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Making Research Translatable:
Articulating and Shaping Synthetic Biology in the UK

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THESIS ABSTRACT

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Synthetic biology, an engineering approach to genetic modification, has emerged at a time when academics are increasingly expected to translate research to other domains of society. Proponents of synthetic biology often deploy promissory rhetoric to create expectations of major improvements in medicine, energy and food production. How else are actors in the field of synthetic biology addressing these translational expectations? This thesis takes synthetic biology in the UK as an empirical site to explore the various ways in which research translation involves multiple rhetorical, organisational and material transformations.

In this project I developed a conceptual framework using post-Actor Network Theory, post-social theory and other STS concepts. I generated data by employing qualitative research methods including observations, interviews and by collecting documentation from various institutions. I visited field sites such as academic science laboratories, academic events and administrative offices. Participants included scientific researchers, research administrators, industry representatives and policymakers. I transcribed the interview data, typed up field notes and iteratively coded the texts and documents to generate themes.

From my analysis I identified a variety of strategies and practices that appear to make synthetic biology translatable. These included: *articulating* synthetic biology research with absences in other areas of society (e.g. state economic and industrial deficits, problems with

private-public collaborations) and imagining a future industry; *demarcating* synthetic biology research from other programmes such as genetically modified organisms; *realising* rhetorical promises in the everyday organisation, research training and material work of synthetic biology practices.

My research indicates that translation in synthetic biology involves multiple groups orientating research facilities and researcher training, particularly towards industrial manufacturing. I go on to theorise synthetic biology as an *unfolding multiple*. Actors expand synthetic biology and in the process they entangle the state, institutions, laboratories, cells and molecules. To achieve this, actors *mobilise vulnerabilities* that others have identified in science, state and society to create a central heroic object of synthetic biology. These conclusions offer a conceptual framework to further investigate and interpret contemporary technoscience and its connections in society.

For Jojo

Contents

Part II: Articulations & Contributions

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List of Figures

Part I

Connections

Chapter One

Introductions

> Matters grow from the middle, and from many places. But one also has to start *somewhere*.
>
> (Law 2002, p.1)

Research and innovation policymakers have identified a number of challenges facing contemporary society. The European Commission, for example, discerns problem areas in the health and wellbeing of changing populations; food security and sustainable agriculture; secure energy; integrated transport; climate change and resource usage; inclusive societies; and liberty (European Commission 2014, pp.11–15). In the UK, policymakers include the digital economy, energy, global food security, security for all in a changing world, environmental change and lifelong health and wellbeing as research foci (Research Councils UK 2015a). These are not clearly defined technical goals, like putting a man on the moon or mapping a human genome, but open-ended social projects that "pertain to heterogeneous elements and forces, which have to be mobilised, guided and integrated" (Kuhlmann & Rip 2014, p.1). A challenge facing allocators and recipients of public funds for research is to demonstrate how knowledge production contributes to these complex projects.

This thesis is concerned with how scientists, engineers, administrators and policymakers shape a field of scientific research to be relevant to society in the UK. Broadly, the thesis is connected to perspectives associated with the Social Shaping of Technology (SST) that

reject technological determinism and linear models of innovation (Bijker & Law 1992; MacKenzie & Wajcman 1999; Sorensen & Williams 2002; Williams & Edge 1996). Instead, I emphasise multiplicity and contingency. To do so, I use a variety of conceptual tools to a) describe the different activities in which actors engage b) to understand the ways that actors make and unmake connections between a field of science and other domains in society and c) to explore how their activities and connections shape a field of research.

First, in this introductory chapter, I suggest a number of different places to begin this thesis in order to highlight some of the intersecting issues I address in later chapters. I then introduce the context for this study – an emerging field of research called 'synthetic biology' which involves researchers collaborating to 'make biology easier to engineer' (Endy 2008; Lentzos et al. 2008; Silver 2009; Jefferson et al. 2014a). In the final section I explain the structure of the thesis, outline how each chapter contributes to the development of the overall arguments and propose the ways in which the thesis builds on knowledge about the organisation of science, innovation practices and social theory.

