieved as part of a live performance, using particular forms of field-based DNA sequencing technology. Personally, I am once again troubled by 'using' resources in this way and the destruction of the organisms to reveal their DNA is an act that I am investigating for further iterations of this work in relation to my *Transformation* workshop series.

[194] See Section 6.6.

[195] https://www.loumackenzie.com/workshops

[196] An interesting exercise outside the scope of this project would be a comparison of the patenting of *Oncomouse* by chemical company, DuPont to the holding of exclusive rights to the colour, *Vantablack* by artist, Anish Kapoor (Delaney, 2016).
[197] https://www.loumackenzie.com/bioassemblage-1
[198] Bioartist, Adam Zaretsky takes a radical approach to humour in his laboratory practice that one might describe as like heroin: high risk, an immediate hit but not to everyone's tastes. Whereas my own subtle brand of humour might be more akin to a medicinal tonic: subtle, gentle and more people are likely to accept it.
[199] https://www.loumackenzie.com/lively-material
[200] I appropriate the term cellves from artist, Guy Ben Ary's sonic bioartwork, *CellF* (Ben Ary, 2014), in which his living neural cells are linked to a synthesizer and respond audibly to sonic input. My use of the term is specifically plural, as a part of my overall project to consider the cell as always already a part of a community-being of cells that we are, in part, responsible for.
[201] For further details on the specific arrangements for exhibiting genetically modified organisms, see Section 2.2.1.2).
[202] http://www.ascus.org.uk/transformational-thinking-through-making-with-life/
[203] Of course the space is still in a sense constructed, perhaps it might be construed as a pedagogical space.
[204] The name, *Cells of L'Avenir* is derived from Jacques Derrida's concept of *l'avenir*, the future to come, that we cannot possibly know in the present (Dick and Ziering Kofman, 2002).
[205] The projection shows a spinning ball, constructed from a microscope image of *E. coli* cells transformed with *BioAssemblage #1*.
[206] Whitehead challenged Cartesian logic on the basis that it does not take into account time and location, instead suggesting that material as defined within scientific theory is an abstraction: 'among the primary elements of nature as apprehended in our immediate experience, there is no element whatever which possesses this character of simple location. … [Instead,] I hold that by a process of constructive abstraction we can arrive at abstractions which are the simply located bits of material, and at other abstractions which are the minds included in the scientific scheme' … 'this juggling with abstractions can never overcome the inherent confusion introduced by the ascription of misplaced concreteness to the scientific scheme of the seventeenth century.' p.72 and p79, Science and The Modern World, A. N. Whitehead, 1925.
[207] I use phenomena here in Karen Barad's sense of the production, in time and space, of a specific intra-action (Barad, 2007, pp. 169–170).
[208] http://www.viralexperiments.co/bio-artefactuality

REFERENCES

Adler, J. (2016) *The First Patented Animal Is Still Leading the Way on Cancer Research*, *Smithsonian.com*. Available at: https://www.smithsonianmag.com/smithsonian-institution/first-patented-animal-still-leading-way-cancer-research-180961149/ (Accessed: 12 November 2017).

Agapakis, C. (2014) *If you wish to make a gene from scratch*, *Scientific American Blog Network*. Available at: https://blogs.scientificamerican.com/oscillator/genes-cannot-be-made-from-scratch/ (Accessed: 23 October 2017).

Amino.bio (2017) *BioExplorer™ - Advanced Minilab – Amino Labs*, *amino.bio*. Available at: https://amino.bio/products/bioproduction-lab-1 (Accessed: 29 November 2017).

Amino Labs (2017) *Teacher Tester: DNA Playground™ Set*, *Amino Labs*. Available at: https://amino.bio/collections/classroom-packs/products/dna-playground-teacher-set (Accessed: 18 October 2017).

Anderson, L. (2017) *Laurie Anderson on Sculpting Sounds with Brian Eno, Peter Gabriel and her Unique Duet Machine*, *daily.redbullmusicacademy.com*. Available at: http://daily.redbullmusicacademy.com/2015/06/laurie-anderson-feature?linkId=14828846 (Accessed: 29 November 2017).

ANDFestival (2015) 'Microbes as Material Workshop'. Lancaster: ANDFestival. Available at: https://www.andfestival.org.uk/blog/announcing-participants-microbes-as-material-workshop/.

Ben Ary, G. (2014) *cellF*, *guybenary.com*. Available at: http://guybenary.com/work/cellf/ (Accessed: 12 November 2017).

Ascott, R. (2000) *Art, technology, consciousness : mind@large*. Intellect.

Ashby, W. R. (1956) *An Introduction to Cybernetics*. London: Chapman & Hall. Available at: http://pcp.vub.ac.be/books/IntroCyb.pdf (Accessed: 29 November 2017).

Ashley, R. (1979) 'Automatic writing', *Youtube*. Available at: https://www.youtube.com/watch?v=Rh_TC8j_JkE (Accessed: 7 November 2017).

Atwood, M. (2009) *Oryx and Crake*. London: Hachette Digital. Available at: http://www.independent.co.uk/arts-entertainment/books/reviews/oryx-and-crake-by-margaret-atwood-116675.html (Accessed: 29 November 2017).

Barad, K. (2007) *Meeting the Universe Halfway*. Durham & London: Duke University Press.

Barthes, R. (1977) *Image Music Text*. London: Fontana Press.

Bassler, B. (2009) *The secret, social lives of bacteria - YouTube*. TED. Available at: https://www.youtube.com/watch?v=TVfmUfr8VPA (Accessed: 9 September 2017).

Bennett, J. (2010) *Vibrant Matter*. Durham and London: Duke University Press.

Berger, J. (2008) *Ways of Seeing*. London: Penguin.

Black, A. W., Clark, R., Richmond, K., Yamagishi, J., Oura, K. and King, S. (2014) 'Festival Speech Synthesis System (Version 2.4)'.

Bök, C. (2015) *The Xenotext*. Toronto: Coach House Books (The Xenotext). Available at: https://books.google.co.uk/books?id=SmmHCgAAQBAJ.

Bök, C. and Mackenzie, L. (2015) 'Interview with Christian Bok'. Available at: http://www.viralexperiments.co/christian-boek.

Boland, H. (2011) *BANANA BACTERIA*, *Science Gallery*. Available at: https://dublin.sciencegallery.com/growyourown/bananabacteria (Accessed: 30 August 2017).

Boland, H. (2013) *Art from Synthetic Biology*. University of Westminster.

Braidotti, R. (2005) 'Affirming the Affirmative: On Nomadic Affectivity', *Rhizomes*. Rhizomes.net, (11/12). Available at: http://www.rhizomes.net/issue11/braidotti.html (Accessed: 15 August 2017).

Braidotti, R. (2013) *The Posthuman*. Cambridge: Polity Press. Available at: https://www.scribd.com/doc/219850024/Rosi-Braidotti-The-Posthuman (Accessed: 29 November 2017).

Broom, D. M. (2016) 'Sentience and animal welfare: New thoughts and controversies', *Animal Sentience*, 5(11). Available at: http://www.animal-welfare-indicators.net/site/index.php/professor-donald-m-broom (Accessed: 30 August 2017).

Brown, A. (2012) *The Great Work of the Metal Lover*, *Adam W. Brown*. Available at: http://adamwbrown.net/projects-2/the-great-work-of-the-metal-lover/ (Accessed: 30 August 2017).

Brown, A. W. (2010) *ReBioGeneSys – Origins of Life | Adam W. Brown*. Available at: http://adamwbrown.net/projects-2/rebiogenesys-origins-of-life/ (Accessed: 4 August 2017).

Bureau d'etudes, Chardronnet, E., Tsang, M. and Petric, S. (2017) *Manifesto – Aliens in Green*, *aliensingreen.eu*. Available at: http://aliensingreen.eu/index.php/manifeste/ (Accessed: 2 December 2017).

Burroughs, W. S. (2005) *The Electronic Revolution*. ubu classics. Available at: http://www.ubu.com/historical/burroughs/electronic_revolution.pdf (Accessed: 21 September 2017).

Catts, O. and Zurr, I. (2002) 'Growing Semi-Living Sculptures: The Tissue Culture & Art Project', *Leonardo*, 35(4), pp. 365–370. doi: 10.1162/002409402760181123.

Catts, O. and Zurr, I. (2004) *Victemless Leather*, *The Tissue Culture and Art Project*. Available at: http://www.tca.uwa.edu.au/vl/vl.html (Accessed: 30 August 2017).

Catts, O. and Zurr, I. (2008) 'The Ethics of Experiential Engagement with the Manipulation of Life', in da Costa, B. and Kavita, P. (eds) *Tactical Biopolitics: Art, Activism, and Technoscience*. Leonardo Books.

Crick, F. (1958) 'On Protein Synthesis', *The Symposia of the Society for Experimental Biology*. Cambridge University Press, 12(Article 13), pp. 138–163. Available at: https://profiles.nlm.nih.gov/ps/retrieve/ResourceMetadata/SCBBZY (Accessed: 9 September

2017).

Crick, F. (1988) *What mad pursuit : a personal view of scientific discovery*. Basic Books.

Crick, F. H. C. (1968) 'The Origin of the Genetic Code', *J. Mol. Biol*, 38, pp. 367–379. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.3600&rep=rep1&type=pdf (Accessed: 9 September 2017).

Cuboniks, L. (2015) *Xenofeminism: A Politics for Alienation*. Available at: http://www.laboriacuboniks.net/qx8bq.txt (Accessed: 16 August 2017).

Cuboniks, L. (2017) *Laboria Cuboniks*, *Question of Will*. Available at: http://questionofwill.com/en/laboria-cuboniks-3/ (Accessed: 18 October 2017).

Davis, J. (1996) 'Microvenus', *Art Journal*. [Taylor & Francis, Ltd., College Art Association], 55(1), pp. 70–74. Available at: http://www.jstor.org/stable/777811.

Davis, J. (2017) 'Joe Davis, Facebook, 18 November, 20:12'. Facebook.

Davis, J. and Egan, K. (2000a) *Audio Microscope*, *Genetics and Culture*. Available at: http://geneticsandculture.com/genetics_culture/pages_genetics_culture/gc_w03/davis_audio_scope.htm (Accessed: 30 August 2017).

Davis, J. and Egan, K. (2000b) *Audio Microscope_ Joe Davis _ Genetics and Culture*, *Design|Media Arts 98T Genetics and Culture*. Available at: http://geneticsandculture.com/genetics_culture/pages_genetics_culture/gc_w03/davis_audio_scope.htm (Accessed: 24 October 2013).

Debord, G. (1956) *Theory of the Derive*, *Les Levres Nues #9*. Available at: http://www.cddc.vt.edu/sionline/si/theory.html (Accessed: 23 September 2015).

DeLanda, M. (2011b) *Metaphysics as Ontology: Aristotle and Deleuze's Realism*, *European Graduate School Video Lectures*. Available at: https://www.youtube.com/watch?v=1ZjMKGTYfK4 (Accessed: 25 June 2016).

Deleuze, G. and Patton, P. (trans) (2004) *Difference and Repetition*. Continuum.

Derrida, J. (1979) *Of Grammatology*. Edited by G. C. Spivak (trans.). Baltimore and London: The John Hopkins University Press. doi: 10.2307/1771131.

Derrida, J. (1988) 'Eating Well or the Calculation of the Subject', in Weber, E. (ed.) *Points...Interviews, 1974-1994*. Stanford University Press, pp. 255–287.

Derrida, J. (2000) *Of Hospitality*. Stanford: Stanford University Press.

Derrida, J. and Wills, D. (2002) 'The Animal That Therefore I Am (More to Follow)', *Critical Inquiry*, 28(2), p. 369. doi: 10.1086/449046.

Dewey-Hagborg, H. (2013) *Stranger Visions*, *Heather Dewey-Hagborg*. Available at: http://deweyhagborg.com/projects/stranger-visions (Accessed: 11 September 2017).

Dewey-Hagborg, H. (2015) *Radical Love: Chelsea Manning*, *Heather Dewey-Hagborg* . Available at: http://deweyhagborg.com/projects/radical-love (Accessed: 11 September 2017).

Dewey-Hagborg, H. (2017) *Probably Chelsea*, *Heather Dewey-Hagborg*. Available at: http://deweyhagborg.com/projects/probably-chelsea (Accessed: 11 September 2017).

Dick, K. and Ziering Kofman, A. (2002) *Derrida*. USA: Zeitgeist Films.

Dillon, R. and Parry, J. (2015) 'Night of the Living Deadwood'. Grizedale Forest: Abandon Normal Devices. Available at: https://www.andfestival.org.uk/events/night-of-the-living-deadwood/.

Dorsett, C. and Bowen, S. (2015) 'Paper, table, wall & after'. Available at: http://nrl.northumbria.ac.uk/25854/ (Accessed: 6 November 2017).

Dumitriu, A. and Farsides, B. (2014) *Trust Me, I'm an Artist*. Blurb. Available at: http://www.blurb.co.uk/b/5511117-trust-me-i-m-an-artist (Accessed: 30 August 2017).

Foucault, M. (2005) *The Order of Things: An Archaeology of the Human Sciences*. New York: Routledge.

Frow, E. and Calvert, J. (2013) '"Can simple biological systems be built from standardized interchangeable parts?" Negotiating biology and engineering in a synthetic biology competition', *Engineering Studies*, 5(1), pp. 42–58. doi: 10.1080/19378629.2013.764881.

Gena, P. and Strom, C. (1995) 'A Physiological Approach to DNA Music'. Available at: http://www.petergena.com/docs/gena-strom-DNA.pdf (Accessed: 24 October 2017).

Gibson, W. (1984) *Neuromancer*. London: Orion Publishing Group.

Goldman, N., Bertone, P., Chen, S., Dessimoz, C., LeProust, E. M., Sipos, B. and Birney, E. (2013) 'Towards practical, high-capacity, low-maintenance information storage in synthesized DNA.', *Nature*, 494(7435), pp. 77–80. doi: 10.1038/nature11875.

Le Guin, U. (1989) 'The Carrier Bag Theory of Fiction', in *Dancing at the Edge of the World: Thoughts on Words, Women, Places*. New York: Grove, pp. 165–170. Available at: http://www.trabal.org/texts/pdf/LeGuin.pdf.

Guthrie, K. S. and Fideler, D. R. (1987) *The Pythagorean sourcebook and library : an anthology of ancient writings which relate to Pythagoras and Pythagorean philosophy*. Phanes Press.

Hall, S. S. (2012) 'Journey to the Genetic Interior', *Scientific American*. Nature Publishing Group, 307(4), pp. 80–84. doi: 10.1038/scientificamerican1012-80.

Haraway, D. (1988) 'Situated Knowledges: The Science Question in Feminism and the Priviledge of Partial Perspective', *Feminist Studies*, 14(3), pp. 575–599.

Haraway, D. (1991) *Simians, Cyborgs, and Women*. New York: Routledge. doi: 10.1177/0263276406069231.

Haraway, D. (1992) 'The Promises of Monsters: A Regenerative Politics for Inappropriate/d Others', in Grossberg, L., Nelson, C., and Treichler, P. A. (eds) *Cultural Studies*. New York: Routledge, pp. 295–337. Available at: https://www.well.com/~willard/Donna Haraway_The Promises of Monsters92.htm (Accessed: 22 August 2017).

Haraway, D. (2008) *When Species Meet*. Minneapolis: University of Minnesota Press. Available at: http://projectlamar.com/media/harrawayspecies.pdf (Accessed: 26 October 2017).

Haraway, D. J. (2003) *The companion species manifesto : dogs, people, and significant otherness*. Available at: http://press.uchicago.edu/ucp/books/book/distributed/C/bo3645022.html (Accessed: 1 July 2017).

Haraway, D. J. (2016) *Staying with the Trouble*. Durham and London: Duke University Press.

Harper, D. (2010) *Origin and history of microbe*, *Online Etymology Dictionary*. Available at:

http://www.etymonline.com/index.php?allowed_in_frame=0&search=microbe (Accessed: 9 September 2017).

Harrison, J. E. (1991) *Prolegomena to the study of Greek religion*. Princeton: Princeton University Press.

Harvard Medical School (2016) *The Evolution of Bacteria on a 'Mega-Plate' Petri Dish (Kishony Lab) - YouTube*, *YouTube*. Available at: https://www.youtube.com/watch?v=plVk4NVIUh8 (Accessed: 21 September 2017).

Hermann, T., Hunt, A., Neuhoff, J. G., Dombois, F. and Eckel, G. (2011) 'The Sonification Handbook', *The Sonification Handbook*, pp. 301–324.

High, K., Anker, S., Levy, E. K., Aristarkhova, I., Nadarajan, G., de Menezes, M., Kaniari, A., Kemp, M., Zwijnenberg, R., Pollier, P., Antonopoulos, A., Zaretsky, A. and Melanitis, I. (2017) *Institutional Critique to Hospitality: Bio Art Practice Now*. Edited by A. Kaniari. Grigori.

Hjelmslev, L. (1961) *Prolegomena to a Theory of Language*. Madison: University of Wisconsin Press. Available at: https://www.scribd.com/doc/130368171/Hjelmslev-1961-Prolegomena-to-a-Theory-of-Language (Accessed: 10 October 2017).

Holder, J. (2016a) *Ophiuchus*, *joeyholder.com*. Available at: http://www.joeyholder.com/index.php/ophiuchus/ (Accessed: 14 November 2017).

Holder, J. (2016b) *Ophiux*, *Joey Holder*. Available at: http://www.joeyholder.com/index.php/ophiux/ (Accessed: 19 September 2017).

Ihde, D. (2012) 'The Auditory Dimension', in Sterne, J. (ed.) *The Sound Studies Reader*. Abingdon: Routledge.

Jarvis, C. (2012a) *Blighted By Kenning : Charlotte Jarvis*, *ArtForEating*. Available at: http://www.artforeating.co.uk/restaurant/index.php?/blighted-by-ken/project-overview/ (Accessed: 25 August 2017).

Jarvis, C. (2012b) *Blighted By Kenning, Documentation*, *Charlotte Jarvis*. Available at: http://www.artforeating.co.uk/restaurant/index.php?/blighted-by-ken/trying-to-exhibit-gmo-in-the-uk/ (Accessed: 18 October 2017).

Jarvis, C. (2015) *Music of the Spheres*, *ArtForEating*. Available at: http://www.artforeating.co.uk/restaurant/index.php?/project/music-of-the-spheres/ (Accessed: 25 August 2017).

Jeremijenko, N. (2004) *biotechhobbyistmagazine*, *BioTechHobbyist*. Available at: http://www.nyu.edu/projects/xdesign/biotechhobbyist/index.html (Accessed: 12 September 2017).

Kac, E. (1998) 'Transgenic Art', *Leonardo Electronic Almanac*, 6(11).

Kac, E. (1999) *Genesis*. Available at: http://www.ekac.org/geninfo.html.

Kac, E. (2001) *The Eighth Day*. Eduardo Kac. Available at: http://www.ekac.org/8thday.html.

Kac, E. (2003) 'GFP Bunny', *Leonardo*, 36, pp. 97–102. Available at: http://www.mitpressjournals.org/doi/abs/10.1162/002409403321554125.

Kac, E. (2009) *Natural History of the Enigma*, *http://www.ekac.org/nat.hist.enig.html*. Available at:

http://www.ekac.org/nat.hist.enig.html (Accessed: 19 October 2017).

Kac, E. and Mackenzie, L. (2016) 'Interview with Eduardo Kac'. Available at: http://www.viralexperiments.co/eduardo-kac.

Kay, L. E. (2000) *Who Wrote the Book of Life?* Stanford: Stanford University Press.

Kay, L. E. (2000) *Who Wrote the Book of Life?: A History of the Genetic Code*. Stanford: Stanford University Press. Available at: http://www.sup.org/books/title/?id=377.

Korzybski, A. (1958) *Science and sanity; an introduction to non-Aristotelian systems and general semantics.* Englewood, New Jersey: International Non-Aristotelian Library Pub. Co.; distributed by Institute of General Semantics.

Land, C. (2005) 'Apomorphine Silence: Cutting-up Burrough's Theory of Language and Control', 5(3), pp. 450–471.

Latour, B. (1987) *Science in Action: How to Follow Scientists and Engineers through Society.* Harvard University Press, Cambridge, Massachusetts.

Latour, B. (1993) *We Have Never Been Modern*. Harvard University Press, Cambridge, Massachusetts.

Latour, B. (1999) *Pandora's hope : essays on the reality of science studies*. Cambridge, US: Harvard University Press.

Latour, B. and Woolgar, S. (1979) *Laboratory Life - The Construction of Scientific Facts*. Princeton: Princeton University Press.

Lucier, A. (1965) *Music for Solo Performer*. Youtube.

Lucier, A. (2014) *Alvin Lucier on 'I am sitting in a room'*, *Arts at MIT*. Available at: https://www.youtube.com/watch?v=v9XJWBZBzq4 (Accessed: 17 October 2017).

Mackenzie, L. (2013a) 'Life Support'. Newcastle. Available at: https://www.loumackenzie.com/life-support.

Mackenzie, L. (2013b) 'Oltramarino'. Newcastle. Available at: https://www.loumackenzie.com/oltramarino.

Mackenzie, L. (2013c) *Oltramarino*. Blurb.

Mackenzie, L. (2014) *transformation content*, *Louise Mackenzie*. Available at: https://www.loumackenzie.com/transformation-content-information (Accessed: 20 September 2017).

Mackenzie, L. (2015a) 'Combined Knowledge, Unknown Territory'. Louise Mackenzie. Available at: http://www.viralexperiments.co/combined-knowledge-unknown-territor.

Mackenzie, L. (2015b) 'Memento Perimortem'. Louise Mackenzie. Available at: http://www.viralexperiments.co/memento-perimortem.

Mackenzie, L. (2015c) *Molecular Relations*, *Louise Mackenzie*.

Mackenzie, L. (2015d) 'The Stars Beneath Our Feet'. Louise Mackenzie. Available at: https://www.loumackenzie.com/thestarsbeneathourfeet.

Mackenzie, L. (2015e) 'Unknown Territory'. Louise Mackenzie. Available at: http://www.viralexperiments.co/unknown-territory-2.

Mackenzie, L. (2016a) 'Ouroboros'. Louise Mackenzie. Available at: http://www.viralexperiments.co/ouroboros.

Mackenzie, L. (2016b) 'Pithos'. Newcastle. Available at: https://www.loumackenzie.com/pithos (Accessed: 22 August 2017).

Mackenzie, L. (2016c) *Untourage #3*, *Baltan Laboratories*. Available at: http://baltanlaboratories.org/article/research-project/untourage-3.

Mackenzie, L. (2017a) '-Phage'. Newcastle: Louise Mackenzie. Available at: https://www.loumackenzie.com/phage.

Mackenzie, L. (2017b) *Genocentric*, *Summerhall*. Available at: https://www.summerhall.co.uk/visual-arts/genocentric/ (Accessed: 9 November 2017).

Mackenzie, L. (2017c) 'Lively Material'. Louise Mackenzie. Available at: https://www.loumackenzie.com/lively-material.

Mackenzie, L. (2017d) 'Memento Perimortem 2016-17'. Louise Mackenzie. Available at: https://www.loumackenzie.com/memento-perimortem-2016-17.

Mackenzie, L. (2017e) *Transformation*, *ACSUS Art & Science*. Available at: http://www.ascus.org.uk/transformational-thinking-through-making-with-life/.

Mackenzie, L. (2017f) 'Viral Experiments'. Hexham: Queens Hall Arts Centre. Available at: https://www.loumackenzie.com/viral-experiments.

Mackenzie, L. and de Crécy, É. (2016) 'The Genophone'. Louise Mackenzie. Available at: https://www.loumackenzie.com/genophone.

Mackenzie, L. and Reed, M. (2015) 'Natura Naturans'. Available at: https://www.loumackenzie.com/natura-naturans.

de Menezes, M. (2003) *Inner Cloud*, *Marta de Menezes*. Available at: http://martademenezes.com/portfolio/inner-cloud/ (Accessed: 12 November 2017).

de Menezes, M. (2014) *Immortality for Two*, *Marta de Menezes*. Available at: http://martademenezes.com/portfolio/immortality-for-two/.

metaPhorest (2016) *World's first memorial for artificial cells at KENPOKU ART – Waseda University*, *Waseda University*. Available at: https://www.waseda.jp/top/en-news/45404 (Accessed: 23 October 2017).

Mitchell, R. (2010) *Bioart and the vitality of media*. University of Washington Press.

Moisy, A. (2017) *Tales of Synthetic Biology*, *Anaïs Moisy*. Available at: https://anaismoisy.com/tales-of-synthetic-biology/ (Accessed: 11 November 2017).

Morton, T. (2010a) 'Queer Ecology', *PMLA*, 125(2), pp. 273–282. doi: 10.1632/pmla.2010.125.2.273.

Morton, T. (2010b) *The Ecological Thought*. Cambridge, US and London: Harvard University Press, Cambridge, Massachusetts.

Museum Of Modern Art (1936) *Edward Steichen Archive, Delphiniums, Original Press Release*. New York: Museum of Modern Art. Available at: https://www.moma.org/momaorg/shared/pdfs/docs/press_archives/331/releases/MOMA_1936_0027_1936-06-18_18636-17.pdf?2010&_ga=2.37658784.1002515044.1512380154-

1305185942.1493904015 (Accessed: 7 March 2015).

Nail, T. (2017) 'What is An Assemblage?', *SubStance*. University of Wisconsin Press, 46(142), pp. 21–37. Available at: https://muse-jhu-edu.libproxy.ncl.ac.uk/article/650026 (Accessed: 22 August 2017).

Ohio State University (2015) *BioPresence*, *ArtAnd*. Available at: http://artand.org/ (Accessed: 12 October 2018).

Oxford Dictionaries (2017) *transformation*, *Oxford University Press*. Available at: https://en.oxforddictionaries.com/definition/transformation.

Oxford University Press (2017a) *memento mori*, *Oxford Dictionaries*. Available at: https://en.oxforddictionaries.com/definition/memento_mori (Accessed: 12 November 2017).

Oxford University Press (2017b) *perimortem*, *A Dictionary of Forensic Science*. Oxford University Press. doi: 10.1093/acref/9780199594009.001.0001.

Pelling, Andrew; Niemetz, A. (2004) *The dark side of the cell*. Available at: http://www.darksideofcell.info/composition.html (Accessed: 14 December 2015).

Pinker, S. (2005) *What our Language Habits Reveal*, *TEDGlobal2005*. TED. Available at: https://www.ted.com/talks/steven_pinker_on_language_and_thought#t-416963.

Plohman, A. (2001) *Adam Zaretsky*, *La Fondation Daniel Langlois pour L'Art, La Science et la Technologie*. Available at: http://www.fondation-langlois.org/html/e/page.php?NumPage=264 (Accessed: 9 September 2016).

Radomska, M. (2016) *Uncontainable Life*. University of Linkoping.

Saussure, F. de, Bally, C., Sechehaye, A. and Riedlinger, A. (1986) *Course in general linguistics*. Open Court. Available at: https://books.google.co.uk/books/about/Course_in_General_Linguistics.html?id=B0eB8mvov6wC (Accessed: 21 September 2017).

Serres, M. (2007) 'The Parasite', in. University of Minnesota Press.

Seyfried, G. (2017) *Polycinease.com*, *polycinease.com*. Available at: http://www.polycinease.com/ (Accessed: 8 September 2017).

Seyfried, G., Dierendonck, R. van, Petschko, H. and Muffatto, F. (2017) *Return to Dilmun*, *polycinease.com*. Available at: http://www.polycinease.com/return-to-dilmun/ (Accessed: 8 September 2017).

Seyfried, G., Grabher, C. and Bartenstein, D. (2004) *Polycinease Film Transformation*. Available at: http://www.polycinease.com/polycinease-film-transformation/ (Accessed: 3 October 2015).

Seyfried, G., Grabher, C. and Feurle, D. (2008) *Mutants from Innerspace*, *polycinease.com*. Available at: http://www.polycinease.com/mutants-from-innerspace/ (Accessed: 3 October 2015).

Silvestrin, D. (2012) *Dialogues on 'Bioart' #1. A conversation with Jens Hauser*, *DIGICULT*. Available at: http://www.digicult.it/news/dialogues-on-bioart-1-a-conversation-with-jens-hauser/ (Accessed: 31 August 2017).

Smith, D. (curator) (2017) '#FEED'. Hexham: Queen's Hall Arts Centre.

Solanki, S. (2012) *Super-natural*, *Vane*. Available at: http://vane.org.uk/past-exhibitions/super-natural

(Accessed: 8 November 2017).

Spectrum Brands (2017) *GloFish® - Experience the Glo!®*, *GloFIsh*. Available at: https://www.glofish.com/ (Accessed: 18 October 2017).

Sperber, D. (1996) *Explaining Culture - A Naturalistic Approach*. Oxford: Blackwell Publishers Ltd.

Steyerl, H. (2010) 'A Thing Like You and Me', *e-flux*, (15).

Strom, S. (2014) *Companies Quietly Apply Biofuel Tools to Household Products - The New York Times*, *The New York Times*. Available at: https://www.nytimes.com/2014/05/31/business/biofuel-tools-applied-to-household-soaps.html (Accessed: 23 October 2017).

SymbioticA (2017) *Newsletter*, *SymbioticA*. The University of Western Australia. Available at: http://www.symbiotica.uwa.edu.au/activities/newsletter (Accessed: 20 November 2017).

SynthSys (2017) *Edinburgh Genome Foundry*, *genome foundry.org*. Available at: http://www.genomefoundry.org/#/ (Accessed: 29 November 2017).

Tamura, K., Stecher, G., Peterson, D., Filipski, A. and Kumar, S. (2013) 'MEGA6: Molecular Evolutionary Genetics Analysis Version 6.0 Molecular Biology and Evolution:30 2725-2729'.

Thacker, E. (2004) *Biomedia*. Minneapolis: University of Minnesota Press.

The Cornell Lab of Ornithology (2017) *Macaulay Library*, *Cornell University*. Available at: http://macaulaylibrary.org/search?media_collection=1&taxon_id=10519329&taxon_rank_id=8&q=Insects (Accessed: 17 November 2017).

Tsang, M. (2015) *Open Source Estrogen*, *magic.ooo*. Available at: http://maggic.ooo/Open-Source-Estrogen-2015 (Accessed: 7 September 2016).

Tzara, T. (1920) *Dada Manifesto On Feeble Love And Bitter Love by Tristan Tzara, 12th December 1920 - 391.org - Manifestos*, *391.org*. Available at: http://391.org/manifestos/1920-dada-manifesto-feeble-love-bitter-love-tristan-tzara.html#.WcPUzNOGP5U (Accessed: 21 September 2017).

Villareal, L. P. (2008) 'Title: Are Viruses Alive?', *Scientific American, a division of Nature America*, (December), pp. 101–105.