1.1 Origins

A central concern of this thesis is how things are connected to one another. This thesis is itself connected to many things, academically, empirically, materially and philosophically. So, following John Law's (2002) strategy in his introduction to *Aircraft Stories: Decentering the Object in Technoscience*, I offer four places to start other than with the societal challenges in the opening paragraph. This thesis is connected to the idea of translating academic research and innovation; to changes in academic biosciences; to social research about translating knowledge in biomedicine; and to my own biography.

One place to begin is with the meanings of translation and the use of translation as a metaphor in research and innovation. The term translation has different dictionary meanings:

- The process of rendering of a text or word in another language
- The conversion of something from one form to another
    - *In biology, the reading of RNA to produce an amino acid sequence*
- The formal process of moving something from one place to another, such as relocating a religious relic from one site to another
    - *In maths, the movement of a body, without deformation, in a given direction*

(Google 2015)

Translation therefore implies both movement from one place or text to another and a change in meaning, a betrayal (Law 2006).

In contemporary biomedicine, "translational research" refers to transferring laboratory research to clinical practice, sometimes called 'bench to bedside' research (Woolf 2008). Translational research can be seen as a new "agenda for public health policy, commercial pharmaceutical innovation and academic science" (Mittra & Milne 2013, p.xiii). Since the turn of the millennium researchers have increasingly included "translational research" in abstracts and titles of published biomedical research (Kraft 2013). A translational research "imperative" (Harrington & Hauskeller 2014) can be understood partly as a response to the perceived slowness of innovation, which is conceived as a 'gap' between laboratory and clinic (van der Laan & Boenink 2012). The emphasis on translation can also be understood as a result of the global investment in the Human Genome Project (HGP) and the lack of expected clinical benefits (Kraft 2013; Rajan & Leonelli 2013).

Translation is not a new metaphor for transferring research. For instance, it appeared in medical literature, in France, in the 1970s (Greenhalgh & Wieringa 2011). Furthermore,

translation is not confined to the domain of academic biomedicine. The metaphor crops up in various policies referring to academic funding and knowledge transfer in other biosciences and beyond (Cooksey 2006; House of Commons Science and Technology Committee 2013; House of Commons Science and Technology Committee 2010; Technology Strategy Board 2012b). Science and Technology Studies (STS) commentators have used the metaphor in a broad sense to refer to sociotechnical systems that may need to be "reconfigured, 'translated' and redesigned to meet the new requirements" (Williams & Edge 1996, p.874). David Edge (1995) used the metaphor reflexively:

> Perhaps the next phase in the development of STS must be a more urgent concern for *communication* and *translation*: for "making real" its true potential.
>
> (Edge 1995, p.4)

Researchers note that academic knowledge needs to undergo some kind of process to be of use beyond the bench, desk or laboratory. Thus, the metaphor of translation seems to capture the imaginations of academics, clinicians and policymakers. This thesis contributes to the ways practitioners and scholars understand the metaphor of translation by describing how translation is enacted in a contemporary field of biotechnology.

A second place to begin this thesis is with changes in bioscience at large. When the media reported a draft of the human genome in 2000, they announced scientists had produced a "map"; a "blueprint"; a "manual"; a "book of life" (Nerlich et al. 2002). Researchers in the HGP had "cracked the code" and could now "read, write and spell" with genetic information (Nerlich et al. 2002, p.456). The metaphors implied a new ability to understand life. But there was a surprise. The whole genome, which had been estimated to contain up to 100 000 genes, turned out to be made up of 20 000-25 000 genes (Stein 2000). In a response that had implications for how genomic knowledge might be utilised in healthcare, scientists had

to rethink their understanding, from deterministic genes to genomes as a more holistic entity that interacted with cells' environments (Fox Keller 2014).

Raising expectations for applications of research, such as with the HGP, are an important part of securing funding for projects (Brown & Michael 2003; Brown 2003; van Lente 1993):

> A key factor is the need for innovators and their sponsors to create high expectations to get access to the very considerable resources (money, people, and intellectual property) required to develop new medical technologies. No one is going to invest in a start-up company, or a large-scale scientific endeavour, such as the Human Genome Project, unless they genuinely believe it has the potential to yield significant returns in a defined timescale. The emergence of the biotechnology industry has rested heavily on the creation of these high hopes and many people in the sector have been active in promoting the idea of a biotech revolution.
>
> (Nightingale & Martin 2004, pp.566–567)

But, despite the promises of genomics and biotechnology more broadly, there does not appear to have been a 'biotech revolution' in healthcare and instead innovation progresses incrementally, slowly and nonlinearly (Hopkins et al. 2007; Nightingale & Martin 2004). Furthermore, following the HGP, other biosciences including "epigenetics, immunology, physiology, cell biology and ecology" have enjoyed renewed interest and status (Rajan & Leonelli 2013, p.11). The heyday of genomics funding appears to have passed and given way to other biosciences such as the focus of this study: synthetic biology.

An exemplar of this shift beyond genomics can be found in the biography of American geneticist Craig Venter. He left the HGP to set up a private company, Celera Genomics, which then competed with the publicly funded HGP to be the first to sequence the whole genome (Shreeve 2004). Venter was first author on an important paper published in *Science*, jointly written by Celera staff and HGP scientists (Venter et al. 2001). After he was

fired from Celera in 2005 Venter set up a new company, Synthetic Genomics, which received $600m investment from Exxon Mobil to develop engineered algal strains that could manufacture biofuels (Howell 2009). Synthetic Genomics later announced that it was the first to create "a synthetic life-form" (Sample 2010; Gibson et al. 2010). Furthermore, Venter is well known for his attempts to patent genes (Pottage 2006; Calvert 2008). His story highlights some of the contemporary issues in biotechnology including how life is valued in processes of commercialisation, ownership and the potential for future applications.

At the same time as a shift from genomics, the working practices and the expectations of academic knowledge production are changing. There is already an on-going debate that the relationships between society, industries, governments and university-based research are in flux. This includes the ideas that research and development is non-linear, multidisciplinary and produced by heterogeneous groups (Gibbons et al. 1994; Nowotny et al. 2001) and that university, government and industry are intertwined in a relational *triple helix* (Leydesdorff 2000; Leydesdorff & Etzkowitz 1996; Etzkowitz & Leydesdorff 2000; Etzkowitz 2011). There are increasing audit systems, imported from the finance sector, aimed at ensuring accountability and promoting responsibility in academia (Shore & Wright 2004). One example, the *Research Assessment Framework* (REF) is a "new system for assessing the quality of UK research" and "provides accountability for public investment" (Research Excellence Framework 2014, p.3). Another example, the *Responsible Research and Innovation* (RRI) agenda, particularly in European and US academia, emphasises the production of knowledge "for society, with society" and the inclusion of stakeholders in the production of knowledge (Owen et al. 2012). Thus, claims that "translational research" in biomedicine can be understood within a framework of, on the one hand, changes emphasising accountability of academic bioscience and, on the other hand, changes in bioscience resulting from globalisation and capitalisation of life sciences (Rajan & Leonelli

2013) also apply to the biosciences more broadly. This thesis addresses ways in which, along with these shifts, the field of synthetic biology is emerging.

Third, there are small bodies of academic literature in STS that report and theorise translational research in the UK. One of these literatures examines translation in stem cell research (SCR) (Cribb et al. 2008; Wainwright et al. 2006b; Wainwright et al. 2006a; Wainwright et al. 2009; Williams et al. 2008). Here, the research mostly focuses on the cultural and ethical differences between laboratory researchers and clinical researchers. A second set of publications examines the translation of genomic research in *Genetics Knowledge Parks* (Swan et al. 2007; McGivern & Dopson 2010; Robertson 2007; Swan et al. 2010). These papers examine different logics of academic knowledge production and the 'lives of objects' (Engestrom & Blackler 2005) as groups of researchers, clinicians and health administrators develop knowledge and medical technologies. Related scholarship explores the roles of "knowledge brokers" (Meyer 2010; Meyer & Kearnes 2013) that include research translators and clinician-scientists (Vignola-Gagne 2013; Wilson-Kovacs & Hauskeller 2012; Morgan et al. 2011). These literatures address translation particularly between biomedical science and medical practice. They focus, for the most part, on genomics and stem cells. However, as I have mentioned, translation does not only take place between laboratory and clinical practice. There is currently little ethnographic sociology on the relations between academia and industry and this thesis develops some of the approaches in the above literature to inquire into how academics prepare for research translation and the problems that may or may not transpire.