Vitale, F. (2014) 'The Text and the Living: Jacques Derrida between Biology and Deconstruction', *Oxford Literary Review*. Edinburgh University Press 22 George Square, Edinburgh EH8 9LF UK , 36(1), pp. 95–114. doi: 10.3366/olr.2014.0089.

Volk, T. (2017) *Quarks to Culture : How We Came to Be*. New York: Columbia University Press.

Watson, C. (2015) *Warkworth Dunes Sound Walk with Chris Watson*, *soundstrata.co.uk*.

Webster, J. (2016) 'Animal Welfare: Freedoms, Dominions and "A Life Worth Living"', *Animals : an open access journal from MDPI*, 6(35). doi: 10.3390.

Whitehead, A. N. (1925) *Science and the modern world*. New York: The Macmillan Company.

Wikipedia (2017) *Genome Project*.

Williams, J. J. (2009) 'Science Stories: An Interview with Donna J. Haraway', *The Minnesota Review*, 2010(73–74), pp. 133–163. doi: https://doi.org/10.1215/00265667-2010-73-74-133.

Zaretsky, A. (2017a) *[-empyre-] Between the Blinds of Heredity: Transgenic Humans as an Ecological and Non-Human Animal Study*, *[-empyre-]*. Available at: http://lists.artdesign.unsw.edu.au/pipermail/empyre/2017-October/009951.html (Accessed: 30 October 2017).

Zaretsky, A. (2017b) *Transgenic Humans as Bioart*, *Youtube*. Available at: https://www.youtube.com/watch?v=bgRkqh2DFLY (Accessed: 9 November 2017).

Zeitlin, F. I. (1996) 'Signifying Difference: The Case of Hesiod's Pandora', in *Playing The Other: Gender and Society in Classic Greek Literature*. Chicago and London: University of Chicago Press, p. 474. Available at: http://sites.middlebury.edu/feastsandfestivals/files/2015/09/Froma-Zeitlin-Signifying-Difference-53-74.pdf (Accessed: 26 August 2017).

ZonMW, NWO, MU and BioArt Laboratories (2017) *Bio Art & Design Awards*, *badaward.nl*. Available at: http://www.badaward.nl/ (Accessed: 14 November 2017).

BIBLIOGRAPHY

Ailenberg, M. and Rotstein, O. D. (2009) 'An improved Huffman coding method for archiving text, images, and music characters in DNA', *BioTechniques*, 47(3), pp. 747–754. doi: 10.2144/000113218.

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. and Walter, P. (2002) 'DNA Repair'. Garland Science. Available at: https://www.ncbi.nlm.nih.gov/books/NBK26879/#A835 (Accessed: 18 July 2017).

Amino.bio (2017) *BioExplorer™ - Advanced Minilab – Amino Labs*, *amino.bio*. Available at: https://amino.bio/products/bioproduction-lab-1 (Accessed: 29 November 2017).

Amino Labs (2017) *Teacher Tester: DNA Playground™ Set*, *Amino Labs*. Available at: https://amino.bio/collections/classroom-packs/products/dna-playground-teacher-set (Accessed: 18 October 2017).

Anderson, G. (2004) *Reinventing the museum : historical and contemporary perspectives on the paradigm shift*. AltaMira Press.

Arlen, S. (1996) '"For Love of an Idea": Jane Ellen Harrison, heretic and humanist', *Women's History Review*, 5(2), pp. 165–190. Available at: http://www.tandfonline.com/doi/pdf/10.1080/09612029600200114 (Accessed: 12 July 2017).

Art Works and National Endowment for the Arts (2017) *Biodesign Challenge*, *Biodesign Challenge*. Available at: http://biodesignchallenge.org/ (Accessed: 14 November 2017).

Arts Catalyst (2017) *Trust Me, I'm an Artist - Exhibition*, *Arts Catalyst*. Available at: http://www.artscatalyst.org/trust-me-exhibition (Accessed: 17 November 2017).

Barad, K. (2003) 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter', *Signs: Journal of Women in Culture and Society*, 28(3). Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.466.5231&rep=rep1&type=pdf (Accessed: 24 August 2017).

Barad, K. (2014) 'On touching - the inhuman that therefore I am', *The Politics of materiality*. doi: 10.1215/10407391-1892943.

Barrick, J. E., Yu, D. S., Yoon, S. H., Jeong, H., Oh, T. K., Schneider, D., Lenski, R. E. and Kim, J. F. (2009) 'Genome evolution and adaptation in a long-term experiment with Escherichia coli', *Nature*. Nature Publishing Group, 461(7268), pp. 1243–1247. doi: 10.1038/nature08480.

Baudrillard, J. (1994) *Simulacra and Simulation*, *Idea*. Edited by S. F. Glaser. University of Michigan Press (The Body, in theory). Available at: http://www.amazon.com/dp/0472065211.

Beyer, C. (2017) *Ouroboros*, *ThoughtCo.com*. Available at: https://www.thoughtco.com/ouroboros-4123019 (Accessed: 21 September 2017).

Bhutkar, R. (2015) 'Quantum Fields of Consciousness & the Mind (Part I)', *Journal of Consciousness Exploration & Research*|, 6(2), pp. 70–79. Available at: www.JCER.com (Accessed: 24 October 2017).

BOM (2017) *The Chemistry of Biology: An Alchemy of DNA*, *BOM*. Available at: http://www.bom.org.uk/event/the-chemistry-of-biology-an-alchemy-of-dna/ (Accessed: 17 November 2017).

Borges, J. L. (1993) 'The Analytical Language of John Wilkins', in Simms, R. L. C. (transl. . (ed.) *Other Inquisitions 1937-1952*. Texas: University of Texas Press. Available at: https://pdfs.semanticscholar.org/ce86/d21fdeb73e2cfe8664b15d58060b7613c79e.pdf (Accessed: 24 October 2017).

Bos, L. (1999) 'Beijerinck's work on tobacco mosaic virus: historical context and legacy.', *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*. The Royal Society, 354(1383), pp. 675–85. doi: 10.1098/rstb.1999.0420.

Bostrom, N. and Yodkowsky, E. (2014) 'The Ethics of Artificial Intelligence', in Frankish, K. and Ramsey, W. M. (eds) *The Cambridge Handbook of Artificial Intelligence*, p. 354.

Brain, C. M. and Caldwell, G. S. (2015) 'Improvements in the synthesis of phycocyanins'. Google Patents. Available at: https://www.google.com/patents/WO2015110844A1?cl=en.

Brown, N. (2016) 'Are viruses alive?', *Microbiology Today*, 43(2), pp. 58–61.

Burroughs, W. S. (1999) *Word Virus: The William S. Burroughs Reader*. Edited by J. Grauerholz and I. Silverberg. New York: Flamingo. Available at: http://traumawien.at/stuff/theory/burroughs/william-s-burroughs-word-virus-the-william-s-burroughs-reader-1.pdf (Accessed: 21 September 2017).

Calarco, M. (2008) *Zoographies : the question of the animal from Heidegger to Derrida*. Columbia University Press.

Calvert, J. (2013) 'Engineering Biology and Society: Reflections on Synthetic Biology', *Science, Technology and Society*. SAGE Publications India, 18(3), pp. 405–420. doi: 10.1177/0971721813498501.

Capuozzo, L. (2012) *Thomas Feuerstein: Bio Deception, The Realization Of An Idea*, *DIGICULT*. Available at: http://www.digicult.it/digimag/issue-071/italiano-thomas-feuerstein-bio-inganni-la-messa-in-scena-di-unidea/ (Accessed: 31 August 2017).

Catts, O. and Zurr, I. (2003) 'The Ethical Claims of Bio Art: Killing the Other or Self-Cannibalism?', *Australian and New Zealand Journal of Art*, 5(1), pp. 1–19. Available at: http://www.tca.uwa.edu.au/publication/theethicalclaimsofbioart.pdf.

Catts, O. and Zurr, I. (2006) 'Towards a New Class of Being: The Extended Body', *Intelligent Agent*, 6(2), pp. 1–9. Available at: http://www.intelligentagent.com/archive/Vol6_No2_transvergence_cattszurr.htm.

Chandler, D. (2002) *Semiotics for Beginners*. Second. London and New York: Routledge. Available at: http://s3.amazonaws.com/szmanuals/bb72b1382e20b6b75c87d297342dabd7 (Accessed: 21 September 2017).

Church, G. M., Gao, Y. and Kosuri, S. (2012) 'Next-Generation Digital Information Storage in DNA', *Science*, 337(6102), pp. 1628–1628. doi: 10.1126/science.1226355.

Collins, F. S. (2007) *The Language of God: A Scientist Presents Evidence for Belief*. London: Pocket

Books.

Collins, F. S. (2010) *The language of life : DNA and the revolution in personalized medicine*. London: Profile.

Crasnow, S., Wylie, A., Bauchspies, W. K. and Potter, E. (2015) 'Feminist Perspectives on Science', in *Stanford encyclopedia of philosophy.* Stanford: Stanford University. Available at: https://plato.stanford.edu/entries/feminist-science/ (Accessed: 31 August 2017).

de Crécy, É. (2016) *Deep Neural Network Statistical Parametric Speech Synthesis from DNA*. Edinburgh.

Creighton, J. (2015) *Science Explained: Do Atoms Last Forever?*, *Futurism*. Available at: https://futurism.com/science-explained-atoms-last-forever/ (Accessed: 14 November 2017).

Crick, F. (1988) *What mad pursuit : a personal view of scientific discovery*. Basic Books.

Crick, F. H. C. (1968) 'The Origin of the Genetic Code', *J. Mol. Biol*, 38, pp. 367–379. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.3600&rep=rep1&type=pdf (Accessed: 9 September 2017).

Crick, F. and Watson, J. (1953) 'A Structure for Deoxyribose Nucleic Acid', *Nature*, 171, pp. 737–738. Available at: http://www.sns.ias.edu/~tlusty/courses/landmark/WatsonCrick1953.pdf (Accessed: 10 October 2017).

Dawson, M. (2003) 'Martha Chase dies', *The Scientist*, August.

DeLanda, M. (2011a) *A Materialist Theory of Language*, *European Graduate School, YouTube*. Available at: https://www.youtube.com/watch?v=AAhaXe3BRe0 (Accessed: 29 September 2017).

Delaney, B. (2016) *'You could disappear into it': Anish Kapoor on his exclusive rights to the 'blackest black'*, *The Guardian*. Available at: https://www.theguardian.com/artanddesign/2016/sep/26/anish-kapoor-vantablack-art-architecture-exclusive-rights-to-the-blackest-black (Accessed: 25 September 2017).

Dely, C. (2004) *Sens public*, *Sens Public*. G. Wormser. Available at: http://www.sens-public.org/article312.html?lang=fr (Accessed: 26 August 2017).

Denning, P. J. and Lewis, T. G. (2017) 'Exponential laws of computing growth', *Communications of the ACM*, 20 December, pp. 54–65. doi: 10.1145/2976758.

Department for Business Innovation & Skills and Willetts, D. T. R. H. (2013) *Over £60 million for synthetic biology - GOV.UK*, *UK Government*. Available at: https://www.gov.uk/government/news/over-60-million-for-synthetic-biology (Accessed: 22 August 2017).

Department of Audiovisual Arts (Ionian University). (2017) *Interdisciplinary Conference, Taboo – Transgression – Transcendence in Art & Science.* Available at: https://avarts.ionio.gr/ttt/2017/en/ (Accessed: 17 November 2017).

Derrida, J. (1967) 'Structure, Sign & Play', in *Writing & Difference*. Routledge, pp. 351–370.

Devlin, H. (2017) 'Jennifer Doudna: "I have to be true to who I am as a scientist"', *The Guardian*, 2 July. Available at: https://www.theguardian.com/science/2017/jul/02/jennifer-doudna-crispr-

i-have-to-be-true-to-who-i-am-as-a-scientist-interview-crack-in-creation.

Doudna, J. A. and Charpentier, E. (2014) 'The New Frontier of Genome Engineering with CRISPR-Cas9', *Science*, 346(6213), pp. 1077–1085.

Dunn, R. (2010) *Painting With Penicillin: Alexander Fleming's Germ Art*, *Smithsonian.com*. Available at: http://www.smithsonianmag.com/science-nature/painting-with-penicillin-alexander-flemings-germ-art-1761496/ (Accessed: 29 August 2017).

Dunne, K. A., Chaudhuri, R. R., Rossiter, A. E., Beriotto, I., Browning, D. F., Squire, D., Cunningham, A. F., Cole, J. A., Loman, N. and Henderson, I. R. (2017) 'Sequencing a piece of history: complete genome sequence of the original Escherichia coli strain.', *Microbial genomics*. Microbiology Society, 3(3), p. mgen000106. Available at: http://www.ncbi.nlm.nih.gov/pubmed/28663823 (Accessed: 10 September 2017).

EMBL-EBI (2017) *The European Bioinformatics Institute (Home)*, *EMBL-EBI*. Available at: http://www.ebi.ac.uk/ (Accessed: 5 September 2017).

Endy, D. and Zoloth, L. (2016) 'Should We Synthesize a Human Genome?' DSpace@MIT. Available at: https://dspace.mit.edu/handle/1721.1/102449 (Accessed: 6 November 2017).

Enguix, G. B. and Dolores Jiménez-López, M. (2012) 'Natural Language And The Genetic Code: From The Semiotic Analogy To Biolinguistics', pp. 771–780. Available at: http://ruc.udc.es/dspace/bitstream/handle/2183/13378/CC-130_art_76.pdf;sequence=1 (Accessed: 3 October 2017).

Erasmus, D. and Barker, W. (William W. (2001) *The adages of Erasmus*. University of Toronto Press.

Eurofins (2017) *Experience The Power Of DNA*, *Eurofins*. Available at: https://eurofinsgenomics.eu/ (Accessed: 25 November 2017).

FACT (Foundation for Art and Creative Technology) (2008) *sk-interfaces*, *FACT (Foundation for Art and Creative Technology)*. Available at: http://www.fact.co.uk/projects/sk-interfaces.aspx (Accessed: 17 November 2017).

Federation of American Societies for Experimental Biology (2013) *After the human genome project: The human microbiome project.*, *Science Daily*. Available at: https://www.sciencedaily.com/releases/2013/02/130228093831.htm (Accessed: 3 October 2015).

Finkel, T. and Holbrook, N. J. (2000) 'Oxidants, oxidative stress and the biology of ageing.', *Nature*, 408(6809), pp. 239–247. Available at: http://www.nature.com/doifinder/10.1038/35041687.

Flusser, V. (1988) 'Curie's Children', *Art Forum*, October.

Forterre, P. and Krupovic, M. (2012) 'The Origin of Virions and Virocells: The Escape Hypothesis Revisited', in *Viruses: Essential Agents of Life*. Dordrecht: Springer Netherlands, pp. 43–60. doi: 10.1007/978-94-007-4899-6_3.

Frere-Jones, S. (2015) *All About Yves: The Story of International Klein Blue*, *Departures*. Available at: https://www.departures.com/art-culture/the-truth-behind-yves-klein-international-klein-blue-ikb (Accessed: 25 September 2017).

Freyer, G. A. and Sturr, M. (2006) *Why did mother nature use uracil to replace thymine in mRNA*

(messenger ribonucleic acid)? What is the advantage of using U instead of T in the RNA?, *NSTA News*. Available at: http://www.nsta.org/publications/news/story.aspx?id=52606 (Accessed: 7 November 2017).

GenScript (2014) *Gene Synthesis Handbook*. New Jersey: GenScript.

Ghose, T. (2016) *Minds Everywhere: 'Panpsychism' Takes Hold in Science*, *Live Science*. Available at: https://www.livescience.com/53791-what-is-consciousness.html (Accessed: 30 August 2017).

Gibas, P., Pauknerová, K. and Stella, M. (2011) *Non-humans in social science: animals, spaces, things*. Pavel Mervart.

Gibson, D. G., Glass, J. I., Lartigue, C., Noskov, V. N., Chuang, R.-Y., Algire, M. A., Benders, G. A., Montague, M. G., Ma, L., Moodie, M. M., Merryman, C., Vashee, S., Krishnakumar, R., Assad-Garcia, N., Andrews-Pfannkoch, C., Denisova, E. A., Young, L., Qi, Z.-Q., Segall-Shapiro, T. H., Calvey, C. H., Parmar, P. P., Hutchison, C. A., Smith, H. O. and Venter, J. C. (2010) 'Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome', *Science*, 329(5987), pp. 52–56. doi: 10.1126/science.1190719.

Ginsberg, A. D., Calvert, J., Schyfter, P., Elfick, A. and Endy, D. (2014) *Synthetic Aesthetics: Investigating Synthetic Biology's Designs on Nature*. Cambridge, US and London: MIT Press.

Griffith, F. (1928) 'The Significance of Pneumococcal Types.', *The Journal of hygiene*. Cambridge University Press, 27(2), pp. 113–59. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20474956 (Accessed: 8 September 2017).

Grindhouse Wetware (2012) *Grindhouse Wetware*, *Grindhouse Wetware*. Available at: http://www.grindhousewetware.com/ (Accessed: 14 November 2017).

Guillard, R. R. and Ryther, J. H. (1962) 'Studies of marine planktonic diatoms. I. Cyclotella nana Hustedt, and Detonula confervacea (cleve) Gran.', *Canadian Journal of Microbiology*, 8, pp. 229–39. Available at: http://www.ncbi.nlm.nih.gov/pubmed/13902807 (Accessed: 4 December 2017).

Le Guin, U. K. (1985) 'She Unnames Them', *The New Yorker*. Available at: http://lchc.ucsd.edu/mca/Mail/xmcamail.2013_01.dir/pdf4gQ1dofjT0.pdf (Accessed: 25 October 2017).

GV Art London (2013) *Art & Science | An exhibition to provoke debate & discussion*, *gvart.com*. Available at: https://www.gvart.co.uk/exhibitions-1/2017/6/19/art-science-an-exhibition-to-provoke-debate-discussion-31-january-16-march-2013 (Accessed: 17 November 2017).

Haraway, D. (2000) *Donna Haraway. Cyborgs, Dogs and Companion Species 2000 9/9 - {YouTube}*. Available at: http://www.youtube.com/watch?v=1Oy0IFlEX-Q&feature=BFa&list=SPC017E496EEE63132&lf=list_related (Accessed: 7 August 2015).

Haraway, D. J. (1997) *ModestWitness@SecondMillennium. FemaleManMeets_OncoMouse : feminism and technoscience*. Routledge.

Haraway, D. J. (2004) *The Haraway Reader*. London, New York: Routledge.

Harman, G. (2010) *brief SR/OOO tutorial*, *Object-Oriented Philosophy*. Available at: https://doctorzamalek2.wordpress.com/2010/07/23/brief-srooo-tutorial/ (Accessed: 7 November 2017).

Hauser, J. and Martin, C. (2015) *There Is No Bio Art !*, *Ars Electronica Blog*.

Health and Safety Executive (2014) *The Genetically Modified Organisms (Contained Use) Regulations 2014 Guidance on Regulations Health and Safety Executive Health and Safety Executive*. 5th edn. Health and Safety Executive. Available at: http://www.hse.gov.uk/pubns/priced/l29.pdf (Accessed: 25 August 2017).

Heidegger, M. (1977) *The Question Concerning Technology and Other Essays*, *Technology and values: Essential readings*. Edited by W. Lovitt (trans.). New York and London: Garland Publishing. doi: 10.1007/BF01252376.

Herper, M. (2017) *Illumina Promises To Sequence Human Genome For $100 -- But Not Quite Yet*, *Forbes*. Available at: https://www.forbes.com/sites/matthewherper/2017/01/09/illumina-promises-to-sequence-human-genome-for-100-but-not-quite-yet/#631e21df386d (Accessed: 5 September 2017).

Higgs, C. (2010) *Notes on Derrida's The Animal That Therefore I Am*. Available at: http://htmlgiant.com/random/notes-on-derridas-the-animal-that-therefore-i-am/ (Accessed: 26 November 2014).

Holzinger, A. and Karsten, U. (2013) 'Desiccation stress and tolerance in green algae: consequences for ultrastructure, physiological and molecular mechanisms.', *Frontiers in plant science*. Frontiers Media SA, 4, p. 327. doi: 10.3389/fpls.2013.00327.

Honnef, K., Ruhrberg, K., Fricke, C., Schneckenburger, M. and Walther, I. F. (2000) *Art of the 20th century*. Taschen.

Hornung, E. and Lorton, D. (1999) *The ancient Egyptian books of the afterlife*. Cornell University Press.

Hossein, S. M., Yazdi, T., Yuan, Y., Ma, J., Zhao, H. and Milenkovic, O. (2015) 'A Rewritable, Random-Access DNA-Based Storage System.', *Scientific reports*. Nature Publishing Group, 5, p. 14138.

Howarth, S. (2000) *'IKB 79', Yves Klein, 1959*, *Tate*. Available at: http://www.tate.org.uk/art/artworks/klein-ikb-79-t01513 (Accessed: 25 September 2017).

Huffman, D. A. (1952) 'A Method for the Construction of Minimum-Redundancy Codes*', in *Proceedings of the I.R.E*, pp. 1098–1101. Available at: http://compression.ru/download/articles/huff/huffman_1952_minimum-redundancy-codes.pdf (Accessed: 15 September 2017).

Humphries, C. (2010) *A Moore's Law for Genetics*, *MIT Technology Review*. Available at: https://www.technologyreview.com/s/417628/a-moores-law-for-genetics/ (Accessed: 5 September 2017).

iGEM (2017) *iGEM, About*, *iGEM Foundation*. Available at: http://igem.org/About (Accessed: 29 June 2017).

Ihde, D. (2007) *Listening and Voice: Phenomenologies of Sound*. Albany: State University of New York Press. Available at: https://grrrr.org/data/edu/20110509-cascone/Idhe_listening_voice_phenomenologies.pdf (Accessed: 21 September 2017).

Innovate UK (2017) *Synthetic Biology Special Interest Group - innovateuk*, *connect.innovateuk.org*. Available at: https://connect.innovateuk.org/web/synthetic-biology-special-interest-group/funding-competitions (Accessed: 29 November 2017).

Jacques, N. (ed) and Ngo, N. (ed) (2014) *Escherichia coli*, *MicrobeWiki*. Available at: https://microbewiki.kenyon.edu/index.php/Escherichia_coli (Accessed: 10 September 2017).

Jahn, I. (2017) *Ehrenberg, Christian Gottfried, Complete DIctionary of Scientific Biography*, *Encyclopedia.com*. Available at: http://www.encyclopedia.com/science/dictionaries-thesauruses-pictures-and-press-releases/ehrenberg-christian-gottfried (Accessed: 9 September 2017).

Johung, J. (2014) 'Vital maintenance: Tissue Culture & Art', *Artlink Magazine*, September. Available at: https://www.artlink.com.au/articles/4212/vital-maintenance-tissue-culture-26-art/ (Accessed: 5 November 2017).

Judson, H. F. (2003) 'No Nobel Prize for Whining', *The New York Times*, 20 October.

Jukes, T. H. and Cantor, C. R. (1969) 'CHAPTER 24 – Evolution of Protein Molecules', in *Mammalian Protein Metabolism*, pp. 21–132. doi: 10.1016/B978-1-4832-3211-9.50009-7.

Kac, E. and Mackenzie, L. (2016) 'Interview with Eduardo Kac'. Available at: http://www.viralexperiments.co/eduardo-kac.

Kaebnick, G. E. (2010) 'Is the "Synthetic Cell" about Life?', *The Scientist*, 24(7), p. 27. Available at: http://www.the-scientist.com/article/display/57523/.

Keller, E. F. (1983) *A feeling for the organism : the life and work of Barbara McClintock*. W.H. Freeman.

Keller, E. F. (2010) *The Mirage of a Space Between Nature and Nurture*. Durham & London: Duke University Press.

Kirkham, G. (2009) 'Is biotechnology the new alchemy?', *Studies in History and Philosophy of Science Part A*, 40(1), pp. 70–80. doi: 10.1016/j.shpsa.2008.12.004.

KNAW (2017) *Erwin Chargaff, USA*, *Koninklijke Nederlandse Akademie Van Wetenschappen*. Available at: https://www.knaw.nl/en/awards/laureates/dr-h-p-heinekenprijs-voor-biochemie-en-biofysica/erwin-chargaff (Accessed: 8 September 2017).

Kumar, V., Palazzolo, S., Bayda, S., Corona, G., Toffoli, G. and Rizzolio, F. (2016) 'DNA Nanotechnology for Cancer Therapy.', *Theranostics*. Ivyspring International Publisher, 6(5), pp. 710–25. doi: 10.7150/thno.14203.

Lederberg, J. (1996) 'Interview with Joshua Lederberg [Oswald Avery and the dawn of molecular genetics: a revolution in science]', *Joshua Lederberg interview. VHS Tape 1. Beta SP timecodes 01:20:30:00 - 01:23:18:00*. Available at: https://profiles.nlm.nih.gov/ps/retrieve/ResourceMetadata/CCAANV (Accessed: 8 September 2017).

Lenski, R. (2010) *Overview of the E. coli long-term evolution experiment*. Available at: http://myxo.css.msu.edu/ecoli/overview.html (Accessed: 16 August 2017).

Limbachiya, D., Dhameliya, V., Khakhar, M. and Gupta, M. K. (2016) 'On optimal family of codes for archival DNA storage', in. Institute of Electrical and Electronics Engineers Inc., pp. 123–127. doi: 10.1109/IWSDA.2015.7458386.

Lodish, H., Berk, A., Zipursky, S. L., Matsudaira, P., Baltimore, D. and Darnell, J. (2000) *Molecular cell biology*. 4th edn. W.H. Freeman.

Manchester, E. (2009) *Louise Bourgeois, Maman, 1999*, *Tate*. Available at: http://www.tate.org.uk/art/artworks/bourgeois-maman-t12625.

Margulis, L. (1998) *Symbiotic Planet: A New Look At Evolution*. New York: Basic Books (Science Masters). Available at: https://books.google.co.uk/books?id=vD1Xe3Y04aEC.

Margulis, L. and Schwartz, K. V. (1998) *Five kingdoms : an illustrated guide to the phyla of life on earth*. W.H. Freeman.

Martirosyan, V., Baghdasaryan, N. and Ayrapetyan, S. (2013) 'The study of the effects of mechanical vibration at infrasound frequency on [^{3} H]-thymidine incorporation into DNA of *E. coli K-12*', *Electromagnetic Biology and Medicine*, 32(1), pp. 40–47. doi: 10.3109/15368378.2012.701189.

Mather, J. A. (2011) 'Philosophical background of attitudes toward and treatment of invertebrates.', *ILAR journal*, 52(2), pp. 205–12. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21709313 (Accessed: 30 August 2017).

McDonough, R. (2017) *Plato: Organicism*, *Internet Encyclopedia of Philosophy*. Internet Encyclopedia of Philosophy Pub. Available at: http://www.iep.utm.edu/platoorg/ (Accessed: 21 November 2017).

Mead, M. (1928) *Coming of age in Samoa: a psychological study of primitive youth for western civilisation*. New York: William Morrow & Company. Available at: https://archive.org/stream/comingofageinsam00mead/comingofageinsam00mead_djvu.txt (Accessed: 7 September 2017).

MEGA (2017) *MEGA Molecular Evolutionary Genetics Analysis*, *MEGA*. Available at: http://www.megasoftware.net/ (Accessed: 30 November 2017).

Merriam, A. P. (1964) *The Anthropology of Music*. Evanston: Northwestern University Press. Available at: http://www.posgrado.unam.mx/musica/lecturas/etno/complementarias/Merriam Alan-The_Anthropology_of_Music-1.pdf (Accessed: 7 September 2017).

Merrick, R. (2009) *Interference : a grand scientific musical theory*. R. Merrick. Available at: http://www.interferencetheory.com/Books/BooksInterference/Summary.html (Accessed: 7 September 2017).

Merrick, R. (2010) *Harmonically Guided Evolution*, *interferencetheory.com*. Available at: http://interferencetheory.com/files/Harmonic_Evolution.pdf (Accessed: 7 September 2017).

Merrick, R. (2017) *Toward a New Harmonic Framework*, *interferencetheory.com*. Available at: http://www.interferencetheory.com/Articles/files/232ab7508119d502bcda37d5ff0d0d2c-

35.html (Accessed: 19 September 2017).

Miko, I. (2008) 'Gregor Mendel and the Principles of Inheritance', *Nature Education*, 1(1), p. 134. Available at: https://www.nature.com/scitable/topicpage/Gregor-Mendel-and-the-Principles-of-Inheritance-593 (Accessed: 8 September 2017).

Miller, S. L. (1953) 'A Production of Amino Acids under Possible Primitive Earth Conditions', *Science*, 117(3046), pp. 528–529. Available at: http://www.abenteuer-universum.de/pdf/miller_1953.pdf (Accessed: 4 August 2017).

Montgomery, K. (2003) 'Siccar Point and Teaching the History of Geology', *Journal of Geoscience Education*, 51(5). Available at: http://nagt.org/files/nagt/jge/abstracts/Montgomery_v51n5.pdf (Accessed: 11 November 2017).

Morton, T. (2010b) *The Ecological Thought*. Cambridge, US and London: Harvard University Press, Cambridge, Massachusetts.

Morton, T. (2013) *Hyperobjects: Philosophy and Ecology after the End of the World*. University of Minnesota Press. Available at: http://massivelyinvisibleobjects.org/wp-content/uploads/2015/04/Hyperobjects.pdf (Accessed: 16 August 2017).

Moskowitz, C. (2010) 'Truth Behind the Photos: What the Hubble Space Telescope Really Sees', *Space.com*, March. Available at: https://www.space.com/8059-truth-photos-hubble-space-telescope-sees.html (Accessed: 6 November 2017).

Myers, C., Clancy, K., Misirli, G., Oberortner, E., Pocock, M., Quinn, J., Roehner, N. and Sauro, H. M. (2015) 'The Synthetic Biology Open Language', in *Methods in molecular biology (Clifton, N.J.)*, pp. 323–336. doi: 10.1007/978-1-4939-1878-2_16.

Nail, T. (2017) 'What is An Assemblage?', *SubStance*. University of Wisconsin Press, 46(142), pp. 21–37. Available at: https://muse-jhu-edu.libproxy.ncl.ac.uk/article/650026 (Accessed: 22 August 2017).

NCBI Nucleotide Database (2017) *homo sapiens keratin 18*, *National Center for Biotechnology Information*. Available at: https://www.ncbi.nlm.nih.gov/nuccore/?term=homo+sapiens+keratin+18 (Accessed: 10 October 2017).

Nobel Media (2014) *The Nobel Prize in Physiology or Medicine 1969*, *Nobel Media AB*. Available at: https://www.nobelprize.org/nobel_prizes/medicine/laureates/1969/index.html (Accessed: 8 September 2017).

Nuffield Council of Bioethics (2012) *Emerging Technologies*, *Nuffield Council - Annual Report*. Available at: http://nuffieldbioethics.org/annualreport2012/report.html#emerging (Accessed: 29 November 2017).

O'Connor, C. (2008) 'Isolating Hereditary Material: Frederick Griffith , Oswald Avery , Alfred Hershey and Martha Chase', *Nature Education*, 1(1), p. 105. Available at: http://www.nature.com/scitable/topicpage/Isolating-Hereditary-Material-Frederick-Griffith-Oswald-Avery-336 (Accessed: 9 August 2016).

O'Neill (Chair), J. (2015) *Antimicrobials in Agriculture and the Environment: Reducing Unnecessary Use and Waste*. Available at: https://amr-review.org/sites/default/files/Antimicrobials in agriculture and the environment - Reducing unnecessary use and waste.pdf (Accessed: 25 August 2017).

Ockenga, W. (2012) 'Total Internal Reflection Fluorescence (TIRF) Microscopy'. Available at: https://www.leica-microsystems.com/science-lab/total-internal-reflection-fluorescence-tirf-microscopy/ (Accessed: 1 December 2017).

Olby, R. and Posner, E. (1967) 'An Early Reference to Genetic Coding', *Nature*. Nature Publishing Group, 215(5100), pp. 556–556. doi: 10.1038/215556a0.

Oliver, K. (2009) *Animal Lessons : How They Teach Us To Be Human*. New York: Columbia University Press.

OpenWetWare (2009) *OpenWetWare*, *MediaWiki*. Available at: http://www.openwetware.org/index.php?title=Special:Cite&page=Main_Page&id=290994.

Paabo, S. (2017) *A High-Quality Neandertal Genome Sequence*, *Department of Evolutionary Genetics*. Available at: http://www.eva.mpg.de/neandertal/index.html (Accessed: 5 August 2017).

Packer, M. S. and Liu, D. R. (2015) 'Methods for the directed evolution of proteins', *Nat Rev Genet*. Nature Publishing Group, a division of Macmillan Publishers Limited. All Rights Reserved., 16(7), pp. 379–394. Available at: http://dx.doi.org/10.1038/nrg3927.

Palkopoulou, E., Mallick, S., Skoglund, P., Enk, J., Rohland, N., Li, H., Omrak, A., Vartanyan, S., Poinar, H., Götherström, A., Reich, D. and Dalén, L. (2015) 'Complete Genomes Reveal Signatures of Demographic and Genetic Declines in the Woolly Mammoth', *Current Biology*, 25(10), pp. 1395–1400. doi: 10.1016/j.cub.2015.04.007.

Panofsky, D. and Panofsky, E. (1962) *Pandora's Box: The Changing Aspects of a Mythical Symbol (Mythos: the Princeton/Bollingen Series in World Mythology)*. 52nd edn. New York: Bollingen Foundation. Available at: https://monoskop.org/images/4/40/Panofsky_Dora_and_Erwin_Pandoras_Box_The_Changing_Aspects_of_a_Mythical_Symbol.pdf (Accessed: 24 August 2017).

Park, D.-H., Han, C. J., Shul, Y.-G. and Choy, J.-H. (2014) 'Avatar DNA Nanohybrid System in Chip-on-a-Phone.', *Scientific reports*, 4, p. 4879. doi: 10.1038/srep04879.

Philippians 3:21 (2017) *Philippians 3:21*, *biblia.com*. Available at: https://biblia.com/bible/esv/Phil 3.21 (Accessed: 29 November 2017).

Plato (no date) *Plato: Timaeus*, *Sacred Texts - Hermetic Library*. Available at: https://hermetic.com/texts/plato/timaeus (Accessed: 21 September 2017).

Pray, L. A. (2008) 'Discovery of DNA Structure and Function : Watson and Crick', *Nature Education*, 1(1), p. 100. Available at: http://www.nature.com/scitable/topicpage/Discovery-of-DNA-Structure-and-Function-Watson-397 (Accessed: 9 August 2016).

Proctor, H. (2012) 'Animal Sentience: Where Are We and Where Are We Heading?', *Animals : an open access journal from MDPI*. Multidisciplinary Digital Publishing Institute (MDPI), 2(4),

pp. 628–39. doi: 10.3390/ani2040628.

Pye, J. D. (1993) 'Is fidelity futile? The "true" signal is illusory, especially with ultrasound.', *Bioacoustics*, 4(4), pp. 271–286.

Pye, J. D. and Langbauer, W. R. (1998) 'Ultrasound and Infrasound', in Hopp, S. L., Owren, M. J., and Evans, C. S. (eds) *Animal Acoustic Communication: Sound Analysis and Research Methods*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 221–250. doi: 10.1007/978-3-642-76220-8_7.

Rao, T. V (2012) *Bacteriophage*. Available at: https://www.slideshare.net/doctorrao/bacteriophage-11454471 (Accessed: 14 July 2017).

Redfield, R. (2012) *Useful Genetics Part 1: How Our Genes Shape Us | edX*. Available at: https://www.edx.org/course/useful-genetics-part-1-how-genes-shape-ubcx-usegen-1x-0 (Accessed: 19 July 2017).

Ren, K., Liu, Y., Wu, J., Zhang, Y., Zhu, J., Yang, M. and Ju, H. (2016) 'A DNA dual lock-and-key strategy for cell-subtype-specific siRNA delivery', *Nature Communications*. Nature Publishing Group, 7, p. 13580. doi: 10.1038/ncomms13580.

Rucker, R. (2007) *What is Wetware?*, *Rudy's Blog*. Available at: http://www.rudyrucker.com/blog/2007/08/25/what-is-wetware/ (Accessed: 20 October 2017).

Sample, I. (2015) *What are the risks of DIY synthetic biology? – Science Weekly podcast | Science | The Guardian*, *The Guardian*. Available at: https://www.theguardian.com/science/audio/2015/jan/12/risks-diy-synthetic-biology-safety (Accessed: 29 November 2017).

Schweizer, J., Bowden, P. E., Coulombe, P. A., Langbein, L., Lane, E. B., Magin, T. M., Maltais, L., Omary, M. B., Parry, D. A. D., Rogers, M. A. and Wright, M. W. (2006) 'New consensus nomenclature for mammalian keratins.', *The Journal of cell biology*. The Rockefeller University Press, 174(2), pp. 169–74. doi: 10.1083/jcb.200603161.

Science Gallery London (2017) *Blood*, *Science Gallery London*. Available at: https://london.sciencegallery.com/blood/london/ (Accessed: 17 November 2017).

Science Literacy Project (2016) *Where are GMOs grown and banned? #GMOFAQ*, *Genetic Literacy Project*. Available at: https://gmo.geneticliteracyproject.org/FAQ/where-are-gmos-grown-and-banned/ (Accessed: 18 October 2017).

Sebeok, T. A. (1994) *Signs : an introduction to semiotics*. Toronto: University of Toronto Press.

Seeman, N. C. (1982) 'Nucleic acid junctions and lattices', *Journal of Theoretical Biology*, 99(2), pp. 237–247. doi: 10.1016/0022-5193(82)90002-9.

Seeman, N. C. (2005) 'From genes to machines: DNA nanomechanical devices', *Trends in Biochemical Sciences*, 30(3), pp. 119–125. doi: 10.1016/j.tibs.2005.01.007.

Shukman, D. (2012) *Early days in a DIY biological revolution*, *BBC News*.

Shukman, D. (2013) *BBC News - The BBC's David Shukman explains synthetic biology*, *BBC News*. Available at: file:///Users/louisemackenzie/Library/Application Support/Mendeley Desktop/Downloaded/Unknown - Unknown - BBC News - The BBC's David Shukman

explains synthetic biology(2).html (Accessed: 29 November 2017).

Slater, M. B. (2012) 'Rethinking Human-Animal Ontological Differences: Derrida's "Animot" and Cixous' "Fips"', *Contemporary French and Francophone Studies*. Routledge, 16(5), pp. 685–693. Available at: http://dx.doi.org/10.1080/17409292.2012.739440.

Snow, C. P. (1959) 'The Rede Lecture', in. Cambridge: Cambridge University Press.

Stevenson (ed.), A. and Waite (ed.), M. (2011) *Concise Oxford English DIctionary*. Oxford: Oxford University Press.

Straebel, V. and Thoben, W. (2014) 'Alvin Lucier's Music for Solo Performer: Experimental music beyond sonification', *Organised Sound*, 19(1), pp. 17–29. doi: 10.1017/S135577181300037X.

Stromberg, J. (2013) *What Is the Anthropocene and Are We in It? | Science | Smithsonian*, *Smithsonian Magazine*. Available at: https://www.smithsonianmag.com/science-nature/what-is-the-anthropocene-and-are-we-in-it-164801414/ (Accessed: 28 November 2017).

Suvák, V. (2000) 'The Essence of Truth (aletheia) and the Western Tradition in the Thought of Heidegger and Patocka', in *Thinking Fundamentals, IWM Junior Visiting Fellows Conferences*. Vienna: IWM Junior Visiting Fellows Conferences. Available at: http://www.iwm.at/wp-content/uploads/jc-09-04.pdf (Accessed: 1 October 2017).

Taylor Redd, N. (2013) *Space Junk: Tracking & Removing Orbital Debris*, *Space.com*. Available at: https://www.space.com/16518-space-junk.html (Accessed: 13 October 2017).

The Editors of Encyclopaedia Britannica (2016) *Dmitry Ivanovsky*, *Encyclopaedia Britannica*. Available at: https://www.britannica.com/biography/Dmitry-Ivanovsky (Accessed: 2 December 2017).

The European Commission (2014) *Preliminary Opinion on Synthetic Biology II Risk assessment methodologies and safety aspects*. Brussels.

The Secretariat of the Convention on Biological Diversity (2000) *Cartagena Protocol on Biosafety to the Convention on Biological Diversity*. Montreal: Secretariat of the Convention on Biological Diversity. Available at: https://www.cbd.int/doc/legal/cartagena-protocol-en.pdf (Accessed: 18 October 2017).

The Synthetic Biology Project (2010) *Trends In Synthetic Biology Research Funding in the United States and Europe*. Available at: http://www.synbioproject.org/site/assets/files/1285/final_synbio_funding_web2.pdf? (Accessed: 22 August 2017).

Thermo Fisher Scientific (2017) 'One Shot TOP10 Chemically Competent E. coli: Safety Data Sheet'. lifetechnologies.com. Available at: https://www.thermofisher.com/order/catalog/product/C404010 (Accessed: 18 October 2017).

ThermoFisher Scientific (2017) *NanoDrop Microvolume Spectrophotometers and Fluorometer*, *ThermoFisher Scientific*. Available at: https://www.thermofisher.com/us/en/home/industrial/spectroscopy-elemental-isotope-analysis/molecular-spectroscopy/ultraviolet-visible-visible-spectrophotometry-uv-vis-vis/uv-

vis-vis-instruments/nanodrop-microvolume-spectrophotometers.html (Accessed: 25 November 2017).

Thomas, J. (2014) *What-Syn-a-Name? | Science | The Guardian*, *The Guardian*. Available at: https://www.theguardian.com/science/political-science/2014/jul/08/what-syn-a-name (Accessed: 29 November 2017).

Thompson, H. (2014) *What Does 'Deep Time' Mean to You?*, *Smithsonian*. Available at: https://www.smithsonianmag.com/science-nature/what-does-deep-time-mean-to-you-180952603/ (Accessed: 11 November 2017).

Triscott, N. (2012) *Proposal: an arts/science* ethics advisory panel initiative*, *Nicola Triscott: Art, Science, Technology & Society*. Available at: https://nicolatriscott.org/2012/02/22/proposal-an-independent-artsscience-ethics-advisory-panel-initiative/ (Accessed: 5 March 2014).

UK Health & Safety Executive (2017) *Genetically Modified Organisms (GMO) Public Register Report*. Available at: http://www.hse.gov.uk/biosafety/gmo/notifications/publicregister.pdf (Accessed: 18 October 2017).

UK Synthetic Biology Roadmap Coordination Group (2012) *A synthetic biology roadmap for the UK*. Available at: http://www.rcuk.ac.uk/documents/publications/syntheticbiologyroadmap-pdf/ (Accessed: 22 August 2017).

Vaage, N. S. (2016) 'What Ethics for Bioart?', *Nanoethics*. Dordrecht: Springer Netherlands, 10, pp. 87–104. doi: 10.1007/s11569-016-0253-6.

Vanouse, P. (2017) *Paul Vanouse Intro*, *Paulvanouse.com*. Available at: http://www.paulvanouse.com/ (Accessed: 1 December 2017).

Various (2015) *The Nonhuman Turn*. Edited by R. A. Grusin.

Vickers, P. and Alty, J. (2006) 'The Well-Tempered Compiler: The Aesthetics of Program Auralization', in *Aesthetic Computing*. MIT Press, p. 457. Available at: http://nrl.northumbria.ac.uk/11299/ (Accessed: 6 November 2017).

Voyager - Fact Sheet (2017) *Jet Propulsion Laboratory, California Institute of Technology*. Available at: https://voyager.jpl.nasa.gov/frequently-asked-questions/fact-sheet/ (Accessed: 13 October 2017).

Wang, Q., Parrish, A. R. and Wang, L. (2009) 'Expanding the Genetic Code for Biological Studies.', *Chemistry & Biology*. NIH Public Access, 16(3), pp. 323–36. doi: 10.1016/j.chembiol.2009.03.001.

Webster, J. (2016) 'Animal Welfare: Freedoms, Dominions and "A Life Worth Living"', *Animals : an open access journal from MDPI*, 6(35). doi: 10.3390.

Weitemeier, H. (2001) *Klein*. Berlin: Taschen.

Woese, C. (1967) *The genetic code : the molecular basis for genetic expression*. New York: Harper & Row. Available at: http://www.worldcat.org/title/genetic-code-the-molecular-basis-for-genetic-expression/oclc/293697 (Accessed: 9 September 2017).

Wolfe, C. (2003) 'In the Shadow of Wittgenstein's Lion: Language, Ethics and the Question of the Animal', in Wolfe, C. (ed.) *Zoontologies: The Question of the Animal*. Minneapolis, London,

London, pp. 1–48.

Wong, P., Wong, K. and Foote, H. (2006) ‘Storing data encoded DNA in living organisms’. Google Patents. Available at: http://www.google.com/patents/US20060024733.

World Trade Organisation (2017) *Sanitary and Phytosanitary Measures: Text of the Agreement*, *World Trade Organisation*. Available at: https://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm (Accessed: 18 October 2017).

Zayner, J. (2017) *Biohacking - The ODIN*, *the-odin.com*. Available at: http://www.the-odin.com/blog/biohacking/ (Accessed: 14 November 2017).

EVOLUTION OF THE SUBJECT

SYNTHETIC BIOLOGY
IN
FINE ART PRACTICE

APPENDICES

APPENDICES

APPENDICES

APPENDICES

APPENDIX I
LABORATORY DIARY

INTRODUCTION TO LABORATORY DIARY

Originally a working diary, this writing has become re-worked and divided between the main thesis chapters (mostly Chapter 5), the ongoing projects *Memento Perimortem* and *Lively Material* (Mackenzie, 2015b, 2017c) and this Appendix. As a working diary of art practice in the laboratory, the documentation is largely note form. A combination of scientific protocols documented in my own words, scientific definitions transcribed from the internet, and daily observation and reflection, as such the Appendix is divided into three sections: a) Lab Diary, b) Scientific Protocols and c) Scientific Terms. Throughout the diary, I adopt a situated, art-ethnographic approach to working in the laboratory, focusing predominantly on documenting the activities that constitute the laboratory life of the artist-scientist in laborious detail (although not necessarily with scientific precision) whilst also reflecting upon the laboratory life of the micro-organism. The term laboratory life is used here dualistically, both in the anthropological / ethnographic sense employed by Bruno Latour (Latour and Woolgar, 1979) but also in the figurative sense of drawing attention to the laboratory organism.

As Latour has commented, much anthropological work has been conducted in what might be troublingly termed the wild: that external habitat, the environment beyond the habitat of the Western colonial: primitive societies, extreme climates, nature (Latour and Woolgar, 1979, p. 17). Yet ethnographic observation of Western society has, until the last half century at least, been less common. In an art historical context, the Situationist movement led by Guy Debord and Artist Placement Group, led by Barbara Steveni and John Latham in the UK, developed a form of art-ethnographic practice and today, ubiquitous reference to the nebulous field of 'art-science' pre-supposes the emergence of a new field of art-ethnographic practice in the realm of the laboratory. This becomes my situated practice: an enquiry into the environment of the laboratory organism. Within the environment of the laboratory,

one might reasonably argue that all life is domestic, not wild. Yet this suggests a power structure that I argue cannot exist between the micro and the macro. In consideration of all forms of life, including the micro-organism, there is no wild and no domestic: these terms are anthropological constructs that do not give sufficient weight to the communicative power of the micro-organism to exist on and within us, adapting continually regardless of our imagined domination.

In my work in the laboratory, although I adopt synthetic biology techniques, I aim to respect the organism and my place beside it in space and time. Micro-organisms are swift and versatile, communicating genetically, passing on information so that their progeny can adapt. If I must impose upon the organism I must also be mindful of the organism's capacity to communicate across deep time and as such, I attempt to experience and learn with, not through the organism.

LABORATORY DIARY

Lab Diary, 27 July, 2015

I received my plasmid today. It is a circular piece of synthetic DNA that contains a thought, spoken aloud, recorded and translated into DNA as a question to the *E. coli* I shall be working with. I see this act as a transgression, an imposition of my will upon the body of the organism and in framing the act in this way, I wish to understand how the various bodies engaged in the act will respond.

The second transgression comes unexpectedly. The plasmid (my thought) has been given a name: pEX-A2-MacKenzie, by the scientist who helped to design the plasmid with me. The name is a biological classification: p (plasmid) EX (Initials for the Laboratory) A2 (another laboratory code) MacKenzie (name of 'gene', filled out on form when ordering plasmid). My name is not spelled correctly (small k not capital K) and it forces me to think about this small act. Nobody thought it important to ask if I cared to title the plasmid. Nobody thought to ask whether the plasmid cared to be titled.

Plasmids are created synthetically: the DNA is made using sugar cane. My plasmid is a sweet plantation bio-slave, borne and claimed by humanity.

Figure 70: Thought-as-DNA delivered to Institute of Genetic Medicine. Research documentation, 2015. Photo: Louise Mackenzie

Transformation

trɑːnsfəˈmeɪʃ(ə)n

'A marked change in form, nature or appearance
Biology: the genetic alteration of a cell by introduction of extraneous DNA, especially by a plasmid.' (Oxford Dictionaries, 2017)

'He will transform the body of our humble condition into the likeness of His glorious body, by the power that enables Him to subject everything to Himself.' (Philippians 3:21)

'After it happens, that's what they look like in real time. The process is no longer important.' (Atwood, 2009, p. 235)

I like the juxtaposition of the biblical reference with Margaret Atwood's tale of genetic indifference. Transformation seems rather a grand word. I wonder how important the process really is.

1. Switched on water bath (made sure enough water in – used 15 ohms filtered)
2. Took two pre-prepared LB Agar plates out of fridge
3. Took the pre-prepared dilution of pEX at 50ng/µl from freezer
4. Defrosted *E. coli* on ice for 15 minutes
5. Prepared two epps with 20µl E.coli each
6. Added 1µl pEX to one of the epps, labelled both
7. Left to incubate for 15 minutes
8. During this time, placed small amount of LB in a universal tube for step 10, below
9. Took the pEX epp and placed in water bath for 55 secs
10. Then put epp back on ice for 2 minutes
11. Placed 500µl of LB (no Amp) in each epp

12. Placed both epps in universal tube and then placed in incubator for 45 minutes
13. Took 100µl from each epp and spread onto each plate, correctly labelled
14. Placed in static incubator at 12pm.

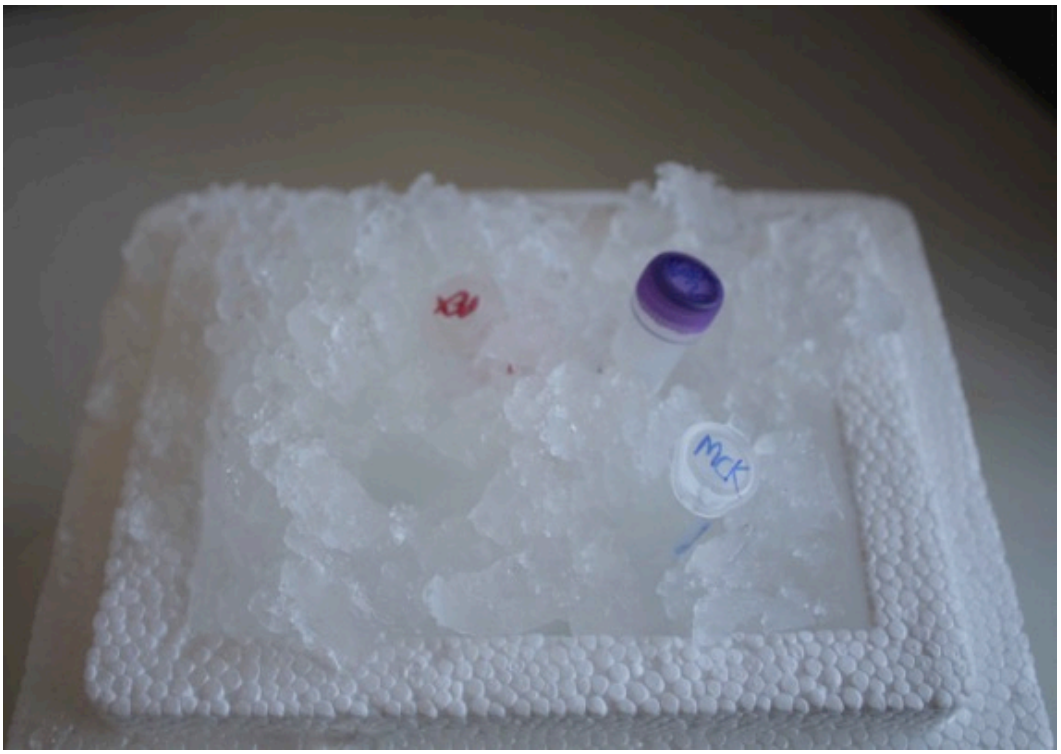

Figure 71: Plasmid on ice during transformation. Research documentation, 2015. Image: Louise Mackenzie

Observations

During transformation, it is important to touch the bacterial cells as little as possible. Even the outside of the container should be handled as little as possible. The temperature changes will affect the bacteria and they will lose their 'competency', i.e. will not transform well.

In the incubator, motion is important throughout. There is a sense of nurturing, a constant rocking and gentle shaking. This is related to the necessary process of mixing, to keep components from settling.

After the transformation process, I was reluctant to discard the excess. These are known as 'competent' *E. coli* (already modified to be suitable for transformation), they are kept in an -80°C freezer. I defrost them (waking them up?) then add the synthetic plasmid DNA that I designed to their immediate environment. Then I briefly place them in an extremely hot water bath at 42°C. It alters their cell membranes allowing the plasmid to enter their bodies, which is a shock to them, but hopefully they are resilient enough to accept it within them and recover. I then have a culture of transformed *E. coli* (I hope) in a small amount of liquid medium. I take some of this solution and attempt to grow colonies from it on a nutrient agar plate, to determine whether the transformation has worked.

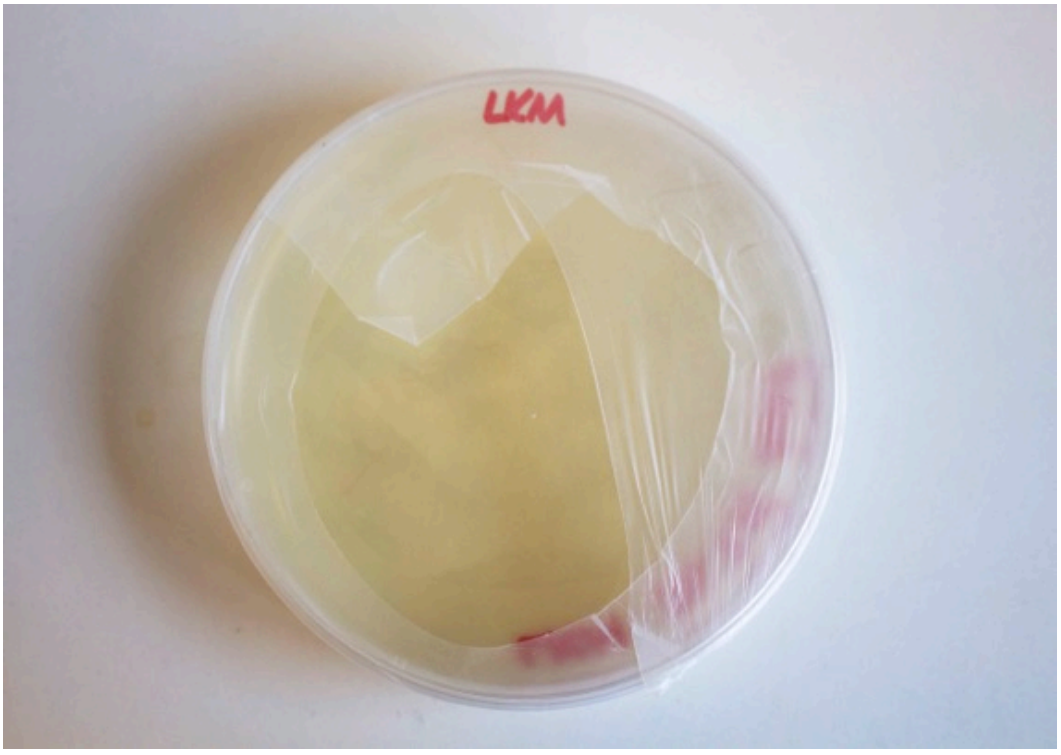

Figure 72: Transformed *E. coli* on agar plate before incubation. Research documentation, 2015. Image: Louise Mackenzie

I am therefore left with some awakened *E. coli* that have been heat shocked to accept my plasmid within their bodies. I don't know whether they have accepted it and I don't know *what it feels like* to them to do so. I also have some awakened *E.*

coli that I did not heat shock, as a control: experimental by-products. I am faced with the prospect of discarding both.

I chose to discard the control *E. coli* that I had roused from their frozen slumber, on the grounds that they no longer served a useful purpose (*to me*). They have become less than tools. Not broken, like a useless hammer, rather the off-cuts of material that made the hammer. They served a purpose and are now surplus to requirements: living waste. I disposed of them in the correct manner: poured into a container of bacterial waste that will be autoclaved (heated to such a high temperature as to kill all life). If I honour them differently, with a poetic, ceremonial send-off for example, do they become discards any less?

I take 1µl and place in 10mls LB (containing 10µl Ampicillin) and culture this in the incubator overnight, labelled as pEX and LB. I chose not to discard the remaining transformed *E. coli*. I have therefore placed them in the freezer.

I am somewhat troubled by my decisions. To choose to discard that which is not useful to me and to keep that which is. These are living organisms. Do I have any right to choose whether they live or die, simply because I am human? I would wipe *E. coli* out of my home with an anti-bacterial spray, what is the difference? I suppose the difference is between *instinct* and *knowledge*. *E. coli* harbours disease and I see it as a threat. I act upon them instinctively, without regard for their being-in-the-world. The laboratory *E. coli* are instead techné. They are a part of the world's machinery: they have been assembled on the genetic production line for human use. They have no place outside of the laboratory environment: it *is* their environment. To release them into the *wild* would be to release them into an unknown situation. Thus they serve a purpose and are culled after they have served that purpose. This is what one might describe as humane.

E. coli are single celled organisms and are not described as sentient: they have no *feeling*. Thus, in our human wisdom, we have decided that, because they do not function as we do, we can decide what to subject them to, according to a scale of human attributes. However perhaps they feel collectively, over deep time, over an extended period. Just as with resistant to antibiotics, a single cell may not sense the cause of its own extinction, but over time, the collective body adapts to tolerate the sensation. Perhaps we must think of these singular cells as a larger organism over an expanded time frame.

It is this logic that contributes to my discomfort at discarding them, our interference in their being-in-the-world, which coincides with our being-in-the-world. After all, we are all a part of the tangled mess of liveliness. We are a complex organic structure, composed of an organised system of cells. What changes occur when we deconstruct our own living components and treat them as non-sentient machine parts? How does our tangled mess of liveliness sense this and adapt to tolerate it?

Lab Diary, 26 January 2016

Today I went to see whether my scions had grown. I was excited to find that they had. The control plate was clear, confirming that the ampicillin agar plates were effective and only the ampicillin resistant bacteria (the ones containing my plasmid DNA) had grown. That is, those *E. coli* that were not ampicillin resistant had died, their use fulfilled.

I also checked the universal tubes in the moving incubator. The old culture that I had saved in the fridge from a few months ago had not grown, suggesting that it was also dead. How do I feel about this? How did they experience it? The new culture however had grown. As this was a 1µl sample from a previous liquid media culture, not from a single colony, there are many colonies within this container: an entire community of colonies: a more diverse social group.

The universal tube containing the remaining transformed *E. coli*, after I had taken a sample, was also now surplus to requirements. I found this harder to discard, leaving it sat under the Class 2 hood whilst I contemplated the fate of its contents.

I considered spinning down the contents of the tube as I had done previously, which would compress the *E. coli*, allowing me to drain off the excess media and freeze the remaining *E. coli*. However it occurred to me that in doing so, I would still be harbouring more *E. coli* than I *needed* given that I now have a plate of colonies. The only advantage to keeping this tube would be to keep the *E. coli* alive. I had created them and so I felt responsible for them. However this would be akin to domesticating fruit flies: the more you keep the more they breed. As I am creating the conditions for their existence, I am also therefore responsible for their population control. I begin to speculate on their environment. Do these microbes not experience their tiny universal tube environment as just that: universal? It is their wild (am I, therefore, their creator?). If observe and act upon them in the laboratory, only the microbes are impacted, it is their fate. They experience no other existence. I must remember that being a progenitor brings great responsibility.

I decided to pour the remaining transformed *E. coli* into the 'Bacterial Waste for Autoclaving' jar and discarded the universal tube containing the trace remains for autoclaving also. Farewell brave souls.

Lab Diary, 27 January 2016

All colonies became successful cultures overnight. This morning I created 5 tubes with 10ml LB and 10µl ampicillin in each. I took a 1µl sample from yesterday's cultures and added to each fresh tube. Then I sat down and contemplated killing the rest again.

These *E. coli* had been through a lot. Brought from cryogenic stasis to life, then subjected to a shock strong enough to weaken the very membranes of their body and allow a foreign body to enter. Having accepted this foreign body and adjusted to incorporate it within their own bodies overnight, only a lucky few were selected to live another day. I'm a killer, we all are, we are all animals, but what distinguishes us is our compassion, surely?

I mark the occasion by photographing the cultures to remember them and audibly bidding them farewell. What would happen if we did this for all species that we impose control over? Then I dispose of them in the 'Bacterial Waste' container.