A fourth place to start is with a flashback to a biomedical laboratory in Sheffield circa 2002. A recent graduate (me) is watching two PhD students, in white coats no less, talking by the computers on one side of the lab. One is explaining to the other their theory. Holding their hands apart like a raconteur fisherman boasting about a catch, they say schizophrenia is

better understood as a spectrum of symptoms rather than as a single disease. For instance, delusions over here (waving one hand) and diminished affect here (waving the other hand). They say the drug companies are instrumental in maintaining schizophrenia as a single thing, because producing a single drug to combat a single disease would yield greater profits, because of economies of scale.

The student's disillusionment reflected my own. I had originally enrolled at university to study biology and philosophy. However, after some brief discussions, I decided to focus on biology and deferred my interest in social and philosophical questions. I graduated with a degree in Biomedical Science and continued working in the laboratory in which I had written my final year dissertation. The work was on the side effects of atypical antipsychotics in rat models. Specifically, many patients experience weight gain when medicated with atypical antipsychotics (Allison et al. 1999) and the project was aimed at understanding a possible mechanism of action. Did the drug Ziprasidone, which appeared to cause less weight gain (Allison et al. 1999), affect the population density of 5-HT_{1A} receptors in rat brains? A little bit (Meckin et al. 2003).

Yes, the laboratory was partly funded by a drug company, despite being a university facility. Yes, we reported to the drug company. But it was the distance between our work and patient experiences that I found hard to reconcile, rather than the academic-industry relationship. We worked in rat models. I once received fifty frozen rat brains in the post. I used various apparatus to create purees of rat brains to which I added radioactive ligands that could bind to the target receptors. Using more equipment I transformed tiny amounts of radioactive compounds to numbers that represented luminosity. From this it was possible to estimate population density of those particular receptors in each brain. But how would this work ever end up being relevant to patients to whom it was meant to benefit? In fact, who was it for? This links to a variant of the first problem I introduced – how does research in the laboratory

relate to patients and clinic? Biography and history are intertwined, and one cannot understand either without taking account of the other (Wright Mills 2000). So, a decade later, I came to study translation in bioscience. In this way, my own story of moving into socially investigating life sciences exemplifies broader concerns that research should be delivering on its promise to address problems.

By acknowledging several origins of the thesis I aim to perform a central point of my argument – objects of knowledge are composites. I turn now to give an introduction to my research site, synthetic biology.

1.2 Synthetic Biology in the UK

Synthetic biology is an emerging field of science that involves collaborations of engineers, biologists, chemists, computer scientists, mathematicians, among others (Vogel 2014; Kearnes 2013; Royal Society of Chemistry 2008; Frow 2013; TNS-BMRB 2010). The official definition in the UK, the one that most actors acknowledged in documents and during interviews, is the Royal Academy of Engineering definition:

> Synthetic biology aims to design and engineer biologically based parts, novel devices and systems as well as redesigning existing, natural biological systems. Synthetic biology strives to make the engineering of biology easier and more predictable.
>
> (Royal Academy of Engineering 2009, p.6)

The logic of synthetic biology is connected to "maker's knowledge" – the "doctrine that building-brings-understanding" (Radick 2013, p.790). Proponents of synthetic biology repeatedly mention the design and engineering principles they are attempting to apply to biology (Calvert 2013). These include:

- *Abstraction (or abstraction hierarchy)*: a system for managing biological complexity by eliminating unnecessary details; abstraction allows researchers at various levels (and in various fields) to work with and share details about biological data without specialized knowledge
- *Modularization*: developing interconnecting parts that can be combined in various ways
- *Standardization*: devising a broad consensus on the composition of parts, devices, and systems so that they may be used reliably in any setting. The biological parts should be discrete, fit together in standard ways, and be well characterised (Kitney & Freemont 2012, p.2035).
- *Decoupling*: de-linking the requirements for design from requirements for manufacture to allow non-biologists to use biological components in various applications
- *Modelling*: testing the projected design and its function

(Joyce et al. 2013, p.12)

The overall approach is then, at least rhetorically, a systematic approach to creating knowledge and technologies with life. However, there are many different forms of interest in synthetic biology.