Lab Diary, 28 January 2016

Again the cultures flourished overnight and I have to resample. Once again, I am left with the 'killing ritual' (see Catts and Zurr, 2003). Suddenly I realise that the life cycle of *E. coli* is such that each individual cell lives a full life in the nutrient medium (LB). It takes an *E. coli* approximately 20 minutes to replicate therefore the only limiting factor for ongoing survival is nutrition. I wonder how long it takes an *E. coli* to die. I am trying very hard not to let go of the feeling I have when faced with disposing of the *E. coli*. Don't let the process become routine. Time and space are critical to the poeisis of living material.

I mix them with the other bacterial waste, which sits out at room temperature (at this time of year, around 15 degrees lower than the optimal temperature for *E. coli*). I wonder does this temperature stop them growing, or slow them growing? Do they survive this new universe and experience something of a multi-cultural utopia? Or is it a hostile wasteland, hard to colonise?

Lab Diary, 29 January 2016

Today I have to run through my *E. coli* ceremony a little faster than usual as I have a meeting to get to in half an hour. I have to go through the motions and just do what needs to be done, quickly. Humans are taking priority: I am not respecting (honouring) my microbial subjects fully.

I bid them a hasty farewell as they are sampled and then the remainder sent to their multi-cultural utopia (hostile wasteland). The fresh sample generations are placed in the incubator at 09:50 and then after my meetings I remove them and place them in the fridge, at 12:00, to grow more slowly over the course of the weekend. I will incubate again on Monday.

Lab Diary, 01 February 2016

On Monday I returned to the room to take my *E. coli* out of the fridge and place into the incubator at 13:20. A very small and simple step for my *E. coli* today: moving from a chilly, slow growing environment to a warmer, more vigorous one.

Lab Diary, 02 February 2016

Today I re-cultured my *E. coli* at 09:20. Again I was short of time today and I fear that I am becoming desensitised to the process. I again photographed the family

members to commemorate them before committing them to the multi-cultural utopia / hostile wasteland, but the process happened fast and my hand shook a little as I poured the elder generations into their resting place.

At 17:00 I returned to the lab and checked on my cultures, which had grown well, therefore I resampled and labelled (same date, sample B), said my farewells and put the new cultures into the incubator at around 17:20.

I have decided to create a family tree in memory of the *E. coli* generations that are now departed.

Lab Diary, 03 February 2016

Today I am attempting to encourage some cultural diversity in my *E. coli* generations. I have resampled my cultures, commemorated them and continued to incubate them (at 10:15) as before (*are my reflections becoming more perfunctory now that I have another 'use' for them?*). Now, as well as continuing with the existing cultures, I am creating new cultures in the following mediums:

A. 'Builders' tea with milk and two sugars
B. Black tea and two sugars (B's suggestion as might be easier to detect if the cultures have grown)
C. Miso (for a salty alternative to the above sweet options)
D. Marmite (another salty, yeasty alternative)

So for each medium (served lukewarm) I took a 1µl sample from culture pEX 1 and placed it in a universal tube containing 10ml of medium. I also have a universal tube containing 10ml of medium with no pEX 1 as a control. All have been placed in the incubator at 10:30.

Lab Diary, 04 February 2016

I prepared my usual daily cultures, commemorated them with a photograph and bade them farewell. The *Cultural Nutrition* cultures as I am calling them for now showed some signs of growth, particularly in medium C (miso) and medium D (marmite). I took a 1µl sample from each of A, B, C and D and placed in 10ml of fresh media, then returned to the incubator at 10:15am.

Lab Diary, 7 March 2016

Mini-Prep Process – Preparing to Die

Recently I mini-prepped my progeny in order to sequence all samples, including a set of colonies that I had subjected to UV tests, where I wondered how a little synthetic sunlight (just a gentle amount) might affect my progeny. All came back either including my inserted DNA sequence in its original state, or in the case of three of my *Cultural Nutrition* samples, the sequence was more or less destroyed[i]. It looks like my bacteria did not enjoy tea or miso so much after all. I may try to re-sequence them, as I feel that the medium got in the way a little (so thick in some cases, as to literally cloud the issue). I may also try sequencing them earlier, not continually growing them in the culture in an incubator over several days. Interestingly, with *Cultural Nutrition* Media Sample D (Marmite) the culture is thriving unchanged.

The purpose of preparing mini-preps is to end up with an increased quantity of DNA from your original source stock. The process is also used to isolate DNA, prior to sending the DNA for sequencing. The body of the *E. coli* is used to enable this.

You have to have first transformed your plasmid into a bacterial host, through the process of heat shock, which makes the cell walls more permeable and enables horizontal gene transfer (i.e. transfer of genetic information that does not involve cell division). Then you grow the bacterial host overnight on an ampicillin plate, to ensure that only your ampicillin resistant bacterial colonies grow. Then you select colonies from the plate to add to LB medium and incubate these overnight so that they can multiply. At the end of this process, you have (in our case) 6 different colonies in solution. These are then centrifuged to form a pellet of bacterial cells in the bottom of each universal tube. The LB is poured away as 'Bacterial Waste' to be autoclaved and disposed of. The remaining pellet is then mini-prepped as per the following (non-standard) protocol, below.

As I observe and comment upon the performance of the mini-prep process in my own words, I realise that the language I choose to use is emotive and I am conscious of attempting to write in a way that refers to the bacteria as living organisms, whilst at the same time, attempting to remain committed to the reductive process required. Therefore there is an immediate disconnect between living material and process. The writing becomes more and more clinical as the various lively components of the bacteria are whittled away. The result is as follows:

After being grown overnight in a warm environment of constant motion, the bacteria (referred to within the lab as cells) are then spun at 13,000 revolutions per minute for 15 minutes (centrifuged), causing them to spiral at speed in a downward motion, where their weight, relative to the liquid broth, causes them to become compressed into one another, forming a mass of compressed bacteria (pellet) at the bottom of the universal tube.

The pellet of compressed bacteria is then re-suspended in solution. The bacterial cells are broken into pieces by the action of a pipette expelling the first of three 'lysing' (see Appendix I, Scientific Terms) buffers into the pellet, thus disturbing not

only the pellet of bacterial cells but also the structure of the cells themselves. The mixture is then sucked back into the pipette and out again repeatedly, to mix the now broken bacterial cells with the buffer sufficiently. The tip of the pipette prods the pellet repeatedly to disturb the cells within the liquid. The sucking and prodding motion is deliberately fast, even aggressive, to ensure that the cells are well mixed with the buffer and that none remain in compressed form at the base of the universal tube. Once thoroughly mixed, the broken bacterial cell solution is sucked into the pipette one final time and transferred to an eppendorf tube.

Add the second 'lysing' buffer, which will change the colour of the solution to a bright blue, to mark that the reaction has taken place. Invert the eppendorf tube containing the cells sharply, 4-6 times to mix this buffer into the lysing cell solution well.
Add the third 'lysing' buffer and again mix thoroughly by inverting the tube 4-6 times, the solution will now turn a cloudy white (again, a marker). The second and third 'lysing' buffers help to break down the components of the bacterial cells further, destroying the proteins, membrane lipids and RNA.

The resulting 'lysed' solution of deconstructed bacterial cells is then spun again at 13,000 revolutions per minute, for 10 minutes, this pushes the destroyed cell components down to the bottom of the tube and leaves only the plasmid DNA in solution (the filter retains DNA of a specific size only, thus only plasmid DNA is retained).

Next, the DNA must be extracted from the solution. The solution is therefore removed from the eppendorf tube using a pipette, taking care not to disturb the dead cell material at the bottom of the tube, and added carefully to the mini-prep spin column: a two sectioned tube, comprising of a simple rounded tube and a funnel ended tube with a filter that sits within the first tube. The filter is made from silica, which adsorbs[ii] the DNA from the solution such that it adheres to the silica

filter. The remaining liquid passes through the filter into the simple rounded tube. The tube is then placed in the centrifuge for 30-60 seconds to thoroughly draw the solution through the filter to the bottom of the tube. This process can be repeated if it was not possible to fit all of the solution into the mini-prep spin column initially.

The mini-prep spin column must now be washed and rinsed to remove any final traces of solution and/or dead cells and leave only the DNA adhered to the filter. Two buffers are used to achieve this. The first buffer is placed into the mini-prep spin column and centrifuged for 60 seconds to wash the filter clean. Any remaining buffer can then be discarded.

The second buffer is then added to the mini-prep spin column and centrifuged for 60 seconds to give a final rinse. Any remaining buffer can then be discarded.

The mini-prep spin column is then centrifuged again for 1 minute to remove any final traces of washing or rinsing fluid.

The filter tube is then removed from the mini-prep spin column and placed in a clean eppendorf tube. Now the adsorbed DNA must be removed from the filter (this process is called *elution*).

Add the final buffer (a solvent) to the filter and allow to stand for 1 minute or longer. Spin in the centrifuge again for 60 seconds. The resulting solution should contain the DNA.

To increase the concentration of DNA in solution, the solution can be sucked into a pipette and passed through the filter again, left for one minute, then centrifuged again.

As a result of this process we are now left with only the DNA of the plasmid, as the filter is designed to hold only this size portion of DNA, all other bacterial cell material has now been disposed of in the appropriate waste bin.

Lab Diary, 11 April 2016

I have been repeating my actions and capturing my progeny with photographs since the last entry. I have made notes, but essentially the process has been one of regular re-culturing and perfunctory commemoration. I fear that I have become bored with my subjects.

Lab Diary, 4 August 2016

Since January I have maintained a visual diary of my *E. coli* sampling, recording all of the dates and a photograph of each sample, before committing to Bacterial Waste. The words 'bacterial waste' haunt me. They are an indicator of the proliferation of waste generated through medical research, bacterial or otherwise. I can't help but feel that in working with *E. coli* I am acting as a conduit for exploring sensations regarding all laboratory life. If I were to give a two-minute silence to all of the bacteria who[iii] bravely gave their lives in the name of science, then I could make a very long film, that no-one would watch. I'm tempted though, to see how long it would be: for my humble project, one of many[iv].

I sequence periodically. When I first sequenced the DNA of my microbes, it was exciting; I couldn't wait to translate the results. The last sequence (late June 2016) I could barely be bothered to translate. I glanced at the visual image of the sequence and it looked like it had not changed. I then went through the fairly laborious process of checking the sequence, nucleotide by nucleotide, and indeed there was no change. Their response to my question is too slow for me to appreciate. I am

ashamed of my glib approach to working with my progeny now. It has become routine, boring. I worry that it ought not to be and I wonder how I can address this. I have begun to explore means to grow them in their synthetic environment via a bioreactor, which could lessen or remove the killing ritual. Julie Legault of Amino Labs has kindly agreed to give me one of her DIY lab kits[v], which will help me to maintain cultures for longer. I'd also be interested in enlivening their environment, with music and light, or perhaps dark and bodily fluids. What is it that they would prefer, to thrive in? What will encourage them to live life to the full? Will this make any difference to the information I have maintained within them? I expect that I can never fully know the answer.

My next steps are as follows:

- find a space where I can maintain a continuous culture
- find a form within which to grow a continuous culture

Lab Diary, 04 January 2017

I have been compiling images and excerpts from my Lab Diary into a film to honour my progeny publicly. Every colony under my care between 13th December 2016 and 20th June 2017 will be commemorated in Hexham later this month.

Lab Diary, 08 August, 2017

I still grow my progeny but I have chosen not to sequence them anymore. The process is expensive (to the laboratory and perhaps to the organism more so). I may do in future, but not until I am satisfied that the reason is sufficient. In the meantime, I continue to commemorate those who have died in the making of this project through a simple photograph and, occasionally, I bring the recently deceased to the public for a ceremonial wake so that they may be contemplated, respectfully.

SCIENTIFIC PROTOCOLS

The following depictions of scientific protocols form part of my laboratory notes, taken whilst preparing to undertake laboratory procedures. The protocols outlined below relate specifically to the activities that I undertook in the laboratory for this artist-led research project and as such, their reproducibility (plagiarism or error free documentation) cannot be guaranteed.

Basic Measures

Working in molecular biology requires an adjustment of scale that can be difficult to comprehend. Measures are most often in micrograms (µg) and nanograms (ng), millilitres (ml) and microlitres (µl). One microlitre of liquid is visible to the naked eye, as a dot no wider than 2mm across. It is worth taking a moment to consider the scale that such experiments are conducted at.

Commonly used prefixes:
The prefix "nano" represents a factor of 10^{-9} (one billionth)
The prefix "micro" represents a factor of 10^{-6} (one millionth)
The prefix "milli" represents a factor of 10^{-3} (one thousandth)

Commonly used measures:
1 millilitre (ml) = 1000 microlitres (µl)
1 microlitre (µl) = 0.001 millilitres (ml)

1 milligram (mg) = 1000 micrograms (µg)
1 microgram (µg) = 1000 nanograms (ng)
1 nanogram (ng) = 0.001 micrograms (µg)

Recipe for Luria Broth (LB) medium for *E. coli*

Ingredients:

(per litre of broth)

10g Tryptone

10g Sodium Chloride (salt)

5g yeast extract (powdered)

Pure water (up to required amount)

Equipment:

Plastic gloves, mixing plate, measuring jug, measuring spoon/spatula, stir bar, autoclave tape, containers for L Broth

Instructions:

Put on gloves,

Measure out ingredients,

Add required amount of pure water to measuring jug,

Place measuring jug containing pure water onto mixing plate,

Add stir bar,

Add ingredients,

Switch on mixing plate until dissolved.

Pour into containers, fasten lids finger tight, ready for autoclaving.

Place autoclave tape onto containers, label (using indelible marker) with your name, contents and date.

L Broth will keep at room temperature for months.

Recipe for LB Agar

Ingredients:

L Broth (as required)

Agar (1.5% per liquid broth, as required)

Equipment:

Plastic gloves, measuring jug, measuring spoon/spatula, containers for LB Agar.

Instructions:

Put on gloves,

Add required amount of L Broth to containers,

Measure out 1.5% of agar to liquid (i.e. for 400mls of L Broth, add 6g agar),

Add agar to liquid and gently rotate container to mix.

Place autoclave tape onto containers, label (using indelible marker) with your name, contents and date.

Autoclave.

LB Agar will keep at room temperature for months.

Recipe for TB (terrific broth) medium for *E. coli*

12g Tryptone

24g Yeast Extract

9.4 g Dipotassium hydrogen phosphate K_2HPO_4

2.2 g Potassium dihydrogen phosphate KH_2PO_4

4 mL Glycerol (0.4%)

Adjust to 1l with distilled H_2O

Sterilise by autoclaving.

Class 1 and Class 2 Hoods

Class 2 Hood contains filters to circulate sterile air, thus preventing microbes from entering or leaving the hooded area

Class 1 Hood sucks in external air, to ensure that nothing escapes into the environment. The environment is not sterile.

Preparing Petri Dishes for growing cultures

Ingredients:

LB Agar

Ampicillin (100 micrograms per ml of LB agar)

Example – 300 mls of LB Agar requires 300 micrograms of Ampicillin

Equipment:

Plastic gloves, Class 2 Hood, Pipette, Sterile Petri Dishes, Microwave

Instructions:

Put on gloves,

Heat LB Agar in microwave (gently, for a minute at a time, with lid on loose, agitate to help dissolve 'plug'),

Leave to cool to around 50° before adding antibiotic,

Take Ampicillin from freezer and hold tube to gently thaw,

Using pipette, set to measure required amount of Ampicillin,

Switch on Class 2 Hood,

Place all equipment under hood,

Open sterile pack of petri dishes and set out required number*,

Using pipette, extract required amount of Ampicillin and release into LB Agar,

Firmly, but not vigorously, rotate LB Agar container to mix Ampicillin,

Carefully pour into sterile petri dishes and allow to cool,

Once cool, invert dishes (to prevent condensation dropping onto Agar/Ampicillin mix),

Stack and place back into plastic packaging to store.

Store LB Agar/Ampicillin in 4° fridge (will keep for at least one month).

*e.g. 12 x 25ml petri dishes for 300 ml of LB Agar/Ampicillin

Transformation Using Heat Shock

The process of transformation using heat shock involves a transfer of *E. coli* bacteria from a frozen state, in an environment of -80°C, to a bath of ice (which enables the *E. coli* to defrost) for 15 minutes and then to a water bath of 42°C for 45-60 seconds, before returning to the ice for 2 minutes to reduce the likelihood of damage to the bacterial cells.

The water bath changes the cell membrane, increasing permeability, which allows the uptake of plasmid DNA from a foreign source. This state would also occur in wild strain *E. coli* but the 'brand' that we will use (Top10) are 'domestic', engineered to be receptive to larger quantities of foreign DNA and able to produce more colonies. These are known as 'competent' cells.

The following process is specific to our proof of concept experiment.

Instructions:

1. Turn on water bath to 42°C

2. Ensure that you have the correct dilutions of the plasmids

3. Remove competent *E. coli* cells (Top10) from -80°C freezer. Try not to 'touch' the cells

4. Defrost *E. coli* cells by placing in ice

5. Transfer the *E. coli* in aliquots to 3 eppendorf tubes (nb: as the total volume of *E. coli* was 50µl, we transferred 20 µl to 2 tubes and 10 µl to the third tube).

6. Add 1µl of pBR322 to one 20µl tube of *E. coli*, giving 50ng in solution

7. Add 1µl of pEX-A2-Mackenzie to one 20µl tube of *E. coli*, giving 50ng in solution

8. The third tube contains only *E. coli* and therefore represents the –ve control, to determine that the Ampicillin plate has been correctly prepared. If bacteria grow on this control plate, then either the *E. coli* are somehow contaminated or the Ampicillin plate does not contain sufficient Ampicillin.

9. Incubate on ice for 15 minutes

10. Put tube(s) with plasmid and *E. coli* into water bath at 42°C for 45-60 seconds

11. Put tubes back on ice for 2 minutes to reduce damage to the *E. coli* cells

12. Pour some LB into a falcon tube for easier sampling

13. Add 500µl of LB (with no antibiotic). Incubate at 37°C in the shaker for between 30-60 minutes

14. Spread 100µl of the culture on LB plates (with Ampicillin added) and grow overnight in the incubator at a temperature of 37 degrees.

15. Pick colonies to do mini-preps

Process for Preparing 6 Mini-preps

Ingredients:

LB

Ampicillin

Plasmid Colonies on Ampicillin Plate

6 x universal tubes

1 x falcon tube

Instructions:

1. Remove plasmid colonies from fridge and warm briefly in incubator.
2. Pour LB into a 50 ml Falcon tube
3. Add ampicillin in a 1µl/ml concentration, therefore 50µl, to the Falcon tube, replace the lid and invert and rotate several times to mix well.
4. Add equal aliquots of the LB/ampicillin mixture to the 6 universal tubes.
5. Use a pipette tip to select one single colony from the plate and drop the pipette tip into the universal tube - repeat 6 times, taking a fresh colony each time.
6. Prepare a control by creating a 7th universal tube containing only ampicillin.
7. Place 7 tubes in the shaker overnight, ideally for 16-20 hours. NB: If you leave the tubes for considerably longer, the ampicillin may begin to degrade, which would mean that you might have colonies that are not ampicillin resistant, as well as colonies that are ampicillin resistant.

QIAGEN Quick-start Protocol for the QIAprep Spin Mini-prep Kit

(available in detail, along with a range of other laboratory protocols, from *QIAGEN* in pdf format)

Notes before starting

- Optional: Add Lyseblue reagent to Buffer P1 at a ratio of 1 to 1000
- Add the provided RNase A solution to Buffer P1, mix and store at 2-8°C
- Add ethanol (96-100%) to Buffer PE before use (see bottle label for volume)
- All centrifugation steps are carried out at 13,000rpm (~17,900 x g) in a conventional table-top micro-centrifuge

1. Pellet 1-5ml bacterial overnight culture by centrifugation at >8000 rpm (6800 x g) for 3 minutes at room temperature (15-25°C)
2. Resuspend pelleted bacterial cells in 250µl Buffer P1 and transfer to a microcentrifuge tube.
3. Add 250µl Buffer P2 and mix thoroughly by inverting the tube 4-6 times until the solution becomes clear. Do not allow the lysis reaction to proceed for more than 5 minutes. If using LyseBlue reagent, the solution will turn blue.
4. Add 350µl Buffer N3 and mix immediately and thoroughly by inverting the tube 4-6 times. If using LyseBlue the solution will turn colourless.
5. Centrifuge for 10 minutes at 13,000 rpm (~17,900 x g) in a table top micro centrifuge
6. Apply the supernatant from step 5 to the QIAprep spin column by decanting or pipetting. Centrifuge for 30-60 seconds and discard the flow-through, or apply vacuum to the manifold to draw the solution through the QIAprep spin column ad switch off the vacuum source.
7. Recommended: Wash the QIAprep spin column by adding 500µl Buffer PB. Centrifuge for 30-60 seconds and discard the flow-through, or apply vacuum to the manifold to draw the solution through the QIAprep spin column and switch off the vacuum source. Note: This step is only required when using

endA+ strains or other bacterial strains with high nuclease activity or carbohydrate content.

8. Wash the QIAprep spin column by adding 750µl Buffer PE. Centrifuge for 30-60 seconds and discard the flow-through, or apply vacuum to the manifold to draw the solution through the QIAprep spin column and switch off the vacuum source. Transfer the QIAprep spin column to the collection tube.
9. Centrifuge for 1 minute to remove residual wash buffer.
10. Place the QIAprep column in a clean 1.5ml micro centrifuge tube. To elute DNA, add 50µl Buffer EB (10mM Tris.Cl, pH 8.5) or water to the centre of the QIAprep spin column, let it stand for 1 minute and centrifuge for 1 minute.

Measuring DNA

A spectrophotometer is used to assess the purity of a sample of DNA once extracted from the source. This is necessary to confirm whether a sample is suitable to send for sequencing. The spectrophotometer measures the absorbance of the molecule of DNA according to a specific wavelength of light from a laser beam, shone directly onto a 1.5 microlitre of DNA in solution. At the Institute of Genetic Medicine, this process is conducted using Thermo Scientific's *NanoDrop* (ThermoFisher Scientific, 2017). The machine holds a single drop of DNA in a column between two metal points and a laser projects through the column, reading the concentration of DNA within the column. The volume of DNA required for measurement is 1.5µl.

1. Switch on the computer and open the *NanoDrop* programme.
2. Wash the *NanoDrop* machine with purified water initially, by placing a 1.5µl drop onto the platform, closing the lever and pressing 'OK' on the application.
3. Clean the machine using the specially provided cloth, both on the upper and lower metal platforms.
4. Run a 'blank' to act as a control for the measurements, by placing a 1.5µl drop of buffer onto the platform, closing the lever and pressing the 'Blank' button. The buffer must be the same as that used to hold the DNA (in our case, this is EB).
5. Place a drop of DNA onto the platform, close the lever, then press 'measure' on the application.
6. The reading should look something like that shown in Fig. 1. The curve should dip initially, then peak at around 260 and drop at around 280. The concentration should be around 3-400 ng (we only achieved around 80 ng in our samples today) and the 260/280 ratio should be around 1.8 - 2.0.

Maxi Prep Process

First begin mini prep to gain 10ml culture overnight

Have 500ml (or 400ml) broth available in large flask from prep room (one floor up)

Pour overnight culture into 500ml flask and place in incubator / shaker first thing in morning, then collect last thing at end of day to catch *E. coli* at top of logarithmic growth phase (with warm cultures growing well, phase will be between 4-6 hours, if not 8-10 hours).

So, for example, come in for 9am, add to flask and incubate until 4-5pm, then place into 10 x 50ml falcon tubes and spin down ready for Maxi Prep process

Can try overnight, but better to do in one day: start at 9am, finish around 6-7pm.

So, two day process:
Day 1 – mini-prep overnight culture
Day 2 – daytime culture followed by maxi-prep

OR, three day process if prepared to let maxi-prep run overnight too.

DNA Agarose Gel Electrophoresis

1. First pour the buffer TAE (Tris base, acetic acid and EDTA) into a flask. The amount required depends upon the size of gel you need to prepare.

2. Determine the concentration of agarose gel you require. For a small DNA fragment, with between 100-1,000 bp, a 2% solution is required. For a larger fragment (1kb-10kb), a 1% solution is required.

3. For a 1% solution, add 1g of agarose powder to 100ml buffer. Rotate the flask to mix well, then heat in the microwave for brief periods, 10-20 seconds at a time, mixing well between heating, to ensure that the agarose is completely dissolved.

4. Cool the agarose solution until it is bearable to hold the bottom of the flask in your hand for 1 minute without it being too hot.

5. Add Safe View reagent (7µl/100ml) to the ***cooled*** liquid agarose (the reagent will be deactivated if you add it whilst the agarose is still very hot). Rotate the flask to mix. Safe View intercalates with the DNA and emits fluorescence.

6. Prepare a tray and comb of the correct size for the amount of gel you have prepared and place in the assemblage tray (made-up term).

7. Pour the liquid agarose into the tray, remove any air bubbles with a pipette tip, and leave to set for around 15 minutes.

8. Once set, remove the comb from the gel by loosening slightly at one side first and then the other, to prevent suction from tearing the gel. Then remove gel tray from the vice by loosening the bolt.

9. Prepare plasmids (or DNA/PCR samples) for the agarose gel by mixing with Orange-G loading buffer (a glycerol and orange dye solution). For our purposes in this experiment, we added:
    - 5µl of loading buffer to 1-2µl of sample (at 50ng concentration)
    - 5µl of glycerol solution to 1µl of plasmid (at 100ng concentration)

10. Place in a tank with TAE

11. Add the prepared plasmids/DNA samples and the necessary control DNA ladder (in our case, 1kb for our 2450bp pEX plasmid):
    - The amount of plasmid used is not relevant, but it may be helpful to keep it consistent for each well. We used around 7µl.
    - Use the tip of the pipette to find the edge of the well and go in at an angle (much like pouring beer without getting a head on it).
    - Only press to first stop and release slowly, remove pipette slowly too, to avoid air bubbles.

12. Hook the tank up to the power source, ensure the +ve and –ve ends are correctly situated, set to 100 volts and run. NB: Voltage can be adjusted slightly to speed up or slow down the process. The standard is 100V, but you could decrease the speed to between 70-80V or increase to as much as 120-140V.

DICTIONARY OF SCIENTIFIC TERMS[vi]

Term	Description
Aliquot	(noun) a portion of a larger whole, especially a sample taken for chemical analysis or other treatment (verb) divide (a whole) into aliquots
Amplification	(noun) *In genetics:* the act of making multiple copies of a sequence of DNA, an increase in the frequency of replication of a DNA segment, inducing replication of a DNA segment through polymerase chain reaction
Anneal	(verb) *In biochemistry:* recombine (DNA) in the double-stranded form
Bacteriophage	(noun) "A bacteriophage (from bacteria and Greek φαγεῖν phagein "to devour") is any one of a number of viruses that infect bacteria. They do this by injecting genetic material [into the] host cell to […] replicate their nucleic acid. The infection may or may not lead to the death of the bacterium." (Rao, 2012)

Term	Description
Clone	(verb) to propagate genetically identical organisms or cells through asexual replication. Commonly carried out in molecular biology to increase quantities of required DNA
DNA	(noun) De-oxyribonucleic acid. DNA or Deoxyribonucleic Acid is a double-stranded molecule that is found within every living cell. It comprises a combination of nucleic acids, sugar and phosphate in a double helix configuration. Genetics commonly refers to the four nucleotide bases present within the structure of DNA: Adenine (A), Cytosine (C), Thymine (T) and Guanine (G). These bases bond together in pairs (Adenine - Thymine and Guanine - Cytosine) thus joining the two strands of DNA (creating the ladder-rung like section) to form the double helix structure. DNA is transcribed (copied) by the cell into RNA, single strands of Ribonucleic Acid, which are then translated by the cell to specify the amino acids that will form proteins, which begin to form the various differentiated elements that comprise a living body.
Elute	(verb) *In analytical and organic chemistry:* extract one material from another by washing with a solvent
Enzyme	(noun) a substance produced by a living organism to act as a catalyst for a specific reaction

Term	Description
Eppendorf tube	(noun) small plastic vial with lid used for safe storage of biological samples. The tube was first created by the company Eppendorf Gerätebau Netheler & Hinz GmbH in 1962 and is commonly known as an 'Eppi'
Hydrolysis	(noun) usually means the cleavage of chemical bonds by the addition of water
In vivo	(adverb and adjective) *Latin*: 'in a living thing' Process (often laboratory experiment) conducted within the body of a living organism
In vitro	(adverb and adjective) *Latin*: 'in glass' Process (often laboratory experiment), generally involving living material but conducted outside of the organism, that is, in a petri dish, test tube or other similar structure. The distinction between in vivo and in vitro is complicated in this thesis through the consideration of the microbiological organism as a living body. Thus, laboratory processes involving the microbiological organism, which are considered to be *in vitro* do not always involve disruption to the body of the organism. In this consideration, the question of the organism's relation to other living bodies is foregrounded.

Term	Description
Ligation	(noun) *In molecular biology:* the covalent linking of two ends of DNA or RNA molecules, most commonly done using DNA ligase, RNA ligase (ATP) or other enzymes
Lysis	(noun) the disintegration of a cell by rupture of the cell wall or membrane
Nucleic acid	(noun) naturally occurring chemical compounds comprised of carbon sugar, a phosphate group and a nitrogenous base, found in all living organisms. DNA and RNA are nucleic acids
Nucleotide	(noun) the organic molecule that forms the base structure of the nucleic acid polymer. Nucleotides consist of a nitrogenous base, a sugar (ribose or deoxyribose) and one to three phosphate groups. The nitrogen base is referred to as either purine or pyramidine depending upon the number of carbon nitrogen rings present and these two base types pair together. The nucleotides found within DNA are Adenine, Guanine (purine bases) and Thymine and Cytosine (pyramidine bases). RNA has Uracil instead of Thymine
Nucleoside	(noun) the name given to nucleotides without the phosphate group

Term	Description
Oligonucleotide	(noun) short strings of DNA or RNA, also known as oligomers, commonly synthesised in the laboratory and routinely used in genetic research
PCR	(noun) Polymerase chain reaction. The synthesis of DNA through melting (a process which separates the two strands of the double helix) and the enzymatic replication of the strands using DNA polymerase
Phage	(noun) short for bacteriophage, a virus which parasitizes a bacterium by infecting it and reproducing inside it. Often used in genetic research
Plasmid	(noun) the plasmid is one of the simplest structures within a living organism. It is described as a circular piece of DNA that floats freely within the body of the bacterial cell, not within the chromosomal DNA of the cell. This means that it is not considered to be a part of the core genetic information within the cell, yet it does contain genetic information and is passed on when the cell replicates. DNA plasmids are found within bacterial DNA and yeast and not within mammalian cells, although in genetic modification, they have been used as mechanisms for delivery of genetic information within mammalian cells.

Term	Description
Polymer	(noun) a large molecule, composed of many repeating sub-units
Polymerase	(noun) an enzyme that synthesizes long chains of nucleic acids
RNA	(noun) Ribonucleic acid. Single stranded nucleic acid present in all living cells. Its principal role is to act as a messenger carrying instructions from DNA for controlling the synthesis of proteins, although in some viruses RNA rather than DNA carries the genetic information
Replication	(noun) *In genetics:* the process by which double stranded DNA makes copies of itself, each strand separates and a complementary strand is synthesized
Transgenic	(adjective) relating to an organism that contains genetic material introduced from another organism. Recent post-humanist discourse suggests that all organisms are transgenic (see interview with Eduardo Kac in Appendix III) and therefore within this thesis, I use the term transgenic to imply the genetic modification of an organism according to human will
Vector	(noun) *In molecular biology:* a vehicle used to transmit genetic material into a cell body. Often a plasmid, virus or phage.

Term	Description
Virus	(noun) 'Viruses are parasites that skirt the boundary between life and inert matter. They have the same kinds of protein and nucleic acid molecules that make up living cells but require the assistance of these cells to replicate and spread. For decades, researchers have argued over whether viruses are alive or not. This conflict has been a distraction from a more important issue: viruses are fundamentally important players in evolution. Huge numbers of viruses are constantly replicating and mutating. This process produces many new genes. An innovative gene, with a useful function, may on occasion be incorporated into the genome of a host cell and become a permanent part of that cell's genome' (Villareal, 2008, p. 102)

[i] See Appendix IV for an example.
[ii] Adsorption is the adhesion of atoms, ions or molecules from a gas, liquid or dissolved solid to a surface.
[iii] It is commonly received wisdom not to refer to bacteria as sentient subjects. The autocorrect facility wants to correct my grammar: my use of "who" in relation to bacteria, to "that", ha! I'm not giving in!
[iv] This idea becomes the basis for the film, Lively Material (Mackenzie, 2017c), to which I add a few other elements of laboratory practice that make it more watchable.
[v] I embrace the concept of the The BioExplorer™ with some trepidation. The BioExplorer™ is designed to enable everyone from school children to DIY-bio hobbyists to make with living material, 'Sounds complicated? No need to worry, with our all-inclusive kits and intuitive instructions, anyone who can mix jello can succeed!' (Amino.bio, 2017).
[vi] Source: The information in this dictionary is a mix of my acquired knowledge from laboratory practice and *Google's* online dictionary facility.

APPENDIX II
A GENETIC STORY: ONE POSSIBLE READING

A GENETIC STORY: ONE POSSIBLE READING

In understanding DNA and the genetic code, I picked through the history and practice of the subject and have provided my brief trace through these below. The narrative history of the discovery of DNA is overshadowed by the race for prestige between the protagonists of the story. This story needs retelling. Here I barely scratch the surface, leaving out (as did the male protagonists of other genetic stories) Lynn Margulis' work on symbiogenesis and Barbara McClintock's work on heredity in maize for example, which are more eloquently captured elsewhere (Keller, 1983; Margulis, 1998). Although outside the scope of this doctoral project, such stories stay with me and influence the research in subtle ways.

DNA

The discovery of DNA is tightly bound to the scientific exploration of inheritance. The story begins with Gregor Mendel's pea plant breeding experiments in the 1860s (Miko, 2008) and quickly shifts to an accidental outcome of bacterial research at the turn of the century. British army surgeon, Frederick Griffith, whilst researching vaccines after the deadly flu epidemic of 1918, discovered that pneumococcal bacterial cells (the strain responsible for the flu) were somehow able to 'transform' other bacterial cells into the same strain (Griffith, 1928). By 1944, Oswald Avery and colleagues Colin MacLeod and Maclyn McCarty, also working on pneumococcal infections, had devised a method of transforming bacteria in vitro (that is, by growing the bacteria in laboratory equipment) rather than in live mice as Griffith had been doing, and as a result, they were able to identify that the specific component responsible for heredity within a cell was DNA (O'Connor, 2008). Prior to this, the commonly held assumption was that proteins would hold the hereditary information, as chemical analyses showed that proteins are more varied. Thus Avery, MacLeod and McClarty's work on transformation has been regarded as marking the beginning of molecular genetics (Lederberg, 1996).

Working together at the Carnegie Institute of Washington in Cold Spring Harbor, New York state, Alfred Hershey and Martha Chase conclusively proved DNA's role in heredity in 1952, through their work on the T2 bacteriophage, a virus that infects the bacterium, Escherichia coli (E. coli). By preparing bacteriophages that contained one of two isotopes, one that attaches to protein only and one that attaches to DNA only, Hershey and Chase were able to trace the path of the isotopes and thus determine that proteins had no function in passing on hereditary information from one generation to the next. Waclaw Szybalski, now Professor Emeritus of Oncology at University of Wisconsin was a working colleague of Chase at the time and recalls being so impressed after Hershey and Chase presented the experiment that "he

invited [her] for dinner and dancing the same evening". In Szybalski's account of that evening he said, "she did not realize what an important piece of work that she did, but I think that I convinced her that evening. Before, she was thinking that she was just an underpaid technician [yet] experimentally, she contributed very much" (Dawson, 2003). Alfred Hershey went on to share the Nobel Prize in 1969 (with Max Delbrück and Salvador Luria) for their "for their discoveries concerning the replication mechanism and the genetic structure of viruses" (Nobel Media, 2014). Avery, often described as cautious, never won a Nobel Prize, although this has been considered as 'a conspicuous omission' (Judson, 2003).

DNA most notoriously comes to our attention in 1953, one year after an X-ray diffraction image (the now notorious Photo 51) was taken by Rosalind Franklin and seen as evidence of a double helix structure. Maurice Wilkins: a student of Franklin's shared this image with James Watson. The following year, Watson and Crick produced their paper on the structure of DNA (Pray, 2008). In 1962, Watson, Crick and Wilkins achieved success for their role in the discovery in the form of the Nobel Prize in 1962. It is unclear whether Franklin would have been included as she died before it was awarded.

In 1971 Jewish Austrian biochemist, Erwin Chargaff began the process of decoding DNA. Chargaff had been compelled to emigrate to the United States in 1935, where at Columbia University, he discovered that regardless of species being studied, the four bases known to exist in DNA (Adenine, Cytosine, Guanine and Thymine) were always found in pairs of equal proportion, that is for every Adenine there was always a Thymine present and for every Guanine there was always a Cytosine present, although he did not develop an understanding of the structure. Offering the first hints at the prevailing perception of DNA, Chargaff said, "Avery gave us the first text of a new language, or rather he showed us where to look for it. I resolved to search for this text." (Pray, 2008).

Shortly after Chargaff's discovery, the United States dropped atomic bombs on Hiroshima and Nagasaki, an event that was forever to be inscribed on Chargaff's mind as the United States displaying the scientific power that he had once fled Nazi Europe in fear of. Positioning himself as an outsider in the world of science, Chargaff became increasingly outspoken on the subject of molecular biology and, perhaps due to his public dissent, was not rewarded with a Nobel Prize for his vital contribution to the discovery of DNA, although he received many other accolades throughout his career (KNAW, 2017).

The Central Dogma

"The Central Dogma. This states that once 'information' has passed into protein it cannot get out again. In more detail, the transfer of information from nucleic acid to nucleic acid, or from nucleic acid to protein may be possible, but transfer from protein to protein, or from protein to nucleic acid is impossible. Information means here the precise determination of sequence, either of bases in the nucleic acid or of amino acid residues in the protein." (Crick, 1958)

The genetic code began from what Francis Crick described in 1958 as the Central Dogma (intentionally and grandiosely capitalised). This framework sets out to explain the flow of biological information within living organisms, as follows:

DNA makes RNA and RNA makes protein

Use of the term dogma was at the time, highly criticised, but perhaps portentous. It was never the case that all information flowed in one direction and therefore this label was never intended as a fact. As a 30-years-wiser Crick acknowledged in his memoirs, although technically, his understanding of the term dogma accurately captures the

notion of belief, it did not help those who were perhaps not aware of his personal opinions on religion.

"Many years later Jacques Monod pointed out to me that I did not appear to understand the correct use of the word dogma, which is a belief *that cannot be doubted*. I did apprehend this in a vague sort of way but since I thought that *all* religious beliefs were without foundation, I used the word the way I myself thought about it, not as most of the world does, and simply applied it to a grand hypothesis that, however plausible, had little direct experimental support." (F. Crick, 1988, italics in original)

The presence and power of Crick's language, casting himself as high priest of science, endured. Crick's phrase became a part of the scientific lexicon and the information-processing approach that he proposed as an idea became the basis of the practice of molecular genetics today, leading to an evolutionary branching in the study of life that disconnects from the living entirely: through fields such as bioinformatics and synthetic biology.

The Genetic Code

"The structure of the genetic code is now fairly well known. The code is a nonoverlapping triplet code. Most, but not all, of the 64 triplets stand for one or another of the 20 amino acids and, in most cases, each amino acid is represented by more than one codon. The best present version of the code is shown in Table 1. This is taken from the 1966 Cold Spring Harbor Symposium on The Genetic Code, to which the reader is referred as a source of references for many of the topics discussed here. Before starting on a detailed examination of this Table a few words of caution are necessary Although the code shown there has been mainly derived from studies on *Escherichia coli* it must be very similar in such widely different organisms as

tobacco plants and man. In what follows I shall assume, for convenience of exposition, that it is identical in all organisms, which is very far from being proved. In fact, it is probably untrue for the starting codons." (Crick, 1968, pp. 367–379)

The genetic code: this well-used metaphor of a translatable language, commonly thought to have been first referred to in these terms by Erwin Schrödinger in 1944[i] was firmly established in the scientific lexicon through the eponymous 1967 book by Carl Woese (Woese, 1967).

After Watson, Crick, Franklin and Wilkins discovered DNA in 1953, theoretical physicist George Gamow set out to understand how the different combinations of nucleic acids could then be translated to form proteins in the body. Correspondence between Watson and Gamow led to the formation of the RNA Tie Club, an exclusive all male group with the aim of understanding how RNA led to the building of proteins. There were 20 members of the group, corresponding to the 20 amino acids that exist within the human body and another four members represented each of the four nucleotides (A, C, U and G) within RNA. Some members of this group achieved great academic success, going on to become Nobel Laureates, although they did not solve the problem that the club set out to tackle. This was eventually achieved by Marshall Nirenberg and Heinrich Matthaei (non-members) in 1961 and the full identification of the genetic code was completed by Har Gobind Khorana in 1968, with Robert Holley identifying the key molecule involved in translating the code into proteins: transfer RNA (tRNA). Khorana, Nirenberg and Holley shared the Nobel Prize for Physiology in 1968.

The last part of this genetic story is the development of the Human Genome Project. Vast bio-databanks, such as the European Bioinformatics Institute in Cambridge, store the growing mass of genomic data currently being captured for all species (and all deficiencies within species) of life on earth (EMBL-EBI, 2017). Through the Human Genome Project and multiple spin off ventures[ii], science attempts to define all living

material at the level of our genetic information, so that we can better understand and use this information to find cures for disease or to create products that will ultimately make our lives easier.

[i] Schrödinger's book, 'What is Life' referenced genetic coding, although some 52 years earlier, Johann Friedrich Mieschner, who discovered nucleic acid, discussed the possibility of a 'chemical code' in letters to his Uncle in 1897 (Olby and Posner, 1967).

[ii] As well as the Human Genome Project, there are projects to map the genome of a variety of animal species, the human microbiome (that is, the microbial life that exists on and within the human body), extinct species of animal and even Neanderthals (Wikipedia, 2017).

APPENDIX III
VIRAL EXPERIMENTS

VIRAL EXPERIMENTS

Viral Experiments is an ongoing research website that follows my activities throughout the doctoral project. It includes the main themes (identified as numbered experiments) that have emerged through the research and gives further details on works produced under each theme. The structure of the website is listed below, with links to the relevant website pages.

APPENDICES

Viral Experiments (http://www.viralexperiments.co)

#1 Viral Poetry (http://www.viralexperiments.co/1)

- Viral Virus, 2015
- Evolution of the Text, 2015
- Ouroboros, 2015
- Genophone, 2016

#2 Microbial Sensing (http://www.viralexperiments.co/2)

- Microbial Sensing (ongoing)
- Infectious Melodies, 2015
- Relational Sensing, 2015
- The Stars Beneath Our Feet, 2015
- Natura naturans, 2015

#3 Curious Animals (http://www.viralexperiments.co/3)

- Unknown Territory, 2015
- Pithos, 2015 (ongoing)
- Genocentric, 2017
- Bio Artefactuality (ongoing)
- Velleity With(out) Volition (ongoing)

#4 Lab Life (http://www.viralexperiments.co/4)

- Untourage, 2016
- Nurtorture Device #1 (ongoing)
- Bioassemblages for Sterilisation (ongoing)
- Memento Perimortem (ongoing)
- Microbes as Materials blog, 2015
- Confess!, 2016

Interviews (http://www.viralexperiments.co/interviews)

Talks/Papers (http://www.viralexperiments.co/papers)

Interviews:

Edited Transcript of Interview with Christian Bök

Edited Transcript of Interview with Eduardo Kac

Notes from Interview with Joe Davis

Interviews with Oron Catts (online only)

Edited Transcript of Interview with Christian Bök
5 February 2015

I'm particularly interested in humanity, our evolution and progress. Our desire to take control of nature and nature's way of re-exerting control over us and the balance and tension that this creates, exploring the agency of microbial organisms when we insert synthetic information within them. I was wondering if you can give me a brief summary of how you came to work this way.

I read an article, several actually, about scientists placing information into the genomes of bacteria with an eye towards securing information against planetary disaster: nuclear war, meteor impact. By putting information into very robust organisms we might be able to reconstitute our cultural heritage by going back and then re-reading the information enciphered in the genome.

I had read an article by astrophysicist, Paul Davies, suggesting that our search for extra-terrestrial life might be misguided if we are looking for a radio beacon, given that it may be much easier and more efficient to insert the information into self-replicating machines that can then adapt themselves to the various environments encountered on an interstellar voyage, sitting and waiting for other creatures to discover them, just like messages in a bottle.

Of course, he suggested that those machines already exist: they could be viruses or organisms on the planet Earth, each used as a repository for information from outer space, information encoded inside their genomes. It's a fun idea for speculation. It could conceivably be put to the test. If you had a complete census of all the organisms on the planet, you could run a computer simulation that might detect whether or not there is a message embedded somewhere in them. Of course, you might then think: why wait and discover such a civilization, when we have the capability to be such a civilization?

Technology was now becoming available to engineer organisms, so I thought poetry should participate on the ground floor of such an activity. Of course, the precedent had been set by Eduardo Kac, in his project to encipher a fragment of the Bible in a colony of *E. coli*. Other scientists have enciphered fragments of text into the genomes of organisms to demonstrate that it is possible to store data in this medium. In my case though, unlike Eduardo's project, I want the organisms to respond to the content of the work that I've implanted in them. If I wanted the organism to enter into a dialogue with me, I'd have to design a text such that the organism would read it and respond to it. It generates a poem in response to a poem that I've implanted into its genome. I managed to get the thing to work properly, according to the constraints of my experiment; I got it to work properly in *E. coli,* the test organism. But the goal is to get it to work in an extremophile bacteria that is capable of surviving all kinds of inhospitable environments, resist genetic drift so that it becomes a very durable repository for artwork. By putting my poem into this bacteria, I could conceivably be writing a book that might outlast the rest of civilization. It could be on planet Earth when the sun explodes. Trying to write a book that effectively endures as a kind of moral artefact, something akin to the Voyager probe or the Pioneer probe. It's honestly just a conceptual exercise. I've gotten as far as engineering the extremophile, but I haven't been able to hit all the benchmarks for success yet.

The extremophile in question, is it a tardigrade?

No, that organism is too complex for me to engineer. I'm engineering an archaic bacteria, called *Deinococcus radiodurans*. It's much like a tardigrade, insofar as it is probably as durable as that organism. It's capable of surviving all kinds of extreme environments: you can scorch it, freeze it, wither it, it doesn't die. It repairs its own DNA so quickly that it doesn't mutate or evolve, but it doesn't have to evolve because it's very well adapted to the lethality of the universe. It can survive in the open vacuum of outer space; it can even survive a dose of gamma radiation high

enough to instantly kill a human being. Because there are no environments on planet Earth with all of these extremes of environmental pressures that might guide an organism to a survivable niche, some scientists speculate that the ancestors of this organism must have spent at least some of its evolutionary history in an extraterrestrial environment. The ancestry of such a terrestrial organism might have blasted off the Earth during a meteor impact, landed on Mars, only to be returned to Earth. These are extravagant speculations of course, but we don't know what it's native habitat is; we don't know where it evolved, since it's found kind of everywhere on the planet: it's found in Antarctica soil and in the dung of Bangladesh elephants.

The challenge of course is that it is a difficult organism to engineer. I've been able to get it to respond to my genetic sequence. I've got it to incorporate the gene sequence into its own chromosome, and it responds: if it's responding properly it actually fluoresces, it glows red. But the cell is destroying the resulting protein or metabolizing it too quickly for us to detect it in its entirety which means that you can't read the poem that it's writing. Which is not very good - akin to faxing a message straight to the shredder.

I'm trying to figure out how to redress the problem: instead of saying that I've created the first unkillable writer, really what I have done is: I've created the first unkillable critic.

I feel that my own work is kind of an opposite, I'm on that critic side – looking at what all of the unpredictable outcomes are. Something I'm really interested in, in relation to your work, is the process. Can you talk a little about the process of encoding and decoding the information?

In my case, I designed a gene sequence that I could generate a correlated amino acid sequence, which enciphers another poem. In many respects the relationship between these two sequences is arbitrary. It took four years to design two poems that would

function according to the biochemical constraints. But characterizing a protein is expensive. If you are thinking of putting something into an organism and then seeing how the outputs change, it's very expensive to characterize a protein, it costs tens of thousands of dollars to do that. But the technologies are changing now, and there are all kinds of new procedures that can assist in doing this kind of project.

If you're going to simulate some random input into an organism by engineering it with random gene sequences, to see what kind of proteins it generates, what they look like, you can do this procedure with a supercomputer but it won't be an accurate simulation.

You can certainly know precisely what the sequence of amino acids are—that's pretty straightforward, that's just bio chemistry, but if you want to characterize a protein, what it will look like, what the structure will be in three dimensions—that's a more difficult task to do. I would certainly be interested in that, characterizing what the resulting poem would look like, as a sculpture, as a physical object.

I saw some images of protein models you have had made in this regard.

Yes

I'm thinking about it in a slightly different way… coding into E. coli and then allowing those E. coli to evolve in a number of ways and then trying to re-translate. The complex issue is finding the needle in the haystack, as it were, to see if anything has changed.

Given your background as a poet, how did you begin to get involved with the science? Were you working with many people? Or on your own?

I had to do the design and creation of all of the experiments myself. I had to do all of the design and problem-solving on my own. The scientists will make things for me, and they will test things for me. They won't do research for me, or any design on my behalf. I have to train myself to do all of the engineering.

My experience has been that you can get a commercial technician or a university scientist to assist you making or testing something, but they won't help you with problem-solving. They may give you advice, but they won't troubleshoot. That's just my experience. Which is fine. Part of the aesthetic exercise for me is that I would become sufficiently expert that I would be able to collaborate effectively with my scientific partners.

With your earlier E. coli experiment, you were able to characterize the protein and have it convey a different poem, can you talk me through how the organism generates the poem?

There's a biochemical correlation between any genetic sequence and its resulting protein sequence. Each codon of a gene has a corresponding amino acid associated with it. Effectively, I have written a poem that emulates such a biochemical relationship. So I try to explain it metaphorically this way: imagine assigning to every letter of the alphabet a complementary letter, it's like a code. If I assign A to T, then I have to assign T to A, if I assign N to D, then I have to assign D to N. There are about 8 trillion different ways of doing that, so you pick one of these 8 trillion ways, out of thin air, I guess—then imagine writing a poem that makes sense and is beautiful, but do so in such a way that if you were to swap every letter with its correlate, it would make a new poem that still makes sense and is still just as beautiful. That's essentially what I've done. It would be like the Sunday section of a newspaper where you might have a cryptogram, giving you a secret message. It looks like gibberish, but through analysis of the letter patterns you can figure out what the assigned letter sequence is supposed to be, and then you can solve the message. I used to wonder, as a kid

when doing those puzzles, why the puzzle maker couldn't give us a meaningful message, that we could then decipher, coming up with another meaningful message, that also makes sense. I know now why they didn't do it, since it's very hard to do, but that's effectively what I've done.

I've been working now for fourteen years on it and the poem took four of those years. The poems are still, in this respect, the hardest part of the project so far. The next most frustrating phase is trying to get the extremophile to obey my will.

Edited Transcript of Interview with Eduardo Kac
10 October 2016

Your work is of great interest to me because of the transgenic art that you have created. One of the biggest things that I have had to deal with working in the laboratory is this sense of life as matter and this sense that I have created something with agency that didn't exist before… I wonder how you feel about that specifically in the works that you have made… on that process of creating with living matter in this way.

It is a fact that working with living matter is distinct from working with inert matter and within living matter there is a gamut, a range, of issues, that go from working with isolated living matter, which by virtue of its isolation is no longer living, because living is contextual right. Living is not an absolute value. DNA by itself is not alive, DNA in the vial is not living, it's not doing anything, it's not metabolizing. But DNA in the context of a cell becomes part of a living thing. So life in that sense is contextual. You can go from that extreme of the spectrum of working with living matter that is not currently living to the other extreme where you have the most complex of all systems, which is the multicellular organism. You could extrapolate and talk about a context made up of many multicellular organisms but then you start calling that a forest or a society, then you are at a different scale, dealing with other sets of issues. Within bioart proper you go from one extreme to another. Somewhere there in the middle, you have the unicellular organism. You have these other cases for example a virus: for some is alive and some is not. They are very philosophically and biologically interesting. You have this middle case of the unicellular organism, which is small and at the lower end of the dynamic living system, but it doesn't exhibit (at least not in a very clear manner) what amounts to one of the most fundamental issues when you are dealing with life, which is consciousness. So bacteria don't exhibit consciousness as we understand it, but they are not inert either and they are not indifferent either and they are not… they don't lack a system that responds to their environment according

to their need. So the question is not so much whether they have consciousness or not but the fact that they are able to somehow understand what is important to them in their environment and communicate that to their fellow bacteria and act accordingly. So they have what is known as an emergent behavior: the hive mind, the collective somehow takes care of business.

So you look at this whole spectrum. It is not all the same, and it is not all the same for several reasons. On this end of the spectrum, when we talk about living material that is not currently living, there is no fundamental issue because if it is living material but it is currently inert, basically all of the previous existing rules and repertoire of emotional responses are in play, it's basically as you see it now as inert matter so there is no fundamental issue. Except of course if that is taken from some body that is unaware of the fact that it was removed from them, if violence was used to obtain it then you are in the realm of ethical behavior of a different kind, perhaps even in the realm of crime. But that would be true also if you make a sculpture by robbing someone on the street and making sculpture with their material, it's not fundamentally different in that sense.

Unicellular organisms it is a bizarre phenomena but society at large has no ethical conundrums when it comes to unicellular organisms, so the issue only really emerges when you move towards multicellular organisms. In regards to that, both artists and audience are not indifferent, intellectually and emotionally because of empathy: it is closer to us and we are able somehow to either see ourselves in that position or somehow we feel that we understand better. It is very hard to understand what it would be like to be a bacteria, it is so far removed from us. But this issue of proximity is more complex than the public realize, for example with my *Natural History of the Enigma*, when I created a flower, we don't think of ourselves as being in any way close to a flower and yet the fact that my DNA is able to be integrated into the cellular machinery and produce a human protein in the body of a flower shows very clearly that yes, we are close and connected to not only a flower but all multicellular

organisms and we are also connected to other non-multicellular organisms but let's kind of try to stay somewhere close.

So you are dealing with your own discoveries, your own understandings but you are also dealing with emotional baggage and a general lack of understanding that still prevails. Biological literacy will increase there is no doubt about that. Suffice to say that if you think about the 50s there were just a handful of computers around the world and they were as big as a house and today children brag about their 16GB iPhone. The vocabulary in 50 years trickled down to society at a level that was unprecedented. So it is to be believed that something along those lines will happen with biology and as people are exposed to the vocabulary and the issues, greater literacy will evolve and as a result at least some level of unawareness will disappear and future audiences will see and understand the kinds of things that artists are talking about today, but in terms of immediate response, precisely because of that empathy and precisely because of the fact that you are literally manipulating life or producing new life, the sense of responsibility is paramount.

What you are saying about biological literacy, is absolutely key. Whilst I want to work in this area to explore these issues, I can't help but feel that I am complicit in making something happen… when you increase the vocabulary, you increase it for a whole range of consequences, right? …that you can't quite have control over. I feel unease and a tension there that I can't quite personally resolve at the moment. Part of me says that it is crucial to reflect in the work. It is part of the connection between artists and audiences in doing this kind of work, but I can't say that I don't find it a challenge to confront. Alba [GFP Bunny] is a key example of that… the myth that evolved around Alba.

The bizarre thing about this is that if there was no censorship from the lab, I doubt that so much writing would have happened. People somehow got interested in the drama of the fact that they didn't let Alba leave as it was originally agreed upon and

that was the… the initial writing was about this conflict. The writing acknowledged the fact that I commissioned the lab to do it and then they interviewed the scientist and then he said that unfortunately he was not allowed to let her leave it was his director who censored the project and the initial writing was all about this conflict and that has subsided but for a while this conflict dominated the headlines but now people just focus on the work itself which as I expected to happen.

This is why the work is fascinating for me, culturally. It shows the way these ideas become a reality. It was always a reality in the lab and then it becomes of cultural significance because of the conflict around the removal from the lab...

I have to interrupt because it was not the reality in the lab. This was what the general public does not understand. This lab was a lab that specialized in transgenic work, obviously, that's why you go to it. This lab did not invent transgenic rabbits because the first transgenic rabbit was created 1985 together with the first transgenic mouse and the first transgenic pig. So, it's not like this lab invented something and I went there and took it, no. This lab was a lab that does transgenic rabbits for a wide array of researchers, they send rabbits to New York, they send rabbits to Berlin and they create what is known as a disease model: they create rabbits with Parkinson's, a rabbit with cancer, a rabbit with some other disease. So I ordered not a diseased rabbit but the rabbit, which expressed GFP ubiquitously.

In that sense, it is part of the dissemination if you like of a particular form of knowledge into a wider public domain and that somehow makes it more acceptable. I feel that because of all of the cultural references now, whether directly to Alba or to green fluorescent animals of various kinds, it becomes a more accepted norm and that fascinates me, you know why shouldn't we have pet green rabbits? Do we really know? It comes back to this idea of the communication within and across cells as to what we are actually doing by making these changes that are generally confined to the lab but at different points do seep out into a wider culture. I am curious as to

how you see that division (or rather, the lack of division) of subject as we start to merge and bring these ideas out of the lab and into the wider public forum.

I think this way of looking at it from the outside is not a perspective which I have, I don't frame the issue in this manner because the idea of bringing issues out and disseminating is something that art has always done. Take for example Cezanne as a painter, so this geometric gaze that he projected upon nature, which was later in a sense purified and further developed by the Cubists was a way of bringing, if you wish, a mathematical way of looking at the world to a wider audience but art is not pedagogy, so art is not seeking to disseminate anything. The work of the artist is a very personal vocabulary that one develops in order to convey one's world view. Likewise you could say that Surrealism by focusing on dream states disseminated the ideas that Freud first developed around 1905 about the relevance of dreams, etc. but Surrealism is not there to disseminate Freud's theories neither is it seeking to do that as a platform of creation and even if you look more closely, at exactly the same time that Freud was writing about dreams, Winsor McCay was creating his amazing, among art experimental, comics with *Little Nemo in Slumberland* in which he also, already, in the realm of art, is exploring a dream state. So, scientists cannot do what they do without images and images were first created by the first artists that ever transformed a plant into a pigment and projected their palm on the cave for painting, or painted animals. So artists have invented tools that scientists use - including the very notion of DNA functioning as a code, which is a metaphor that Schrödinger[i] borrowed from the poets. So I don't really look at it that way at all, I think that whatever the artist touches is an art medium, period: from a pencil, to a molecule, if I use it, it's an art medium, end of story. Now what is it that I am *doing* with this medium, that's where the focus is. Bioart is give or take 20 years old and there isn't really an enormous amount of work… if you look at real bioart, not paintings about genetic modifications, metal sculptures about molecules, none of that stuff, if you look at real bioart there is a fairly limited number of works, but within those works you do have a significant diversity of approaches, ideas and visions and of course it is an

art movement, so there is common ground, there is a sense of shared principles, just as you had in cubism, just as you had in abstract expressionism, but if you look at a Magritte and a Dali they are both surrealist but they are not identical, so they all bring their own issues to bear. So I think that's where the conversation is, what is it that you as an artist offer to this movement: what is your vision, your take, what do you bring that wasn't there before.

For me a part of it is trying to address… to get at a way in which working with life is seen and viewed and understood and whether I can broaden the discussion on what working with life means …I think when you are trained to work with life as a scientist that attention to the liveliness of matter can often be trained out of you. I am thinking about the molecular level where almost all of the work is carried out on computer and the liveliness of the medium is almost overlooked entirely and what I am hoping to consider in my own work is bringing back some of the liveliness at that unicellular level and allowing thought around that kind of hive mentality.

In fact it brings me to another question: I've noticed in a lot of your works an attention to the senses and putting yourself in the place of the other. In a way I want to do this at the unicellular level: to get as deep an understanding as I can of the organism or the hive organism, so I wanted to ask you about the importance of sensation and when you are working to place the audience in a position of having a stronger sense of an other, I wanted to pick up on why that is important to you.