One typology of synthetic biology is composed of six domains, each interested in manipulating life for different purposes (see Figure 1 on the next page). At the molecular level, synthetic biology can involve researchers reengineering existing DNA and making new forms of ‘unnatural’ genetic molecules. At the cellular level researchers may engineer protocells that could help understand evolution or act as ‘chasses’ to carry other DNA. At the community level, researchers manipulate microbial DNA to make different populations of organisms interact with one another in specific ways.

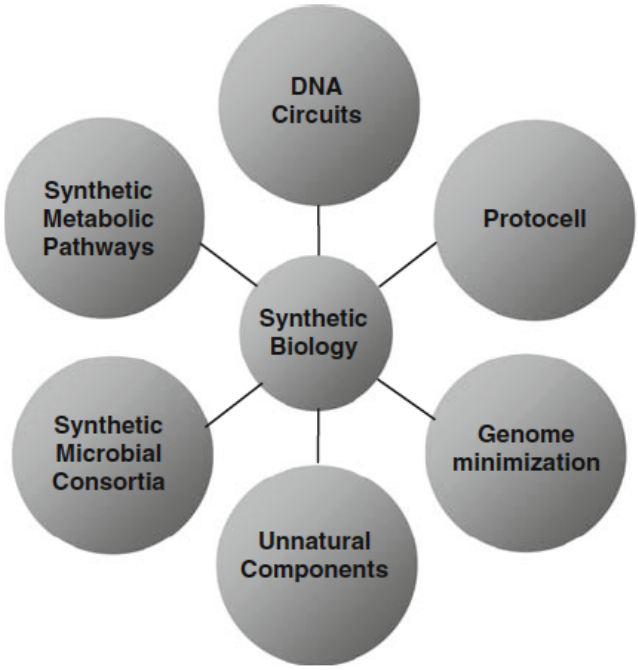

Figure 1. Six domains of synthetic biology (Martins dos Santos et al. 2009, p.26)

Some of the different domains have different underpinning epistemic commitments (see Figure 2 below).

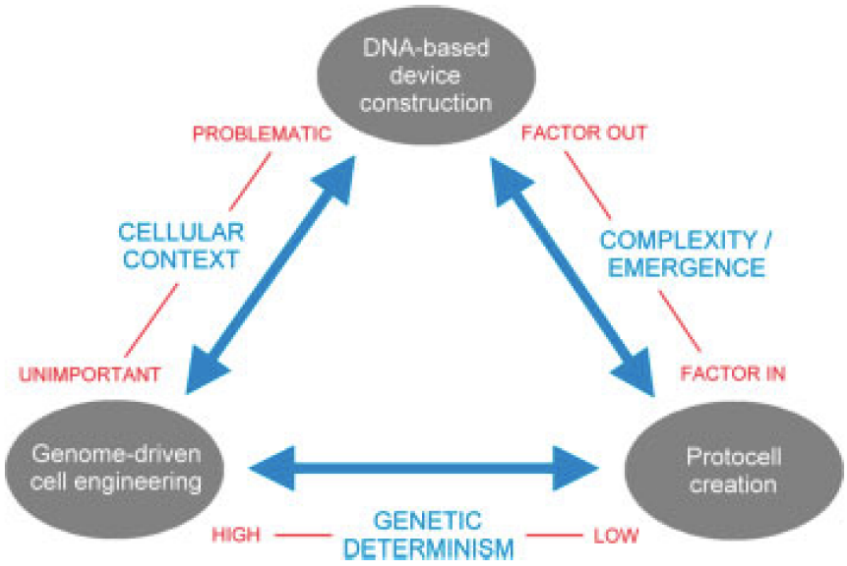

Figure 2. Epistemic commitments in synthetic biology (O'Malley et al. 2008, p.60)