Because we [deal] of the way in which humans think of intrigue, it's predicated on the limit of their experience, that is humans relate to the world based on the way they are. Humans are perfectly able to understand there is something in the world other than themselves and yet they relate to the rest of the living world fundamentally in an anthropocentric mode. That barrier is insurmountable on a physical and mental level, in other words I cannot know what it is like to be you, I can spend my entire life and barely have a sense of what it is like to be myself so it is impossible to know what it is

like to be a dog, but art cannot simulate, but stimulate humans to exercise that perspective, to occupy that point of view. Art can be a context in which understanding that you can't literally do that but culturally, psychologically, emotionally you can exercise that possibility because we do have empathy. How far that can go depends on each person individually but art can do that and that is a very powerful thing. Empathy is not just a mirroring effect it is also a displacement effect that you put yourself in the position of the other and that is why I have worked with telepresence for so long, since 1986, because it was a way to exercise that faculty prior to developing bioart and for a while I created works in which both telepresence and bioart coexisted and then I left, like a rocket that leaves first stage behind, I left telepresence behind and focused on 100% bioart but you see that the issue has always been there for me. So even when the distance seems so great, as in a unicellular organism or a flower, I have looked for ways to accomplish that, so for example with *Genesis*, because we are always looking at the other rarely at ourselves, first you see the bacteria glowing, but because the room is big enough and there are many things happening, eventually your gaze moves away from the glowing bacteria and then you realise that your fellow humans are glowing and then through this ricochet zig zag effect you realize, "oh I'm glowing too" and that telescopes your view back to the bacteria but from a different perspective. It's a subtle, subjective shift in perspective that happens in time within your experience of the piece and you don't even rationalize it, but emotionally you realize there is a connectivity, later you can analyse it and ask yourself why did I respond to this, but initially… the experience of the artwork does not need to involve rationalization and analysis, it can but it doesn't have to. It's equally valid, right. With the flower, whenever possible I like to show the living flower without any 'installational' device, it's just an encounter between two transgenic beings: one that happens to have roots and the other happens to be bipedal, but that's not a requirement, other life forms could be equally interesting and that is because humans are transgenic they just didn't know it.

In the sense that humans have always had other DNA within us? Bacterial DNA for example?

Yes, but we didn't know that until recently. Until the human genome was sequenced we didn't know that. So we always criticize the other for being transgenic, be it in nature or be it in the lab and now that you realize you are transgenic, how are you going to demonise the transgenic? This reversal of gaze: it's very easy to attack what you don't know, but now you cannot unknow what you know. You know you are transgenic now, so, *'Oh, but it's a natural process'*, well to move DNA between organisms whether you are involved or not is a natural process, you can't just put it in there yourself. So, nature has its own mechanisms that allows it to happen whether you are involved or not, '*oh, but well, we shouldn't interfere with nature'* well, then why do you live in the house, there was a tree there before. Where is the scale? Compare a single artist with Monsanto for example, it's ludicrous.

Like you say it is a matter of scale because we are ultimately always working with different levels of respect for the other and I suppose I am trying to look at it from a very reduced scale and think about the questions when you bring it up to a larger scale.

I did want to ask you in a little more detail about Genesis if you have the time. One of the things I have done in my work is encoded a piece of text in E. coli. I am asking a question of the E. coli, I want to allow them to evolve and the answer that they give me will be revealed at some point in the very distant future. It occurs to me in making this work how complex it must have been for you to make Genesis at the time that you did this, and particularly bringing it into a gallery context at that time. How in the gallery were you able to show the translations after mutation under UV light? It is still today a tricky process to work through, timewise, if not in terms of procedures, today.

No, it is exactly what you said, it is not something that you can show in real time. It was exhibited later. The laser etched stones and mutation prints… all of these works that have to do with the translation were produced after the exhibition at *Ars Electronica*[ii]. You can't show that in real time it is not possible.

It is somewhere in the literature?

It is not that it is explicitly stated because I guess to me it is so obvious that it is an impossibility. It is like saying that a painting is flat, in a sense it is a given. Who knows one day it might become possible, but it is certainly not possible today and certainly was not possible at the time. Buck Strome[iii] who was the scientist on the project, he did the extraction and the analysis at the time, the sequencing.

In some ways, for a lot of the lay public and for me in first encountering the work, you don't necessarily understand that and the work has a certain magic about it for that reason. Online, you get to experience this sense of something that can be changed by shining light and a result can occur and the act that you can see all of those stages which did occur over a time period but you can see all of them happening in sequence in a documented sense adds somehow to that accelerated understanding of that process.

Perhaps it's useful to clarify that the mutation does occur in real time in the gallery. Every time you click and you turn the UV on, you're causing mutation and the bacteria glow when you click and you turn the UV light on, so you can see that they are responding, so the mutation does occur in real time and there is visual feedback that that is happening. All of that is true and it is in real time, and it has been exhibited all over the world, more than 40 times. It's just that the sequencing that converts the code back has to be done later. The mutation is real time and you can see it, that it is happening because the bacteria are glowing which means they are responding to the

UV. So it is not inaccurate to say that it is happening in real time and there is a visual feedback that allows you to see that.

It's our understanding of the change that takes the time.

It's a micro-level of understanding of the vocabulary.

Which isn't necessary for the audience.

No, it is not for the general audience because… just take any painting and consider how many books, words have been written. Rothko for example created so many layers with his varnish and the oils, etc. If you are going to analyse all this, that is for the art historian or a conservator, or a student of art history, etc. but for an audience you don't need all of that vocabulary, analysis, explanation, otherwise you are in the realm of didactics, not in the realm of art experience.

Notes from Interview with Joe Davis
8 Dec 2015

(Brief notes taken during meeting only, due to audio recording failure).

Re. Audio Microscope: Microbiological samples in liquid medium were held on non-reflective microscope slides and placed under a microscope where two lasers at precise angles were directed at the samples. Used two lasers Helium Neon lasers and photovoltaic cell (solar cell) and standard optical microscope. Also, a concave thick microscope slide that was coated with a reflective surface underneath: silver, gold or mylar. Then hooked this up to a pre-amp and then an equalizer and also put it through a spectrum analyser so that he was able to detect the specific pattern of different species, according to their cilia.

(Joe kindly offered to share video footage of the paramecium sounds with me.)

Spoke about how different colours pick up different frequencies and that there are many frequencies that we don't hear at all. Radio frequencies, so that processes such as transcription and translation that occur within a cell probably occur at radio frequencies. Boeing etc. interested in the technology and lots have been used since for 'dark' science.

Also, radiation causes pigmentation but we don't really know why. So, cells change colour when exposed to radiation. E.g. the ones at Chernobyl that survived were pigmented.

(We digressed into a conversation about 'nature' that I wish was recorded. All I have captured is the following):

'Art is opposed to nature it says in the dictionary'. I raise the question of responsibility over how humanity uses natural resources. Joe used the analogy of taking matches into a gas station. All of us do it but we don't ever take them out, light the gas and blow up the station. We have a basic faith in humanity. I suggested that this concept of faith therefore paradoxically sets us apart from (yet at the same time we are a part of) nature.

Interviews with Oron Catts

Oron was generous enough to grant me two in-depth interviews which are referenced at points during this thesis and which I intend to publish online in edited form beyond the scope of this research.

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[i] Nobel Prize winning physicist, Erwin Schrödinger (1887–1961)
[ii] *Genesis* was first shown at Ars Electronica in 1999 (Kac, 1999)
[iii] Biochemical and molecular geneticist, Charles Strome (see Gena & Strom, 1995)

APPENDIX IV
CODING & SEQUENCING DNA

CODING & SEQUENCING DNA

The following notes are excerpts from my lab diary that describe the development of a cypher for encoding a thought within the laboratory organism, *E. coli* and the sequencing of DNA containing the encoded thought. These have been separated from Appendix I, Lab Diary, to focus on the specific background work undertaken to develop the cypher and the resulting work to sequence the DNA in attempts to reveal changes to the thought stored within.

Dec 2014 / Jan 2015 - Initial Discussions

Translation/Coding with DNA

Any code is arbitrary, there is no standard because there is no logical correlate between the biological base pairs or codons and binary.

A codon will encode 0-63, so we could encode ASCii characters, but the mapping will be pre-determined according to the criteria we define.

Where to put the DNA?

Option 1 – Plasmid
Extra-chromosomal, replicates autonomously within the bacteria. Can keep selection for the plasmid by antibiotic resistance, as many plasmids have antibiotic resistance to, e.g. ampicillin, so you can grow up large colonies and can guarantee that all of your cells have that plasmid. Can then choose to mutagenize this.

Plasmids are based on antibiotic resistance. It was found that antibiotic resistance was spreading horizontally in populations (i.e. without evolution) and that this resistance was carried on circular pieces of DNA that sit outside of the genome. Was first discovered via naturally occurring antibiotics, which bacteria secrete to kill other bacteria, e.g. colistin.

Option 2 – Incorporate into bacterial genome
Plasmids become viruses higher up evolutionary chain.
Selection for evolved DNA will be an issue: could potentially use PBR322, blue script or bacteriophage, need to research and consider which option might be best. Different organisms select specific codons for proteins depending upon their

frequency, and use them in different ways. Translation of DNA into the synthetic/binary form is arbitrary so perhaps the problem is this: we need to find a method other than binary, a more natural system (e.g. language), perhaps we should stop trying to 'process' the system.

Timings:

Approx. 1 week to synthesise the necessary oligonucleotide

Approx. 1 week to grow plasmids

Time for evolution/mutagen and observation/retranslation? Indefinite!

Lab Diary, 23 June 2015 - Meeting to plan work on 'Thought for Insertion'

Can split the sequence in two to create separate synthetic oligos[i] at reasonable cost, but can also sequence up to 1000 base pairs (bps) for £134.

Can sequence a double or a single strand.

Options for mutating synthetic sequence within *E. coli*:

1. Nutritional selection
2. Antibiotic selection
3. Phage lysogenic/lytic selection (put plasmid in lytic phase gene, C1)

Nutritional selection would work with yeast or bacteria: select for something that they naturally require

Anti-biotic selection: by placing the sequence within an anti-biotic resistant gene, you can know that your synthetic information is selected as it will grow within that anti-biotic whereas another will not. Then you select for another anti-biotic to develop a further resistance.

Sadly, to my disappointment, given that I am drawn to working with the form of the phage, A has advised me that phage resistance is not right for this lab. It would take too long / cost too much.

Actions:

Revise phoneme mapping based on conversation.

Consider removing stop codons

Re-work phoneme phrase.

Consider 'framing' of sentence. Do we place it in an open reading frame, so that the bacteria can 'read' the amino acids? Or do we place it 'off-frame' so that the bacteria cannot read it as amino acids?

APPENDICES

Laboratory Methodology:

Two experiments have been devised:

1) Random mutation

Once sequenced and transformed, the *E. coli* containing the synthetic 'thought' are allowed to grow and evolve over a period of time and are occasionally sequenced to determine if any random mutation has occurred.

2) Selective mutation

Antibiotic selection will be used to enable mutation. We will sequence a 'thought' within a plasmid and we will then engineer the sequence to be inserted within a second plasmid (pBR322). The synthesised plasmid is resistant to ampicillin, pBR322 also contains a second antibiotic, tetracycline. Therefore in order for uptake of the 'thought' to be successful, the plasmid must develop resistance to both. If the 'thought' is engineered to disrupt one of the two antibiotic resistant genes, it must therefore have adapted in order to develop resistance again. This is selective mutation.

I am less drawn to working in this second way, as I want to minimize my level of imposition upon the organism.

The proceeding information details the groundwork for both experiments.

Development of Synthetic DNA

The nucleotide bases that form the A, C, T and G of DNA are 'read' by cell machinery in groups of three, called 'codons'. There are therefore 64 possible combinations of codons (four to the power of three, 4^3). Each of the 20 naturally occurring amino acids

is represented by between 1 and 6 codons, within a total of 64 possible codon combinations.

In order to create the string of DNA nucleotides for insertion within *E. coli*, the creation of the synthetic DNA sequence was outsourced to a commercial laboratory (Eurofins, 2017) and provided as a plasmid.

Lab Diary, 10 July 2015 - Preparing Dilutions of Plasmids

In preparation for the phoneme experiment, we designed a gene of 144 base pairs and sent this to the commercial lab for synthesis (see Figure 73).

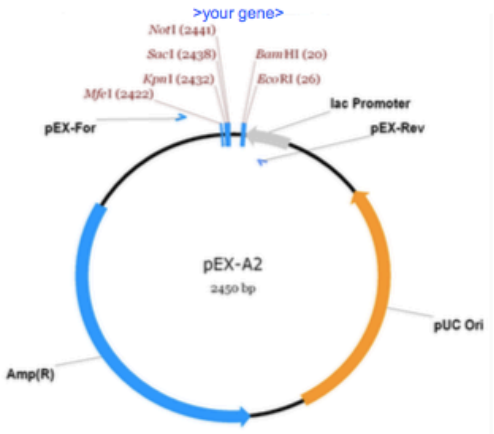
Gene Synthesis Quality Assurance Documentation

Order No.: **3645523/Topf,Ana**

OI33156362

Plasmid Name:	pEX-A2-MacKenzie	**Internal Name:**	OM83-2
Gene Name:	MacKenzie	**Gene Size:**	144bp
Vector Backbone:	pEX-A2	**Antibiotic Selection:**	Ampicillin
Cloning:	via Type IIS restriction enzymes	**Quantity:**	3.0µg

Plasmid Map



5' Restriction Site: BamHI
3' Restriction Site: BamHI
Cloning: via Type IIS restriction enzymes
(Type IIS sites not present in final plasmid)

MCS of pEX-A2

GGAGCAGACAAGCCCGTCAGGGCGCGTCAGCGGGTGTTGGCGGGTGTCGGGGC
TGGCTTAACTATGCGGCATCAGAGCAGATTGTACTGAGAGTGCACcaattgGG
TACCgagctcGCGGCCGCAAGC>your_gene>ACCTGCTTTTGCTCGCTTgg
atccGAATTCCTGTGTGAAATTGTTATCCGCTCACAATTCCACACAACATACG
AGCCGGAAGCATAAAGTGTAAAGCCTG

Figure 73: Gene Synthesis Quality Assurance Documentation for my thought-as-DNA. Process documentation.

We therefore began the experiment with the following plasmid resources:

- 3.0µg of lyophilised[ii] plasmid pEX-A2-Mackenzie[iii]
- 10µg of pBR322 in a 1mg/ml solution

In order to transform the plasmids, they require to be diluted to around 50ng/µl. Given the volumes of plasmid provided therefore, the following calculations and preparations were made:

pEX-A2-Mackenzie

- Add 30µl of filtered water (H_2O) or TE buffer[iv] giving 100ng/µl in solution
- Prepare an eppendorf tube with 5µl of plasmid solution and 5µl of filtered H_2O, giving a 1:2 dilution and therefore 50ng/µl

pBR322

- Prepare an eppendorf tube with 1µl of pBR322 and add 19µl of filtered H_2O, giving a 1:20 dilution and therefore 50ng/µl

Lab Diary, 17 August 2015 – Procedure for Random Mutation Experiment

Time – 1 hr approx.

Procedure began on 17.8.15, therefore:

Day 1 = 17.8.15

Day 2 = 18.8.15

Day 3 = 19.8.15… etc.

1. In the clone room, under the hood, prepare 10 universal tubes, each with 10ml LB and 10µl ampicillin.
2. Number each tube and label each tube with today's date and the words: Day N (look in the incubator/shaker to check the Day number of the tubes inside, N represents the next number in sequence) and pEX.
3. Remove 10 universal tubes from the incubator/shaker (with yesterday's date on them).
4. Place 1µl from Tube 1 (yesterday's date) into Tube 1 (today's date).
5. Repeat for all 10 tubes.
6. Spin down yesterday's tubes in the centrifuge for 15 minutes.
7. Prepare 10 eppendorf tubes by numbering them, labeling them with yesterday's date, yesterday's Day number, and the word pEX.
8. Pour off excess LB into bacterial waste bottle.
9. Place about 9ml LB in a universal tube.
10. Pipette 800µl of LB into the pellet of Tube 1 and suck up and down to mix, then place contents in the eppendorf tube, numbered 1.
11. Repeat process for all 10 tubes.
12. Spin down eppendorfs for 3 minutes at 13rpm.
13. Remove excess LB and discard.
14. Freeze eppendorfs in container marked 'Mackenzie'.

Lab Diary, 30 August 2015 - Batch 10 of Random Mutation Experiment

Mini-prepped and ready for sequencing.

Sample Number	ng/µl	260/280
pEX1	152.2	1.88
pEX2	225.8	1.89
pEX3	266.4	1.88
pEX4	199.8	1.88
pEX5	121.3	1.89
pEX6	37.4	2.02
pEX7	245.9	1.89
pEX8	183.9	1.90
pEX9	95.0	1.95
pEX10	112.7	1.92

Table 1: pEX-Mackenzie plasmid mini-preps, nanograms of DNA per microlitre and spectrophotometer assessment of DNA purity. Research documentation, 2015.

Lab Diary, 04 September 2015 – Sequencing Batch 10

The samples have been returned. The DNA from 10 samples was sequenced and no change was identified. The 'thought' is safe within still (see Figure 74 as an example).

In different sample sequences, I had to start reading the 'thought' from a different point (see below). As I am not familiar with reading such samples, had hoped that this might mean something, for example that the reading frame has shifted, however it is simply a relational marker and not indicative of a change in reading frame.

FR08971877 - the 'thought' begins at 96
FR08971875, FR08971876, FR08971878 - the 'thought' begins at 98

FR08971871, FR08971872, FR08971874, FR08971880 - the 'thought' begins at 99
FR08971873 - the 'thought' begins at 100
FR08971879 - the 'thought' begins at 102

B and I have decided to run another 10 days of culture growth and sequence again. After this point we will stop, break whilst I work on the sonification and audification of micro-algae for the *Lumiere* commission, and then return to run a further set of experiments later in November.

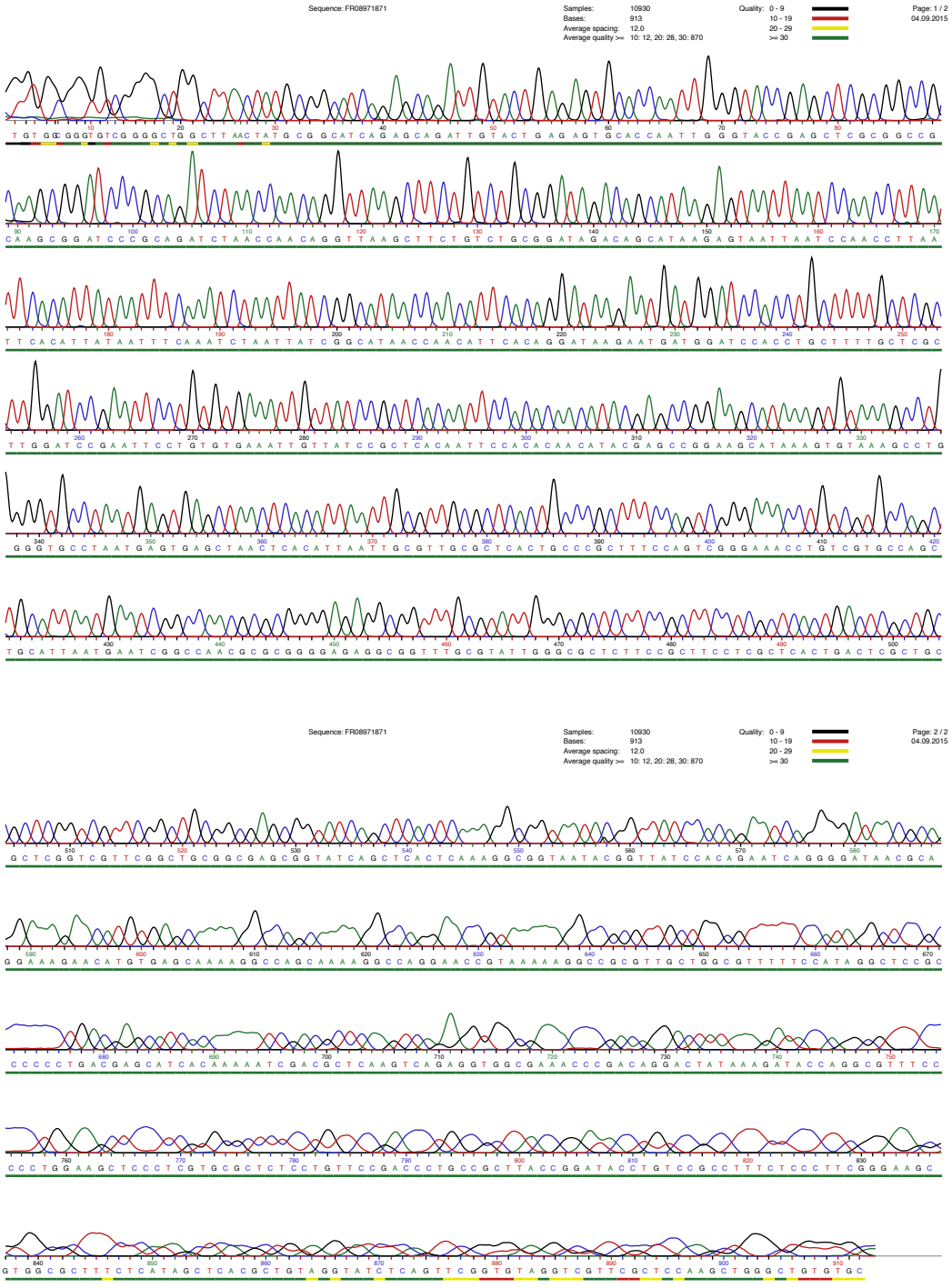


Figure 74: *Sequence FR08971871*. Research documentation, 2015. Image: Louise Mackenzie

[i] The abbreviated lab-speak version of *oligonucleotides*: short strings of DNA (or RNA) synthesized for use in genetic research.

[ii] A term used in reference to biological material that has been freeze-dried in a vacuum. The process extracts moisture without altering the physical substance of the material.

[iii] The name, *Mackenzie*, was given by Scientist A when requesting the plasmid sequence from the commercial genetic laboratory, *Mackenzie* thus becomes the gene name, the prefix *pEX-A2*, was assigned by the company to designate the 'vector backbone' of the plasmid. Knowing the above information in hindsight, I can now consider the nomenclature carefully prior to further experiments.

[iv] TE buffer is a commonly used buffer solution in molecular biology, especially in procedures involving DNA, cDNA or RNA. "TE" is derived from its components: Tris, a common pH buffer, and EDTA, a molecule that chelates cations like Mg^{2+}. The purpose of TE buffer is to solubilize DNA or RNA, while protecting it from degradation. Source: Wikipedia

APPENDIX V
IMAGE-MUSIC-TEXT

IMAGE-MUSIC-TEXT

The reference to Roland Barthes seems obvious now, it didn't initially[i]. Barthes structural semiotic approach has ultimately proved helpful within the context of reductive scientific approaches to lively material, in navigating the ill-mapped territory of DNA and the genetic code, by diffracted readings of denotative and connotative mapping strategies. The relation between DNA and denotative/connotative language is an area identified for further post-doctoral research.

In this Appendix, practical mapping strategies from DNA to image, music and text are illustrated. After initially exploring possible methods (see Section 4.4 of Thesis), attempts were made to map according to defined features of the amino acids[ii], so that some notion of parity could be ascertained. After a few failed attempts, it became apparent that it would prove equally productive to map the codons according to how fabulous they are (this heterotopic classification is of course borrowed from Michel Foucault and Jorges Luis Borges in turn (Borges, 1993; Foucault, 2005, p. xvi)). In the end, I managed to convince my scientific collaborator to heretically describe the characteristics of amino acids in more anthropomorphic terminology.

Amino Acid	Description
Proline	unique in that the amine nitrogen is bound to not one but two alkyl groups
Proline	unique in that the amine nitrogen is bound to not one but two alkyl groups
Proline	unique in that the amine nitrogen is bound to not one but two alkyl groups
Proline	unique in that the amine nitrogen is bound to not one but two alkyl groups
Cysteine	sulhpur containing amino acid occuring in animal proteins such as hair, hooves and keratin, it is a catalytic element in some enzymes
Cysteine	sulhpur containing amino acid occuring in animal proteins such as hair, hooves and keratin, it is a catalytic element in some enzymes
Tyrosine	not normally an essential aa in humans, as it can be synthesised from phenylalanine, found in small amounts in most proteins, particularly insulin and pain (found in papaya fruit)
Tyrosine	not normally an essential aa in humans, as it can be synthesised from phenylalanine, found in small amounts in most proteins, particularly insulin and pain (found in papaya fruit)
Serine	as with threonine, bears an alcohol group, first obtained from silk protein, may also be naturally produced when UV light illuminates simple ices
Serine	first obtained from silk protein, may also be naturally produced when UV light illuminates simple ices, suggesting that it may be easily produced in cold regions of space
Serine	first obtained from silk protein, may also be naturally produced when UV light illuminates simple ices, suggesting that it may be easily produced in cold regions of space
Serine	first obtained from silk protein, may also be naturally produced when UV light illuminates simple ices, suggesting that it may be easily produced in cold regions of space
Serine	first obtained from silk protein, may also be naturally produced when UV light illuminates simple ices, suggesting that it may be easily produced in cold regions of space
Serine	first obtained from silk protein, may also be naturally produced when UV light illuminates simple ices, suggesting that it may be easily produced in cold regions of space
Threonine	as with serine, bears an alcohol group and like isoleucine, has a chiral side chain
Threonine	as with serine, bears an alcohol group and like isoleucine, has a chiral side chain
Threonine	as with serine, bears an alcohol group and like isoleucine, has a chiral side chain
Threonine	as with serine, bears an alcohol group and like isoleucine, has a chiral side chain
Glutamine	colourless, soluble
Glutamine	colourless, soluble
Asparagine	crystalline, occurs in proteins, 1st to be discovered, widely distributed in plants (all legumes) and seeds
Asparagine	crystalline, occurs in proteins, 1st to be discovered, widely distributed in plants (all legumes) and seeds
Glutamic Acid	colourless, increases solubility of associated proteins, helps to remove toxic ammonia from the body
Glutamic Acid	colourless, increases solubility of associated proteins, helps to remove toxic ammonia from the body

Figure 75: Sample from amino acid descriptions. Excel. Research documentation, 2015. Image: Louise Mackenzie.

APPENDICES

Codons	Amino acids	Letter	Implied Characteristics	Hydrophobicity	Essential	Polarity/Acid/Base
G G U	Glycine	G	Introv.	in between		Neutral, non-polar
G G C	Glycine	G	Introv.	in between		Neutral, non-polar
G G A	Glycine	G	Introv.	in between		Neutral, non-polar
G G G	Glycine	G	Introv.	in between		Neutral, non-polar
C C U	Proline	P	Flexible / Introv.	in between		Neutral, non-polar
C C C	Proline	P	Flexible / Introv.	in between		Neutral, non-polar
C C A	Proline	P	Flexible / Introv.	in between		Neutral, non-polar
C C G	Proline	P	Flexible / Introv.	in between		Neutral, non-polar
U G U	Cysteine	C	Manic	Hydrophobic		Neutral, polar
U G C	Cysteine	C	Manic	Hydrophobic		Neutral, polar
U A U	Tyrosine	Y	Extrov.	Hydrophobic		Neutral, polar
U A C	Tyrosine	Y	Extrov.	Hydrophobic		Neutral, polar
U C U	Serine	S	Extrov. / Signal	in between		Neutral, polar
U C C	Serine	S	Extrov. / Signal	in between		Neutral, polar
U C A	Serine	S	Extrov. / Signal	in between		Neutral, polar
U C G	Serine	S	Extrov. / Signal	in between		Neutral, polar
A G U	Serine	S	Extrov. / Signal	in between		Neutral, polar
A G C	Serine	S	Extrov. / Signal	in between		Neutral, polar
A C U	Threonine	T	Extrov. / Signal	in between	essential	Neutral, polar
A C C	Threonine	T	Extrov. / Signal	in between	essential	Neutral, polar
A C A	Threonine	T	Extrov. / Signal	in between	essential	Neutral, polar
A C G	Threonine	T	Extrov. / Signal	in between	essential	Neutral, polar
C A A	Glutamine	Q	Extrov.	Hydrophilic		Neutral, polar
C A G	Glutamine	Q	Extrov.	Hydrophilic		Neutral, polar
A A U	Asparagine	N	Extrov.?	Hydrophilic		Neutral, polar
A A C	Asparagine	N	Extrov.?	Hydrophilic		Neutral, polar
G A A	Glutamic Acid	E	Signal?	Hydrophilic		Negative, Acidic
G A G	Glutamic Acid	E	Signal?	Hydrophilic		Negative, Acidic
G A U	Aspartic Acid	D	Signal	Hydrophilic		Negative, Acidic
G A C	Aspartic Acid	D	Signal	Hydrophilic		Negative, Acidic
A A A	Lysine	K	Gregarious?	Hydrophilic	essential	Positive, Basic
A A G	Lysine	K	Gregarious?	Hydrophilic	essential	Positive, Basic
C A U	Histidine	H	Gregarious?	Hydrophilic	essential	Positive, Basic
C A C	Histidine	H	Gregarious?	Hydrophilic	essential	Positive, Basic

Figure 76: Sample from properties of amino acids. Excel. Research documentation, 2015. Image: Louise Mackenzie.

From: Louise Mackenzie
Sent: 12 March 2015 15:47
To: Steven Laval
Subject: Question re amino acid characteristics

Dear Steve,

Hope you're well. I have another, perhaps slightly odd, question for you...

I know that amino acids are grouped into their various properties and I am trying to get to grips with their various characteristics, but would you say that certain amino acids 'behave' in particular kinds of ways?

For example, I am thinking about Glycine as being the 'most flexible' of the amino acids and Methionine as a 'starter'. Are there any other ways in which you might define particular amino acids, other than their properties? I suppose I am looking for more personal (I hesitate to say 'anthropomorphic') characteristics!

Best,
Louise

Good question. As you know, scientists resist anthropomorphism, although generally unsuccessfully!

Proline is very flexible, and often forms hinges in proteins.

Hyrophobic stretches (long runs of Gly, Ala, Val, Leu, Ile, Pro, Phe and Met) either bury themselves in membranes to form "anchors" or hide in the middle of proteins. I guess they would be introverted.

The opposite is the extroverted amino acids with polar side-chains (Ser, Thr, Cys, Gln and Tyr) which reject membranes and gravitate to the outside of proteins. These side chains are also more "active", generally forming the active sites of enzymes and coordinating co-factors such as metal ions.

Cysteine is particularly sociable, forming disulphide bonds with other, more distant cysteine residues which stabilises the protein tertiary and quarternery structure. Unpaired cysteines are "lonely" and can cause major problems for a protein by forming inappropriate bonds.

Hydroxyl side-chains (Ser, Thr, Asp) are communicative, functioning as signals like holding a flag.

I hope that helps. Please understand how heretical this would be to the majority of my colleagues!

All the best.

Steve

Excellent answer! Making me smile in The Hague, thank you for your heresy.

Louise

Figure 77: Email correspondence between Louise Mackenzie and Dr Steven Laval on the characteristics of amino acids. Research documentation, 2015. Image: Louise Mackenzie

6 bit Gray Code	Codons	Abbrev.	Amino acids	Characteristics	Hexadecimal Colours	Piano key number	Musical Scales English notation	Frequency Hz
0 0 0 0 0 0	U U U	F	Phenylalanine	Introv.	003333	88	C8 - Last tone	4186.01
0 0 0 0 0 1	U U C	F	Phenylalanine	Introv.	006666	87	B7	3951.07
0 0 0 0 1 1	U U A	L	Leucine	Introv.	009999		A7/B7	3729.31
0 0 0 0 1 0	U U G	L	Leucine	Introv.	00CCCC	85	A7	3520.00
0 0 0 1 1 0	C U U	L	Leucine	Introv.	00FFFF		G7/A7	3322.44
0 0 0 1 1 1	C U C	L	Leucine	Introv.	33FFFF	83	G7	3135.96
0 0 0 1 0 1	C U A	L	Leucine	Introv.	66FFFF		F7/G7	2959.96
0 0 0 1 0 0	C U G	L	Leucine	Introv.	99FFFF	81	F7	2793.83
0 0 1 1 0 0	A U U	I	Isoleucine	Introv.	CCCCFF	80	E7	2637.02
0 0 1 1 0 1	A U C	I	Isoleucine	Introv.	9999FF		D7/E7	2489.02
0 0 1 1 1 1	A U A	I	Isoleucine	Introv.	6666FF	78	D7	2349.32
0 0 1 1 1 0	A U G	M	Methionine / START	Introv.	FFFFFF		C7/D7	2217.46
0 0 1 0 1 0	G U U	V	Valine	Introv.	3333FF	76	C7	2093.00
0 0 1 0 1 1	G U C	V	Valine	Introv.	0000FF	75	B6	1975.53
0 0 1 0 0 1	G U A	V	Valine	Introv.	0000CC		A6/B6	1864.66
0 0 1 0 0 0	G U G	V	Valine	Introv.	000099	73	A6	1760.00
0 1 1 0 0 0	U C U	S	Serine	Extrov. / Signal	330000		G6/A6	1661.22
0 1 1 0 0 1	U C C	S	Serine	Extrov. / Signal	660000	71	G6	1567.98
0 1 1 0 1 1	U C A	S	Serine	Extrov. / Signal	990000	70	F6/G6	1479.98
0 1 1 0 1 0	U C G	S	Serine	Extrov. / Signal	CC0000	69	F6	1396.91
0 1 1 1 1 0	A G U	S	Serine	Extrov. / Signal	FF0000	68	E6	1318.51
0 1 1 1 1 1	A G C	S	Serine	Extrov. / Signal	FF3333		D6/E6	1244.51
0 1 1 1 0 1	C C U	P	Proline	Flexible / Introv.	FFFF00	66	D6	1174.66
0 1 1 1 0 0	C C C	P	Proline	Flexible / Introv.	FFFF33		C6/D6	1108.73
0 1 0 1 0 0	C C A	P	Proline	Flexible / Introv.	FFFF66	64	C6 (high C)	1046.50
0 1 0 1 0 1	C C G	P	Proline	Flexible / Introv.	FFFF99	63	B5	987.767
0 1 0 1 1 1	A C U	T	Threonine	Extrov. / Signal	FFCC00		A5/B5	932.328
0 1 0 1 1 0	A C C	T	Threonine	Extrov. / Signal	FF9900	61	A5	880.000
0 1 0 0 1 0	A C A	T	Threonine	Extrov. / Signal	FF6600		G5/A5	830.609
0 1 0 0 1 1	A C G	T	Threonine	Extrov. / Signal	FF3300	59	G5	783.991
0 1 0 0 0 1	G C U	A	Alanine	Introv.	330033		F5/G5	739.989
0 1 0 0 0 0	G C C	A	Alanine	Introv.	660066	57	F5	698.456

Figure 78: Sample from table of potential mappings of codons to image, colour and musical notation, based on implied characteristics of amino acids. Excel. Research documentation, 2015. Image: Louise Mackenzie

Amino acids		Instrument/Timbre	Musical Scales Frequency	English	Rationale
Valine	V	Trombone	82.407	E2	Part of a large structural family (wind) with a range of instruments increasing in size (brass)
Valine	V	Trombone	103.826	G# / Ab2	Part of a large structural family (wind) with a range of instruments increasing in size (brass)
Valine	V	Trombone	110.000	A2	Part of a large structural family (wind) with a range of instruments increasing in size (brass)
Valine	V	Trombone	123.471	B2	Part of a large structural family (wind) with a range of instruments increasing in size (brass)
Tryptophan	W	Bassoon	61.735	B1	Part of the Aromatics, stems from alanine root, part of three that absorb UV so 'sunny' somehow (woodwind)
Alanine	A	Flute	261.626	C4	Part of a large family: can be substituted in many other Aas, so common wind instrument
Alanine	A	Flute	293.665	D4	Part of a large family: can be substituted in many other Aas, so common wind instrument
Alanine	A	Flute	349.228	F4	Part of a large family: can be substituted in many other Aas, so common wind instrument
Alanine	A	Flute	391.995	G4	Part of a large family: can be substituted in many other Aas, so common wind instrument
Cysteine	C	Alto Saxophone	146.832	D3	Sulphurous (wind) and also slightly special
Cysteine	C	Alto Saxophone	220	A3	Sulphurous (wind) and also slightly special
Tyrosine	Y	Oboe	246.942	B3	Part of the Aromatics, stems from alanine root, part of three that absorb UV so 'sunny' somehow (woodwind)
Tyrosine	Y	Oboe	369.994	F# / Gb4	Part of the Aromatics, stems from alanine root, part of three that absorb UV so 'sunny' somehow (woodwind)
Glycine	G	Piano	27.5	A0	Most common, flexible, an instrument used a lot
Glycine	G	Piano	34.648	C# / Db1	Most common, flexible, an instrument used a lot
Glycine	G	Piano	36.708	D1	Most common, flexible, an instrument used a lot
Glycine	G	Piano	41.203	E1	Most common, flexible, an instrument used a lot
Proline	P	Guitar	82.407	E2	The most flexible, a different type of instrument, also used a lot
Proline	P	Guitar	103.826	G# / Ab2	The most flexible, a different type of instrument, also used a lot
Proline	P	Guitar	110	A2	The most flexible, a different type of instrument, also used a lot
Proline	P	Guitar	123.471	B	The most flexible, a different type of instrument, also used a lot

Figure 79: Sample from table of amino acids as musical instruments. Excel. Research documentation, 2015. Image: Louise Mackenzie.

AMINO ACID	CODONS	PHONEME	PHONETIC SOUND
Aspartic Acid	G A U	/aʊ/	**ou**t, n**ow**, cac**ao**, mi**aow**, mi**aowe**d, g**au**ss, b**ough**, pl**oughe**d, v**owe**d, Macl**eo**d
Aspartic Acid	G A C	/ɔɪ/	av**oi**d, t**oy**, l**awy**er, Fr**eu**dian, ch**oll**a, enj**oye**d, b**uoy**ant, b**uoye**d
Lysine	A A A	ɢ	Glottal (g at back of throat, a gulping, glugging sound)
Lysine	A A G	ɤ	Eugh (the sound a child makes when s/he doesn't like something)
Histidine	C A U	|	Tszk (tut-tut or tsk-tsk type noice)
Histidine	C A C	Hm	Hmmm (a nasal mmm, with a breath in front)
Arginine	C G U	B	Brr (rolling of the lips)
Arginine	C G C	H	Hhr (think French r, rolling at back of throat)
Arginine	C G A	ʋ	Vw (revoir)
Arginine	C G G	ɲ	Ny (onion)
Arginine	A G A	ʄ	Dy (would'ya)
Arginine	A G G	ʯ	Ly (will'ya)
STOP	U A A	/uh/	(short intake of breath)
STOP	U A G	/uhh/	(long intake of breath)
STOP	U G A	/1	(pause 1 sec)

Figure 80: Sample of Original Codon to Phoneme Mapping Plan. Excel. Research documentation, 2015. Image: Louise Mackenzie

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[i] Image, music and text, initially identified within the doctoral project as three options for forms of language that may be mapped to DNA, is the title of a collection of essays by literary theorist, Roland Barthes (Barthes, 1977) that has subsequently shaped my thinking on readings of DNA as information (see Section 4.4).

[ii] The properties of amino acids are abundant and varied. A quick internet search reveals several websites that list a range of known properties and also many suggested, but not fixed properties (see also Figure 28). I have created my own amalgamated list of properties, for non-scientific purposes.

APPENDICES

APPENDIX VI
UNTOURAGE #3

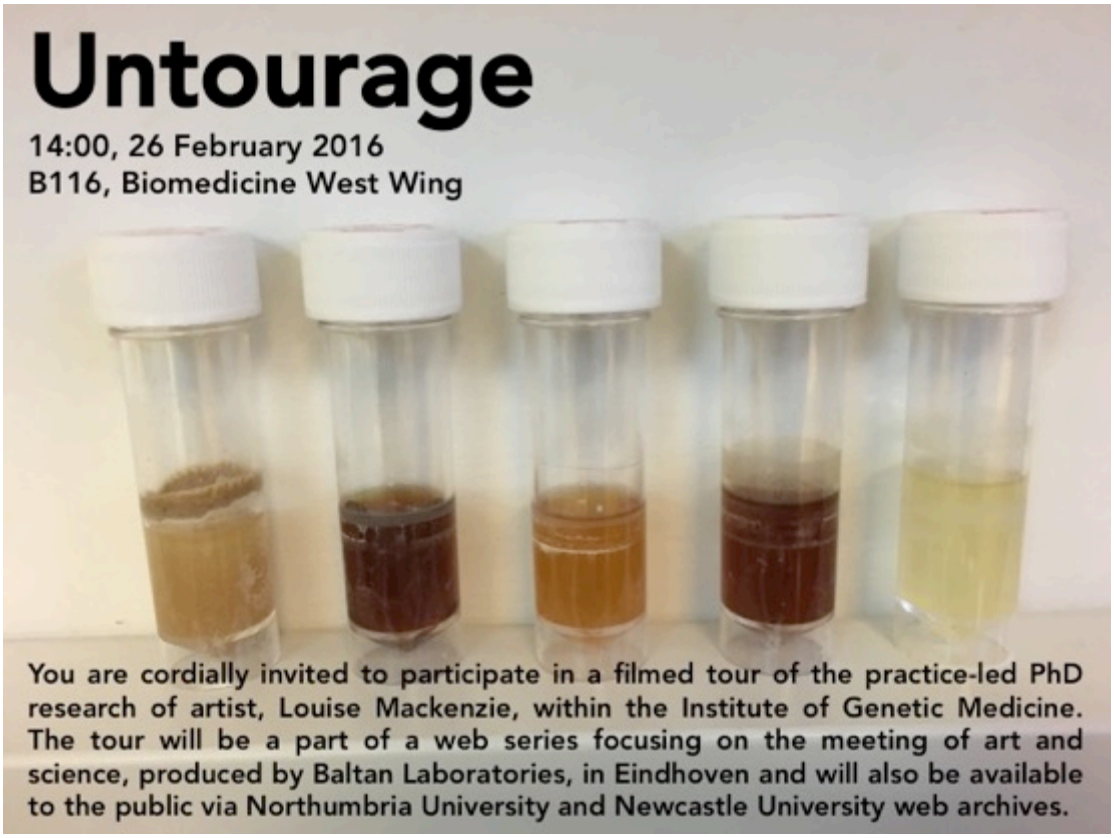

Figure 81: Louise Mackenzie, 2016. Invitation to *Untourage*.

UNTOURAGE #3 – Draft Script

Max Duration: 5 minutes

[Initial outdoor scene – wide shot, pan from DNA sculpture and Centre for Life signs to Biomedical West Wing.]

Untourage #3

[A single shot of the main lab next to B116 where most of my colleagues work. Voice over intro recorded during shooting.]

Guide: In corridor outside lab

"Hi, I'm Louise Mackenzie and I'm an artist and PhD researcher at Northumbria University. I'm researching the evolutionary implications of synthetic biology within art practice and I spend much of my time here, in the Cloning Room at the Institute of Genetic Medicine."

"I'm taking some of my scientist colleagues on a tour here today to see my work. They know what I'm doing in principle, but I'm not sure they know how I practice, so this is what I want to show them."

[Camera follows guide and tour participants into cloning room]

The tour: In the Cloning Room (B116).

Guide:

[Camera on guide initially, then on faces of tour participants]

So when I first came to the lab, I was intent on constructing an organism that contained genetic information that was not naturally a part of that organism. I wanted to create a synthetic organism. Why? Well, science manipulates living matter all of the time, so why differentiate between a scientist doing so and an artist doing so. Indeed many artists have done so. What I wanted to know was what might emerge if I stored some information within an organism. I wanted to understand the evolutionary consequences of doing so and explore the discourse around this.

I'm particularly interested in the writing of biologist and theorist, Donna Haraway, her notion of the companion species and her interest in Lynn Margulis and ideas of emergence.

Hold a universal tube of bacterial culture.

[Camera focuses on tube of bacteria]

"So today I want to show you my companion species or even I might be so bold as to call them my progeny. This is what I call my genetically modified bacteria. I am in a sense their progenitor. These bacteria are somehow descended from me. They wouldn't exist if I hadn't created them and as such I feel a responsibility towards them.

So, how exactly are these my progeny? I wanted to ask a question of this laboratory workhorse, the *E. coli*. I wanted to know, "What will happen if I store this thought safe within you?" so, I asked the question in the form of a synthetic DNA construct, which was then encoded into DNA within a plasmid vector.

Move to the water bath

[Camera focuses on water bath and Guide's hands holding bacteria]

Now, given that I feel a level of responsibility towards these organisms I have to rationalize my actions. I am not treating them as equals, but mentally at least I can afford them some respect.

Using this little hot tub here, I allowed some *E. coli* to jump in with my synthetic DNA question and they opened themselves up to that question, taking it into their bodies. Ok that's a fairly romantic version of the truth. I know that really I'm shocking them. Making them react so dramatically to their environment that they can't help but take up my synthetic question – a form of biological rape and pillage in reverse.

Move to the incubator

[Camera shot inside incubator, focusing on motion of trays]

So then I make amends by placing them in a warm and cosy cradle. I like to think of it as a kind of nurturing, rocking environment, but really it's a bit like some kind of party Jacuzzi because each morning, when I come in to check on them, they have multiplied exponentially. Hundreds of progeny, each with my question stored safe within them, at least I think so.

The problem I then have is with my sense of responsibility to my progeny. How can I look after them all? How can I allow them to grow and multiply and take this question with them, without eventually filling the cloning room? So my work began to diversify into thinking not only about the evolutionary question but also about the mechanics of working with living material itself. Initially, I did try to save them all.

Move to the large centrifuge

[Camera focuses on centrifuge and Guide's hands holding bacteria]

After taking them out of party town here, I took them for a spin at the fair, and then I cooled them off – a little cryogenics: freezing them so that they could enjoy life again at some point in the future, but even that ultimately leads to a massive frozen army of my genetically modified progeny.

In the end I had to at least accept that what I was dealing with here were colonies: whole worlds of bacteria where some survive and others don't.

Open the incubator and take samples to the wall

[Camera shot inside incubator and Guide's hands removing bacteria]

So now I recolonise them daily, like this. I take them out of their warm, nurturing, party world and I commemorate these generations with a photograph, so that they are remembered for posterity. I'm thinking of making a family tree. I reckon it would be pretty hard to construct this for all laboratory *E. coli* but that could be another project.

Move to the Class 2 Hood

[Shot of Guide sitting at Class 2 Hood, cut with close ups under hood]

I then bring them to this air conditioning unit, where I can safely take a small sample of them: complete pot luck, sorry guys, and put that sample into a whole new world to colonise.

It really is like another world. It's not dissimilar to our desire to colonise Mars, so I thought, how about if I offer them different worlds to colonise. Will they thrive? Prefer them even? Or worse.

So I thought about environments that might be suitable and came up with a few let's say, cultural options: tea, miso and marmite. I also considered a world with an altogether hotter climate (or at least stronger UV rays).

None of these are outside the realms of what might be possible for these *E. coli* to survive within. I just wanted to give them options, to see whether my thought still remained safe within them. And so far it has.

Gesture to the incubator

[Camera stays on guide]

So these new colonies are my brave explorers and off they go to colonise a whole new world.

Hold up the Bacterial Waste container

[Camera focuses on Guide's hands holding Bacterial Waste container]

The others are sent to a very strange place. I think of it as either a kind of multi-cultural utopia or a hostile wasteland, where all the generations of days past mix and mingle with unpredictable outcomes. I'd love to know what goes on in this jar, it's a bit like the primordial soup. But I just hope they enjoy their last days because their ultimate end is pretty sad. They're basically annihilated: subjected to such high temperature that none of my progeny can survive. I can't stand to think about it. But then I realize that they only exist because I created them. They have experienced a range of environments and lived full and happy lives over generations and just as I created them, perhaps it is my responsibility to end their lives too. Who am I to say whether this synthetic life ought to remain in the world, beyond my control.

End of tour

UNTOURAGE #3 - Transcript for Subtitles

Louise Mackenzie:

Welcome, my name is Louise Mackenzie and I'm an artist and PhD researcher at Northumbria University and I'm working in collaboration with the Institute of Genetic Medicine here at Newcastle University. Today, I'm taking some of my scientist colleagues on a tour of my research, so please join me in the Cloning Room.

I wanted to come to the Institute of Genetic Medicine because I was inspired by artists like Eduardo Kac and it got me thinking, "What if I took some synthetic information, and put it within an organism and then allowed that organism to grow and evolve, what might emerge?" … that notion of the future unknown…

In here, we have my *E. coli*, which… I'm calling them my *E. coli* and they are my companion species but if I was to be even more provocative I might say that they are my progeny…. because I do see myself as the progenitor. If it wasn't for me they wouldn't actually exist.

How is it that I see them as my progeny? What is it that I have done exactly?

In the tradition of artists like Eduardo Kac and Joe Davis I created a cypher that enabled me to translate a sentence - a question that I wanted to ask these *E. coli* - into DNA. With this plasmid vector, I was then faced with the realisation that I was now responsible for putting something synthetic within a living organism. Culturally it's different, I am not a scientist and I am doing it for very different reasons. I see them as this companion species in the way that Donna Haraway talks about it, but we're not equal, so I have to find a way to rationalise what I am doing.

I bring them to this really inviting hot tub, where I invite them to join my plasmid, my synthetic sentence, and much to my delight; these *E. coli* obligingly open themselves up to the plasmid.

Audience #1:

"I would not say it was like a hot tub, I would rather say it was like a short torture for them."

Louise Mackenzie:

Yes

Audience #1:

"You 'force' them to."

Louise Mackenzie:

And so, then I would take them from there and put them into this nurturing, rocking, gentle environment …

… so much so that when I take them out, they have multiplied exponentially and now there is potentially millions of my little progeny in here. Then I am faced with this responsibility of thinking about the fact that I am using life as a media and I have to deal with the consequences of life, which grows and multiplies and replicates.

…and so, what I have to do is I have to bring them to this sterile environment that I don't like too much because it puts this distance between me and them…

…these guys, at the end of this pipette are my pioneers for the brave new world…

… if they like this world, there might be other worlds that they could like too and so I have tried to see if they would like to colonise some tea with milk, some tea without

milk, some Miso… I'm trying to give them some cultural diversity here… and some marmite.

Audience #2:

"Did they like the marmite?"

Louise Mackenzie:

Yes

Audience #1:

"Yes, because it's actually like the yeast extract that you put in the LB…"

Audience #2:

"But it's horrible, it's disgusting!"

Audience (all):

[laughter]

Louise Mackenzie:

I take a little photograph of them, to commemorate them, because this really is the only way that I can remember all the generations of my progeny and so I'm thinking that I'm going to compile a family tree.

This is the last final resting place for these guys so, it would be great if you could all join me in saying farewell to them today.

Audience (all):

"Bye bye"

"Bye bye bacteria"

"Did you hear them crying?"

Audience #3:

I think the different languages we use to describe one and the same process or procedure… the way you talk about your little creatures there…

Audience #1:

I think the animals are treated better than the PhD students

UNTOURAGE #3 - Preview Discussion (Summarised Transcript)

Volker: Yes… So, looking at this, it is well filmed and if the tone [sound quality] is improved then that would be great.

Louise: There will be some difficulties with the noise in the room, but yes it will be improved.

Volker: I think what is missing a bit and you might want to put it in a different context as well. If you watch it, it was a bit funny, almost too funny. It's important for you as your PhD project as well, some of the discussions that we have had with Fiona, etc. we need to get in the academic perspective: what is this actually about, what you are doing. It is much more than just your personal perspective on bacteria.

I see this currently as, hmmm, they have fun in the lab. That shouldn't be the purpose of an artist coming in to the lab.

Juliane: I remember you were speaking about this for a while at the beginning

Louise: A lot was edited out as it is supposed to be a 5-minute web series. It could be possible to add more in, but it felt a lot like me monologuing as it was and it is supposed to be a tour. If you think that's light-hearted, you should see the other two, they are incredibly light hearted… to the extent that I don't really like them and I wanted to make this significantly different from them.

Volker: Well then you understand what I am saying, I mean, in there, there is no mention of the fact that you have genetically manipulated the bacteria. It is not clear that you have put a thought in there. So it just sounds a bit like there is an artist playing with bacteria. The concept of your project is not really in there.

Louise: There is a point near the start where I do say something about it.

Volker: Even if you do, I at least did not get the impression of what your project is about.

Juliane: I remember, you did talk about it at the beginning and at the lab meeting you talked more about what the work was about.

Louise: I wanted to see this as a part way through my practice insight into how I operate in the lab specifically, and to get your feedback on how I operate in the lab.

[We listen to the part of the video where I explain my research]

Louise: It's not specific enough, is it.

Volker: No, because 'synthetic information'… that is what we all do. So it is not mentioned that it is your thought, an idea. That is what Juliane does and what Grace does, working with synthetic information.

Louise: I can add that in, good point. I'm interested to know what you thought about, I mean I found it very interesting in the parts where I was saying things that were deliberately provocative, like "my progeny", etc. and the humour that you found in that, but I very much feel like that when I am working with them and I am interested in your take on my feeling that I am making these things. Do you ever feel like you are making things in a way that an artist makes?

Juliane: Yes it is funny the first time I do it, but because I have done that a thousand times, now I don't think about it very much. It's different when I work with the zebra

fish because they are animals and they move and look at you, but with bacteria I don't really think that much about it anymore.

Louise: I suppose I do less and less even now. For example at home after a week's holiday we came back to a teapot full of mould and I thought, look at this, this is amazing, and I wanted to keep some, but then I decided to throw it out. Yet that is no different, in a way.

Volker: It didn't contain your thought though.

Louise: That's true, it is a very different type of life. I find that as I am dealing with life as a material… I think maybe it is because of my perspective as an artist… I feel much more responsible in dealing with life as a material and I wonder how you come across that same sense of responsibility, or in what circumstances you come across that same sense of responsibility.

Juliane: I do feel responsible for the animals. Cells and bacteria less, but yes the animals definitely. What I would say in general, science in the years that I have been working in science, it has become more and more standardized and there is less and less room for being creative. For everything you have big machines where you put something in and press start and you don't really know what's happening inside. Whereas in the past you had to build you own things and think about, 'oh this is not working, what can I change?'. Now you just order something form the internet, so I think there is less room now for being more like an artist or being creative with science.

Volker: I also think there is a difference in the feeling of being creative, which I think many scientists are - it is actually a basic concept of science - and what you refer to as responsibility, I mean, what do you mean by feeling responsible? That you feel that you have created something and there is a connection; that's what scientists have

with what they create as well. With scientists you can often be connected to, for example: a band, a protein, you look at it and think 'wow', so I think that creativity and the feeling is separate to responsibility – responsibility in what way?

Louise: Something that came across to me when I was making this short documentary was the sense of responsibility I feel in dealing with life as a material in a way that I don't necessarily do so much with other forms of making that I have. It is a different sense and maybe that's just me. I'm sure there are many other artists who don't have that same sensation. It is not so much… it is responsibility, but it is also being aware of every step of the process in minute detail, to understand it and therefore maybe partly that is just my interest in life as a material and maybe that's where the notion of responsibility comes from because I feel that once I have created these things I find it hard to let them go.

Volker: But I don't buy this really, in the way that we live with micro-organisms and using a deodorant for example kills your microflora. It's not that really anyone cares in a way about killing their own microflora, so I think you have to look at what the specific about your work is – the information that you put in there. That is also what distinguishes you from what the scientists do. We all put information in there, but different information with a different purpose.

Juliane: Yes, and we don't want our information to be changed. We are quite angry if it does!

[laughter]

Louise: Yes, and also you don't want it to be 'out there' and growing and doing its own thing, so it's more of a case of… if I am making some kind of difference to the way that the organism is naturally.

Volker: It is the engineering element that also is the interesting aspect about using these methodologies and technologies. It is genetic engineering and thereby generating life forms that have not existed before. That is more the interesting thing.

Louise: Yes, and I think part of what I am trying to get at is this wider sense of an acceptance of that as part of human nature to explore and discover and make and change and yet there is still a lot of …discomfort for want of a better word around the whole concept of genetic engineering. So part of what I am looking at is: now even 'somebody like me' can change something and that's where this sense of responsibility really sits.

Volker: But that is different from a sense of responsibility around a life form in general, because we as humans cannot… Albert Schweitzer[i] has done a lot of work on this. Every step you do you 'kill' plants: on grass or in a garden or sometimes a lot higher life forms that you step on. We wash things because they are full of micro-organisms and they start smelling. So therefore I wouldn't emphasise so much your responsibility that it's life. It is the specifics that you have manipulated the life and therefore there is a different relation. The manipulation is one where you use the technology in the lab that the scientists have taught you and you as an artist, you do something different by putting in a thought…. Sorry I have to leave now.

[Volker leaves the meeting]

Ana: Partially, I disagree. You said that when you set out to make this film, it was important to show that you had a connection with these creatures for whatever reason. That is your point. Despite what we have said about not constantly caring about what we step on and probably as a scientists, some of care more than others about the material that we work on. But for whatever reason you felt a connection and if you want to show that I don't think there is a problem in that.

Louise: I think I will show it. I think (you missed this earlier in the conversation before you came in) that what is missing from the video is clarification on what I have done because the more crucial point is that it is not so clear what I have done that is different from what you do. Because I just say 'synthetic information', I could be following a procedure that someone has shown me, that has nothing to do with my own research.

Juliane: Yes, if you don't know what the project is about and you watched that, you'd think that you came to the lab to learn a little about what we do with bacteria.

Grace: The connection makes sense once you know that your thought is in there.

Louise: Do you think that is enough then? Or do you have any other immediate feedback?

Grace: I think if anything, if you needed to cut out, then I would cut the end, where we are just talking and it is all very light hearted.

[Juliane agrees]

Grace: Because I like the way that it looked like, we were this line of people who seem completely in another world to your world. Thinking, 'we've never thought about this before'. Even the expression on our faces…

Louise: I really liked the end bit. We got dialogue from both sides.

Juliane: Maybe then you have to make a longer video.

Louise: I think I can add a little more at the start that extends and explains.

Juliane: Or perhaps if you don't want to add more time, a slide with a drawing that explains your research more.

Louise: What I think I will do, because this is supposed to be a fairly informal documentary, I always had in the back of my head that I am going to take all of the footage and use it for a piece of work of my own at a later stage.

UNTOURAGE #3 – Final Edit

Figure 82: Louise Mackenzie & Baltan Laboratories, 2016. Untourage #3. Webisode.

UNTOURAGE #3, BALTAN LABORATORIES

[i] German theologian and philosopher, Albert Schweitzer's philosophy of the Reverence of Life won him the Nobel Peace Prize in 1952 (Jahn, 2017).

APPENDICES

APPENDIX VII
EVOLUTION OF A THOUGHT

EVOLUTION OF A THOUGHT

This Appendix is a series of diary entries that sit both within and outside the laboratory, charting the evolution of the thought that is eventually placed within the *E. coli* bacteria. The process of arriving at the exact information to be stored took time. I wanted to follow synthetic biology tools and techniques to encode information, yet I did not want to commit to meaning. Rather I wanted meaning to emerge and not necessarily be given through language already prescribed. Paradoxically, I was committed to a deterministic approach whilst desiring emergent behaviour. I began by exploring a range of possibilities for encoding information, as documented in Appendix V, Image-Music-Text, before deciding to return to one of the earliest exercises I undertook in the doctoral project where I draw from intuitive thought, arrived at via performative action. The information stored within the organism is DNA. The multiple layers of translation that lead to the construction of the thought-as-DNA are outlined in the diary entries below.

Lab Diary, 4 June 2015

I have decided on syllables. I will record a spoken text and break it up into syllables that we encode as amino acids so that we can read these back as fragments of text.

We need to match the 44 syllables in the English language to 44 amino acids then add pauses and other intonations.

I will then record a short piece of text and transcribe this according to syllables / phonemes.

Experiment with text to use.

Lab Diary, 10 June, 2015 – Unconscious Thoughts

I am contained within a body. I have substance and form but it shifts continually. I am not one thing I am many and I reinvent myself continually.

I take this thought and chop it up into the sounds that form it, then hide it safe within this body. What will happen to it?

I am thought within a body. Does this make me soul?

I am thought within a body. A body that is other contains my thought.

I am thought within the body of an other. What will become of me as I exist within the body of another.

I place a thought, a small piece of myself, within the body of an other. I do not know if my thought will be preserved, contained, kept safe. Perhaps this thought is dangerous.

I am speaking my mind, into this body. It is other, but it is also me.

I am thinking within a body, I am speaking from within this body.

I am trapped inside a body that does not belong to me. I will make what use I can of it and I will continue beyond this body. I will grow and change.

These words are/I am forced to exist within this body.

This body is mine for a period of time, but I will grow, repeat I will grow and I will change, mutate, I will change. I will become more than this body. I will become several bodies and all the bodies will be me.

I am trying to find the body that I want to be. I cannot find it so I shall be every body and I will keep growing, repeat growing and changing, mutate, changing.

I want to be in another body, many bodies, every body. This body is not enough for me.

I am thoughts within a body.

I think I am thought within a body but I have no control.

I will change I do not know what that change will be. It will still be me, my thoughts re-arranged. Perhaps new thoughts will form without my thinking them.

I am a hungry body, an impatient body. I want to meet and mix and mingle with other bodies. I want their thoughts and my thoughts, to share thoughts, exchange thoughts.

My thoughts will not be contained within one body. They must be passed on.

What happens if I hide my thoughts away, keep them very safe, they'll last forever.

What happens if I hide my thoughts away in here, lock them away deep inside. Is it dangerous?

Lab Diary, 11 June 2015 - More Thoughts

I/we can make anything. This thought is dangerous. I/we hide it safe within this body, but fear it cannot be contained.

/'wi:/ /'kæn/ /'meɪk/ /'enɪθɪŋ/

/'aɪ/ /'kæn/ /'meɪk/ /'enɪθɪŋ/

/'ðɪs/ /'θɔ:t/ /'ɪz/ /'deɪndʒərəs/

/'aɪ/ /'haɪd/ /'ɪt/ /'seɪf/ /wɪ'ðɪn/ /'ðɪs/ /'bɒdɪ/ /'bʌt/ /'fɪə/ /'ɪt/ /'kæn/ /'nɒt/ /'bi:/ /kən'teɪnd/

What soul exists within a body made by human kind?