Researchers interested in DNA parts, for example, are not specifically interested in how complex interactions produce emergent properties. Meanwhile, they do concern themselves with the wider cellular milieu (O'Malley et al. 2008). On the other hand, those interested in protocells are less wedded to the idea of genetic determinism than those engineering the whole genome (O'Malley et al. 2008). Thus, synthetic biology is composed of various projects with different epistemic concerns and foci.

A notable feature of synthetic biology is the international genetically engineered machine (iGEM) competition. The iGEM competition involves multidisciplinary teams of students conducting a summer project that uses and develops standardised biological parts known as BioBricks. Typically, the projects involve 'wet lab' (e.g. microbiology), 'dry lab' (e.g. computer modelling) and 'social' (e.g. outreach to schools) components. A guiding principle is that projects should "strive to create a positive contribution to their communities and the world" (iGEM 2015b). Winning undergraduate projects include Heidelberg's heat-stable proteins that can function at high temperatures to speed up reactions (iGEM team Heidelberg 2014) and their gold recycling strain of *E. coli* (iGEM team Heidelberg 2013). Other winners have been a modified strain of *B. subtilis* that could potentially detect meat spoilage (iGEM team Groningen 2012) and a project that demonstrated it was possible to reengineer bacteria to produce components of diesel fuel and, separately, break down gluten (iGEM team Washington 2011). The iGEM competition promotes and encourages high ambitions for synthetic biology.

The competition began in 2003 when Tom Knight, Randy Rettburg and Drew Endy, all members of Massachusetts Institute of Technology (MIT), started a competition to inspire undergraduates (Cockerton 2011, p.27). The following year they widened the competition and five US universities competed. The competition increased rapidly in size. By 2014, the year I acted as advisor to a team, 245 institutions entered the various sub-competitions and

over 2300 participants attended the final "Giant Jamboree" event held in Boston, MA (iGEM 2015c). The attendance was large because, to celebrate the tenth anniversary, there were no regional heats and all the competing teams were invited to the finale.

The foundation that runs the iGEM competition, currently directed by Randy Rettburg, casts itself as:

> An independent, non-profit organization dedicated to education and competition, the advancement of synthetic biology, and the development of an open community and collaboration.
>
> (iGEM 2015a)

However, taking part in iGEM had an almost hypnotic effect on me: sitting in the enormous auditorium; watching the stage relayed live on large projector screens; clapping for iGEM Alumni; watching teams glorified for their hard work. The event felt consuming, proselytising. In the conclusion of her PhD thesis, an ethnographic study of two iGEM teams, Caitlin Cockerton wrote:

> [The iGEM competition] has turned into a competition that educates, inspires and indoctrinates hundreds of students so that they help build, and take forward, synthetic biology's technical and socio-cultural foundations. It is a kind of evangelism that converts students to the cause.
>
> (Cockerton 2011, p.302)

The competition is aimed at educating and promoting one particular strand of synthetic biology – the standardised, BioBrick™ approach – and some teams of students conduct outreach at community 'do-it-yourself' biology clubs (Radick 2013). Though I did not concentrate on this global competition in my research, many participants cited it in various

arguments regarding synthetic biology: it appears to play an important role in the formation of the field (Frow & Calvert 2013a; Molyneux-Hodgson & Meyer 2009).

Aside from its disciplinary organisation, synthetic biology has proven a site amenable to study the emergence of research communities (Molyneux-Hodgson & Meyer 2009; Kastenhofer 2013); the promises and realisations of biotechnology (Frow & Calvert 2013a; Mackenzie 2010; Mackenzie 2013b); the application of standards to life (Steedman 2013; Mackenzie et al. 2013; Calvert 2013); the relationship between epistemic expectations and support for certain kinds of institutions (Schyfter & Calvert 2015); the difficulties in promoting innovation in a conservative industry (Molyneux-Hodgson & Balmer 2014); the practices of teams in iGEM (Balmer & Bulpin 2013; Cockerton 2011). This is partly because social research is often an integral component of funded projects, though this is not always a straightforward collaboration (Calvert & Martin 2009).

I focused on synthetic biology in the UK because of the changing emphases in funding between 2007 and 2014. The first main tranche of synthetic biology funding was aimed at forming a UK synthetic biology community (Molyneux-Hodgson & Meyer 2009). This was a total of approximately £800 000 (Biotechnology and Biological Sciences Research Council 2007). As I was designing my research, the government identified synthetic biology as one the UK's *eight great technologies* (Willetts 2013a). Total funding in the UK has exceeded £180m, with a proportion of investment specifically for commercialisation and innovation (Willetts 2013b). In UK synthetic biology a key aim is to accelerate commercialisation and make synthetic biology into a profitable industry (SynbiCITE 2015a). Indeed, "industrialisation is an important end point of synthetic biology" (Kitney & Freemont 2012, p.2035). The global synthetic biology industry is anticipated to be worth US$13.4 billion by 2019 (Transparency Market Research 2015) and the overarching aim of this thesis is to

investigate how, in the absence of an established industry to which knowledge might be translated, actors render UK synthetic biology translatable.

The administration of public funds for research is also relevant to this research project. The majority of UK research funding is administered by a set of quangos through two systems. In UK, the Higher Education Funding Council for England (HEFCE) and its devolved counterparts administer and allocate funds directly to universities. These can be spent as institutions see fit. Research is also funded directly via seven research councils, whose cooperation is facilitated by Research Councils UK (RCUK). Each council has a remit for a different area of research. The research councils are:

- Arts and Humanities Research Council (AHRC)
- Biotechnology and Biological Sciences Research Council (BBSRC)
- Engineering and Physical Science Research Council (EPSRC)
- Economic and Social Research Council (ESRC)
- Medical Research Council (MRC)
- Natural Environment Research Council (NERC)
- Science and Technology Facilities Council (STFC)

Councils can agree to co-fund projects. For synthetic biology, the main funders to date have been BBSRC and EPSRC.

The two funding routes, one through HEFCE via universities and the other through RCUK, constitute the ‘dual support system’. In addition to this system there is another quango called Innovate UK. This is the UK’s innovation agency and is located at the same site as RCUK in Swindon, but in a different building. Innovate UK funds businesses and companies to develop products and services and, in partnership with RCUK, have co-funded synthetic

biology among other biotechnology projects (Technology Strategy Board 2012b). Innovate UK was previously known as the Technology Strategy Board (TSB). The name change happened towards the end of my data generation period.

The thesis research incorporated various participants including researchers in synthetic biology and administrators and policymakers from universities, RCUK and Innovate UK. This research project is especially timely given the rise in synthetic biology funded by public monies, the emphases on academic accountability and actors' own commitments to 'industrial translation'.

1.3 Outline of the thesis

The thesis is presented in seven chapters and below I describe the contents of the remaining six chapters and their contributions to the overall argument. Part I contains two further chapters. In Chapter Two I review the main literature that is pertinent to the thesis arguments. I conceptualise translation as an entity for social investigation by introducing some of the analytical tools that researchers have employed to study translation in innovation. I review the relevant STS research on biotechnology and synthetic biology. I then move on to discuss methodological principles and 'rules' in STS. I describe how certain theorists expanded the idea of *symmetry* to include both humans and nonhumans in analyses of technoscience. This leads onto a theoretical discussion of objects with the idea that it is important to conceptualise synthetic biology in order to understand how it is, or could be, translated to something else. Overall in this chapter, I argue that a) ethnographic research can enrich understanding of academia-industrial translation in biotechnology and b) it may be possible to develop theories by bringing synthetic biology into dialogue with

specific STS conceptual frameworks. From these points I define the principal research questions.