/'wɒt/ /'səʊl/ /ɪg'zɪsts/ /wɪ'ðɪn/ /'eɪ/ /'bɒdɪ/ /'meɪd/ /'baɪ/ /'hju:mən/ /'kaɪn

We can make anything. I place this thought, a small piece of myself, within the body of an other. I do not know if my thought will be preserved, contained, kept safe. I only wait for the impact of my action.

/w/ē/ /k/a/n/ /m/ā/k/ /e/n/ē/th/i/ng/

/ī/ /p/l/ā/s/ /th/i/s/ /th/ô/t/
/a/ /s/m/ô/l/ /p/ē/s/ /ô/v/ /m/ī/s/e/l/f/ /w/i/th/i/n/ /th/

Phonemic Chart (44 sounds plus stresses)

SAMPA – 53 (phonemes, plus stresses)

Using the CMU Pronouncing Dictionary (39 phonemes):

W IY1 . K AE1 N . M EY1 K . EH1 N IY0 TH IH2 NG

AY1 . P L EY1 S . DH IH1 S . TH AO1 T .

AH0 . S M AO1 L . P IY1 S . AH1 V . M AY2 S EH1 L F .

W IH0 DH IH1 N . DH AH0 . B AA1 D IY0 . AH1 V . AE1 N . AH1 DH ER0 .

AY1 . D UW1 . N AA1 T . N OW1 . IH1 F . M AY1 . TH AO1 T . W IH1 L . B IY1 . P R AH0 Z ER1 V D . K AH0 N T EY1 N D . K EH1 P T . S EY1 F .

AY1 . OW1 N L IY0 . W EY1 T . T UW1 . D IH0 S K AH1 V ER0 . DH AH0 . IH2 M P AE1 K T . AH1 V . M AY1 . AE1 K SH AH0 N .

Lab Diary, 09 November 2015 – Thought Performed

Figure 83: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory*. Video Still.

Figure 84: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory*. Video Still.

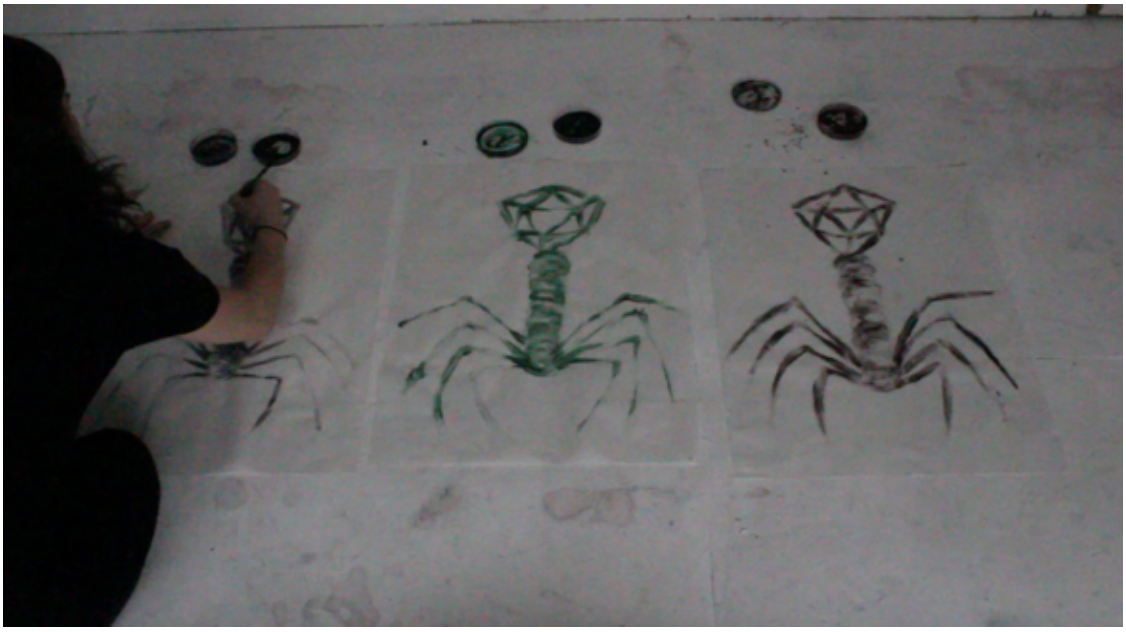

Figure 85: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory*. Video Still.

Figure 86: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory*. Video Still.

Figure 87: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory*. Video Still.

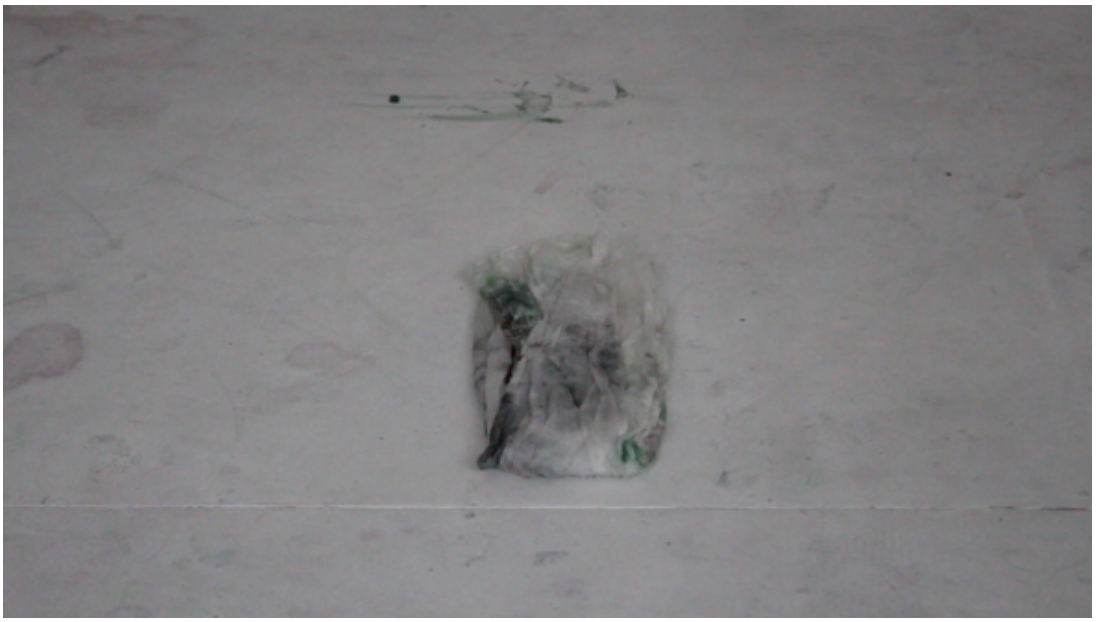

Figure 88: Louise Mackenzie, 2015. *Combined Knowledge, Unknown Territory*. Video Still.

Lab Diary, 22 June 2015 – Thought as Phage Form. Regenerated.

Improvised image making at *Vulnerable* risograph workshop with Fiona Larkin, Kate Liston, Nicola Singh, and Debbie Guinnane, 22 June 2015.

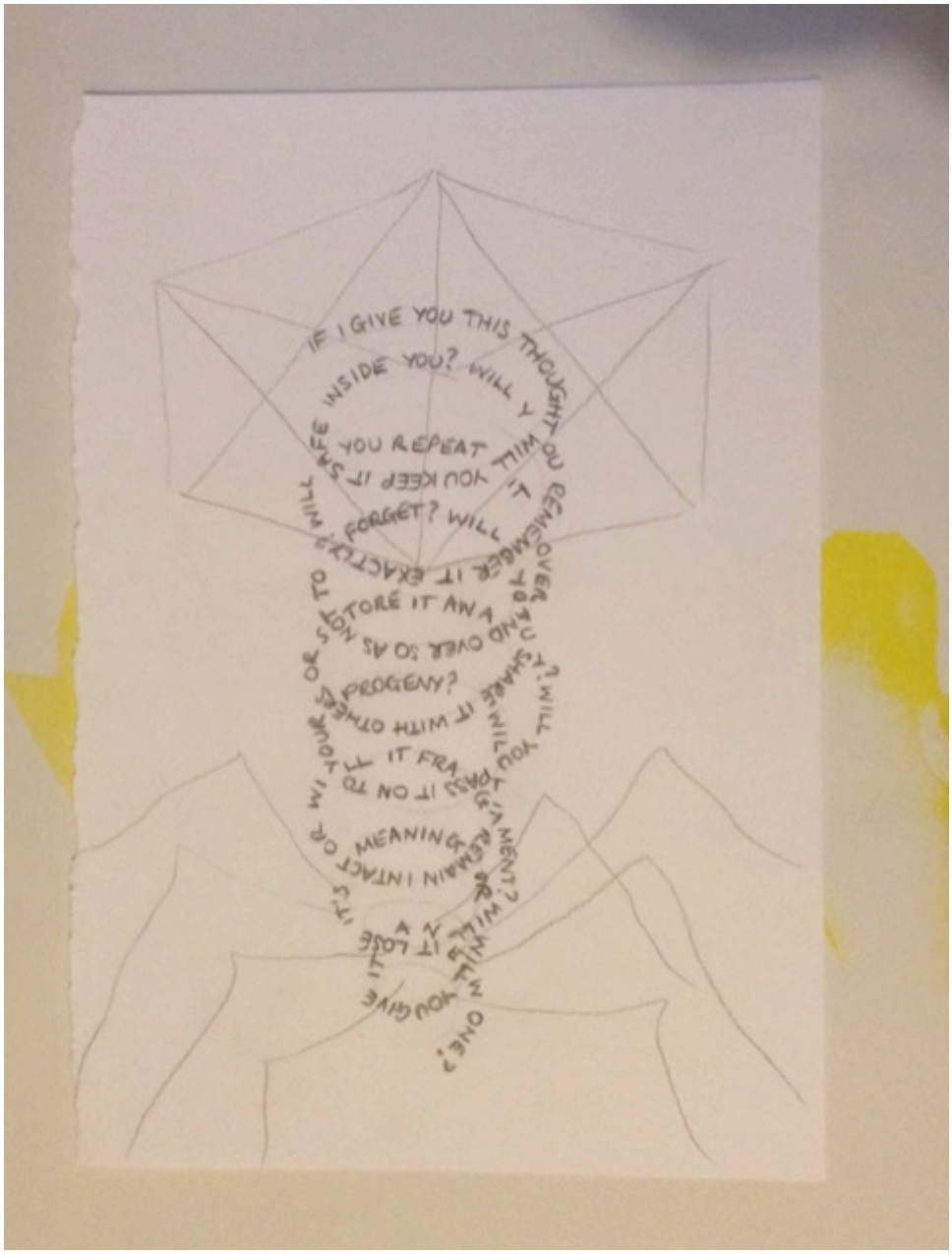

Figure 89: Drawing for use during *Vulnerable* risograph workshop led by artists, Kate Liston and Fiona Larkin at Sunderland University. Research documentation, 2015. Image: Louise Mackenzie.

Figure 90: Making collaborative improvised images, *Vulnerable* risograph workshop led by artists, Kate Liston and Fiona Larkin at Sunderland University (1). Research documentation. Photo: Nicola Singh

Figure 91: Making collaborative improvised images, *Vulnerable* risograph workshop led by artists, Kate Liston and Fiona Larkin at Sunderland University (2). Research documentation. Photo: Louise Mackenzie

Figure 92: Making collaborative improvised images, *Vulnerable* risograph workshop led by artists, Kate Liston and Fiona Larkin at Sunderland University (3). Research documentation. Photo: Nicola Singh

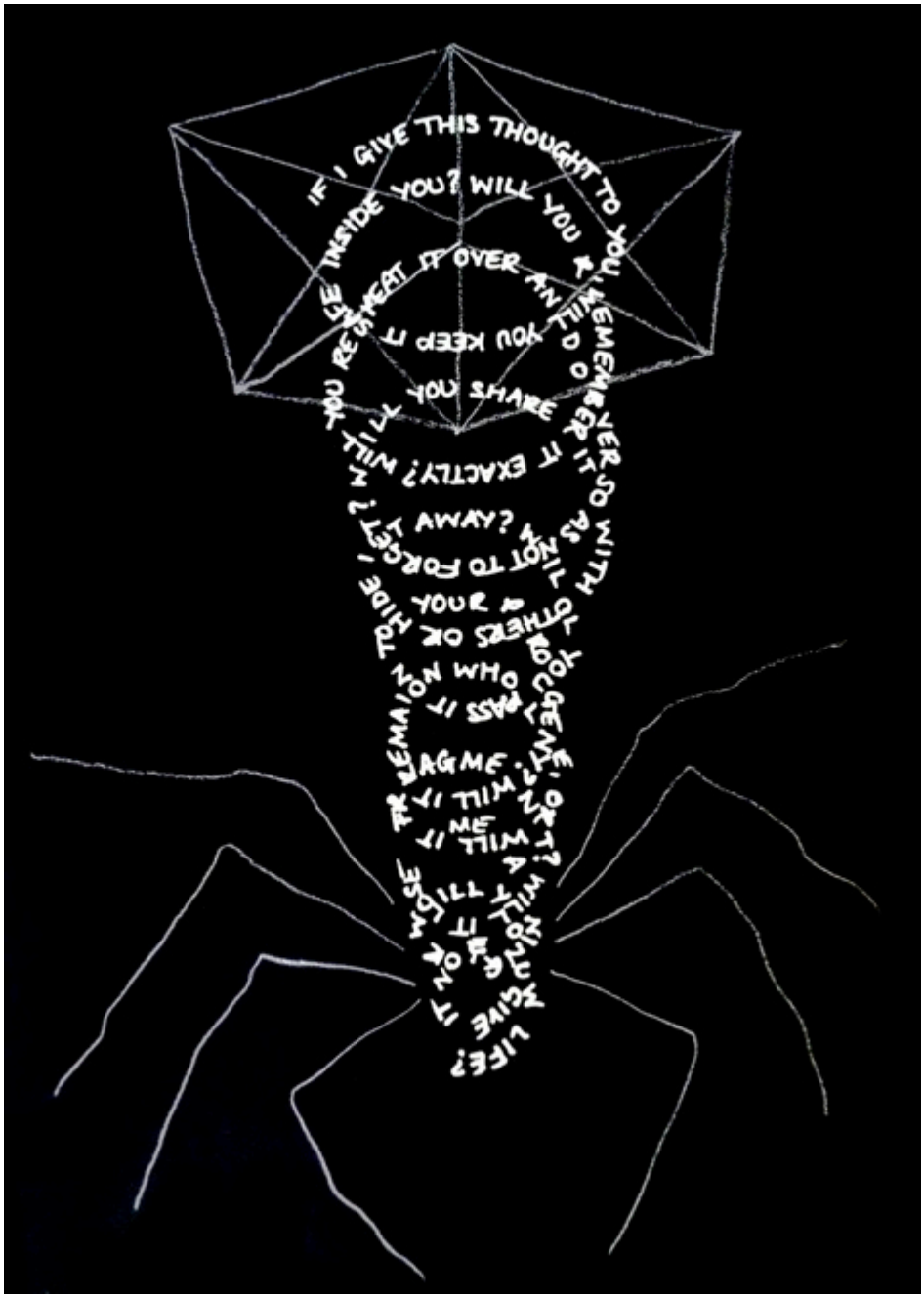

Figure 93: Video still from working Lab Diary. Research documentation, 2015. Image: Louise Mackenzie

Lab Diary, 16 July 2015 - Thought Abbreviated

Thought translated as 144 base pairs of DNA for encoding within synthetic plasmid DNA.

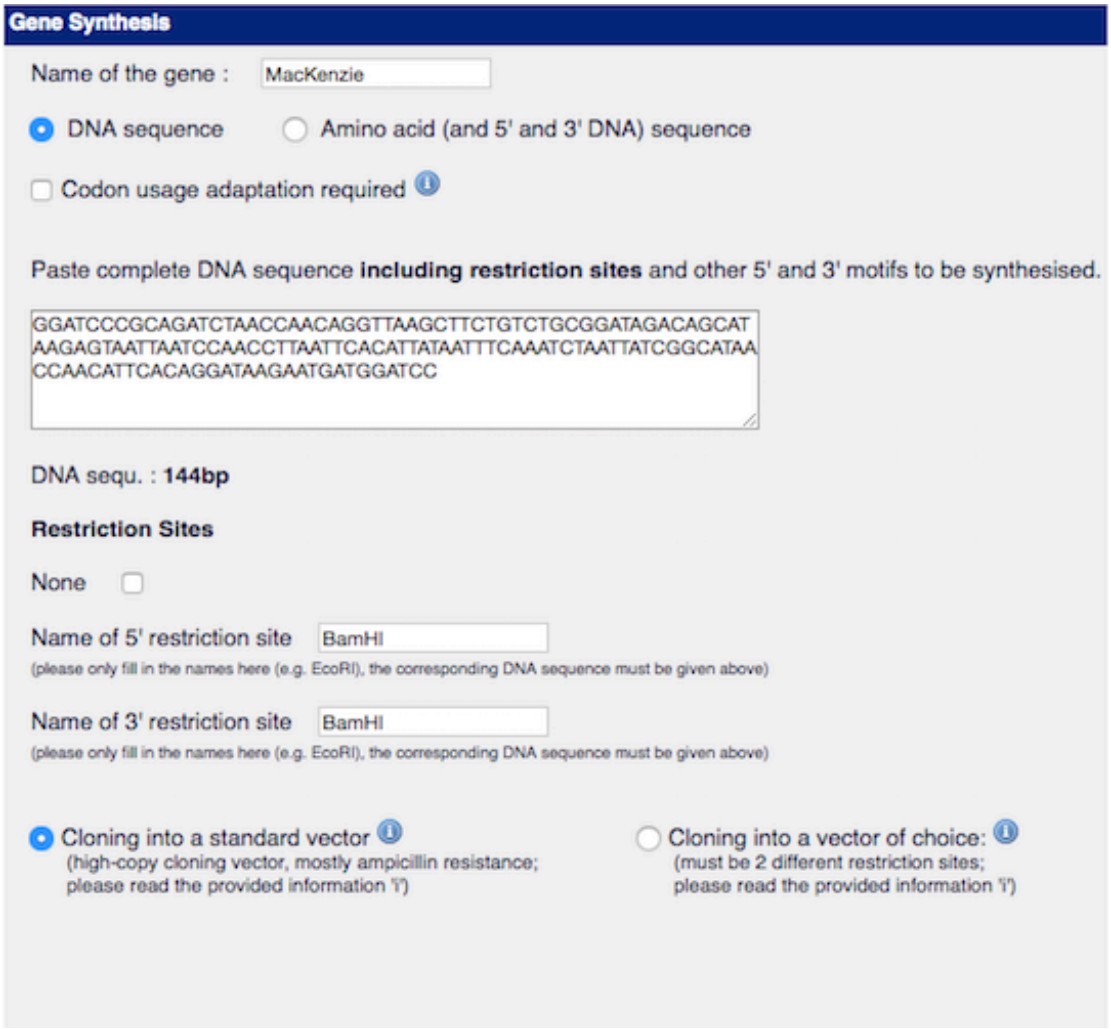

Figure 94: Online Gene Synthesis Form for Production of Plasmid Vector. Research Documentation, 2015. Image: Louise Mackenzie

Lab Diary, 12 April 2016 – Thought Mutated. Manual Mutations for *Pithos*.

The following is a list of artificial mutations of the thought, manually translated after first deriving the DNA mutations using the Jukes-Cantor Model within the genetic modeling software, *MEGA* (MEGA, 2017).

Phonetic Translation of Thought

Phonemes In Silico
Phonetic script: ʌɒt wɪl hæpən ɪf aɪ stɔ:r ðɪs θɔ:t seɪf wɪðɪn ju:
Text for Festival: what will happen if I store this thought safe within you

Phoneme_1 In Silico
ʌɒt wʃl hæpʊn ɪfðɔɪ stɔ:r ðɪs θɔ:t seɪf wɪði:n ju:
Hawt wood yll happoon if thoi store this thought safe within you

Phoneme_1_2 In Silico
Hɒtju:wʃlʊhæpʊn ɪfðɔɪ sdju:r ð s ɒt seɪfɑ:(r)wɪðɛə(r)n ju:
Hawtyouwood yll happoon if thoi sdewr aw s ot sayfar withairn you

Phoneme_1_2_3 In Silico
Hɒtju:ɜ:ʃbʊhæpʊm ffðɔɪ sdju:rɑ̈ð s ɒt sʌfɑ:(r)wɑ̈ðɑ̈hɔ:ju:
Hawtyou ir dboohappoom f thoi sdewrguth s ot swhfarwugothgunyou

Phoneme_1_2_3_4 In Silico
Hɒtju:ɜ:ʃbʊɲæʒʊm wfðɔɪ sdju:rɔ:ð s ɤɒt ɾrfɑ:(r)wɒðɑ̈hɔ:ju:ɑ:(r)
Hawtyou ir jboohajoom wif-thoi sdewr-oath s yuhh -ot rrfawothg-unyouar

Phoneme_1_2_3_4_5 In Silico
Hɒtju:ɜ:ʃbɑ:ɲæʒʊaʊ ɔ:fɑ:ɔɪəsθju:rɔ:ðju:sɑ:(r)ɤɒɪə(r) ɾrfɑ:(r)wɒsɑ̈hɑ̈aʊɑ:
Hawtyou ir jbanyaju-ow oafa-aw eus thyousa yuhh-aw-ea rrfarwawsgunguwa

Phoneme_1_2_3_4_5_6 In Silico
Hɒtnɜ:ʃbɑ:ɲæʒʊh ɔ:gɑ:pʊsθju:rɔ:pju:zɑ:ɤ ɪə(r)ɔ:ɾrfɑ:(r)wɒsɑ̈ɦɾaʊɑ:
Hawtnir jbanyajooh oagapoos thyour-aw pewza-yuhh ee-orefarwawsgun-ruwa

Phoneme_1_2_3_4_5_6_7 In Silico
HHmɪə(r)nHʃbɑ:dʒæʒəɾ ɔ:pɑ:pʊsθju:rɒpgkɑ:ɤ ɪə(r)ɔ:ɪrfɑ:(r)wɒ ɑ̈ɦɾ|ɑ:
Hmeenhdybadgadger oapapoosthyour-apgka-yuhh ee-oh-irfarwagun-r tzka

Phoneme_1_2_3_4_5_6_7_8 In Silico
HHmɪə(r)nHʃbɑ:dʒæʒʊɾ ɑ̈pɑ:pʊsθju:rɒpgkɑ:ɤ ɪə(r)ɔ:ɪrfɑ:(r)ʊɒ ɑ̈ɦɾoʊɑ:
Hmeenhdybadgadgoor g-papoosthyour-apgka-yuhh ee-oh-irfarvwagun-roa

Genetic Translation of Thought

Phonemes In Silico
CCGCAGAUCUAACCAACAGGUUAAGCUUCUGUCUGCGGAUAGACAGCAUAAGAGUAAU
UAAUCCAACCUUAAUUCACAUUAUAAUUUCAAAUCUAAUUAUCGGCAUAACCAACAUUCA
CAGGAUAAGAAUGA

Phoneme_1 In Silico
CCGCAGAUCUAACCAACAGGUUAAGCUUCUGUCUGCGGAUAGACAGCAUAAGAGUAAU
UAAUCCAACCUUAAUUCACAUUAUAAUUUCAAAUCUAAUUAUCGGCAUAACCAACAUUCA
CAGGAUAAGAAUGA

Phoneme_1_2 In Silico
GCGCAGAUCGAACCGAGAGGUUACGCUUCUGUCUACGGAUAGACAGCAUTCGACUAAU
UAAUTGAACCUUAAUUCTAAUUAUAAAUGCAGAUCUGAUUAUCGGCAUCACCAACATUCA
GTGGAUAAGAAUGA

Phoneme_1_2_3 In Silico
GCGCAGAUCGAAACGAGAGTUUACCGUUCUGUCUACGGTUAGGCAGCATTCGACUGAUU
AAUTGAACCUAAAUUCTAAUUAUAAAUGCAGAUCUGAUUACCGGCAUCACCAAAATUCAA
AGGACAAGAATGA

Phoneme_1_2_3_4 In Silico
GCGCAGAUCGAAACGAGAGTUTACCGGUCUCUCUACGGTUAGCCAGCATTCGACUGAUU
AAUTGAACCUCAAUUCTAAUUAUAAAAGCAGATCUGAAUACCTGCAUCACCACAGTUCAA
AGGACAAGAATCA

Phoneme_1_2_3_4_5 In Silico
GCGCAGAUCGAAACGAGAGTUTCCCGGUCUCUCUACGATUAGCAAGCATCCGACUGCUU
ATUTGAACCUCAAUUCGAAUUAUCAAAGCAGACCUGAAUACCTGCAUCACCACAGTUAAA
AGGAAAAGATTCC

Phoneme_1_2_3_4_5_6 In Silico
GCGCAGAUCGGAACGAGAGTUTCCCGGTCUCUCUACGCTUAGCAAGTATCCGTCUACUU
ATUTGAACCUCAAGUCGAAUUGUCCAAGTAGACCCAAAUACCTGCAUCACCACAGTUAAA
AGGAATAGATTCC

Phoneme_1_2_3_4_5_6_7 In Silico
GCGCACACCGGAGCGAGAGTUTCCCTGTCUCUCUGCCCTUAGCAAGTCTCCGTCUACUUA
TUTGAACCUCAGGUCGTAGUGUCCAAGTAGACCCAAACACCTGCAUCACCACAGTAAAAA
GGAATACATTCC

Phoneme_1_2_3_4_5_6_7_8 In Silico
GCGCACACCGGAGCGAGAGTUTCCCTGTCUCUCUACCCTTAGAAAGTCTCCGTCUACUUA
TUTGAACCUCAGGUCGTAGUGUCCAAGTAGACCCAAACACCTGCAUCACGACAGTAAAAA
GGAATAAATTCC

Lab Diary, 12 April 2016 – Thought Recorded. Voice Translated into Audio.

Figure 95: Audio Recording Thoughts for Speech Synthesis, with Étienne De Crécy at Edinburgh University Centre for Speech Technology Research (1). Research Documentation, 2016. Image: Louise Mackenzie

Figure 96: Audio Recording Thoughts for Speech Synthesis, with Étienne De Crécy at Edinburgh University Centre for Speech Technology Research (2). Research Documentation, 2016. Image: Louise Mackenzie

Lab Diary, 11 January 2017 - Thought Mutating. Automated in *Genophone*

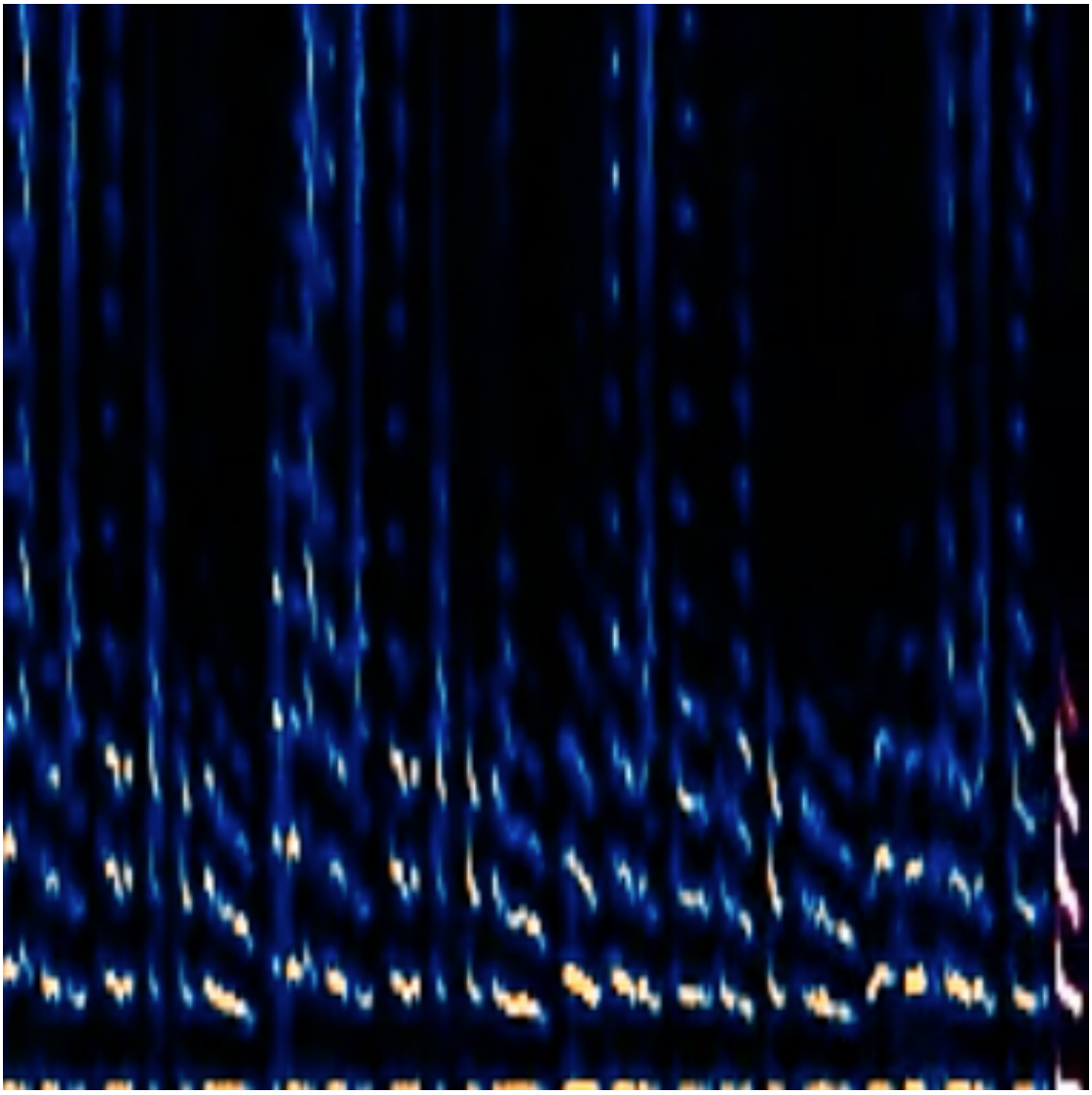

Figure 97: Louise Mackenzie & Étienne De Crécy, 2016. *Genophone*. Spectrogram of the mutating phrase, 'What will happen if I store this thought safe within you?'

The mutating thought and accompanying spectrogram can be seen and heard at http://www.viralexperiments.co/what-will-happen.

Lab Diary, 11 April 2017 - Thought Relating. Plasmid Thought within *E. coli.*

Figure 98: Louise Mackenzie, 2017. *Transformation* psychotransgenic workshop. Transforming *E. coli* with BioAssemblage #1. Image courtesy: Anaïs Moisy.