In Chapter Three I discuss the way I conducted the research and justify the choices I made. I use a narrative approach to detail the project and attempt to highlight the complexities and problems I encountered. In order to attend to the heterogeneity and potential multiplicity of synthetic biology, the project took the form of a "multi-sited ethnography" that involved elements of "virtual ethnography" that took place in various locations, both on- and off-line (Marcus 1995; Hine 2007). I detail the various data-generation methods including interviews, observations and document analyses and how they contributed to the 'extension' of the project (Knorr-Cetina 2005a). I explain how I analysed the data and how the writing up of the thesis played an important role in shaping what it was possible to say. In closing, I summarise the positions I took regarding ontology, epistemology and methodology.

Part II details my analysis and contributions. It is structured using an adapted version of Fujimura's "three levels of work organisation" (Fujimura 1987, p.258).

> These levels include the experiment as a set of tasks; the laboratory as a bundle of experiments and other tasks; and the social world as the work of laboratories, colleagues, sponsors and other players, all focused on the same family of problems.
>
> (Fujimura 1987, p.258)

My 'levels' are alignment practices in the 'wider world' of state and science; institutional practices of universities and businesses; and laboratory experiments. Chapter Four concerns the level of the wider worlds of the UK state and academic biology. I describe how actors make synthetic biology into an object that can meet the state's desire to be a global leader of bioscience. I then show how actors rhetorically demarcate synthetic biology from controversial bioscience, such as genetically modified (GM) organisms, and claim that

synthetic biology can create wealth for the UK state by being a more controlled and powerful science. I argue that actors make their field of research relevant to state and society by imagining a future industry that involves using engineered microbes to produce chemicals and materials, but that does not involve releasing any modified organisms. It is a future industry of *contained bio-manufacturing*. This future makes synthetic biology translatable to the state in two ways – it maps out a plausible route for synthetic biology to realise the state's desire for international research status and, by addressing issues with GM technology, a plausible route to national economic recovery.

Chapter Five concerns the level of the institutions of universities and industry. First of all, I detail how collaborations are framed as an important part of translation, not only to ensure alignment of partners' expectations, but also as leverage to secure further resources. I argue that universities and sponsors attempt to initiate collaborations via events and funding mechanisms and that retelling 'success stories' about collaborations and successful innovation further perform the importance of collaboration. Section 5.2 consists of my analysis of observations and interviews in which participants enacted various problems with collaborations between academia and commercial enterprise. These include the timings and deadlines of project work, the different goals of each institution, the way knowledge is protected in the different domains and the skill sets or competencies of different workers. In the final section I argue that the new institutions of synthetic biology that have been funded in the UK, such as research centres and innovation centres, 'embed' commercialisation in the naming of biological parts, facilities and the training of newer scientists. Translating synthetic biology appears to involve (re)labelling objects and disciplining researchers to consider the applications and the impacts of their projects.

In Chapter Six, I move to the level of laboratory and tell a story of an academic collaboration which was aimed at engineering microbes to produce materials that could be used in

medical surgery. A group of academic tissue engineers had identified a clinical problem: when burns and ulcer patients need cell or skin grafts, the grafts may not 'take' and the cells can die. They reasoned this was because wounds are deficient in many important macromolecules. To remedy this, synthetic biologists wanted to redesign microbes so that they could produce biomaterials that could help skin grafts adhere to wound sites. In the chapter, I explore the material and rhetorical work that collaborators employed to maintain the project's alignment with both industrial hopes of producing a platform for manufacturing biomaterials and the medical hopes of a potential therapy. I show how making synthetic biology translatable partly involves inscribing values into the technological products of scientific research in order to maintain alignment with different futures. The project ends 'on the cusp' and I suggest that it is a realisation of a *contained bio-manufacturing* imaginary I developed in Chapter 4. Furthermore, there are enactments of problems in timings and skills that I discussed in Chapter 5.

In Chapter 7 I summarise the answers to my research questions and synthesise some of the earlier points into two generalizable concepts. This chapter stands as my empirical and theoretical contributions. Having answered the research questions, I conceptualise synthetic biology as an *unfolding multiple* that is expanding in different directions and incorporating practices as it spreads. I suggest that a mechanism driving this expansion is that actors identify different 'lacks' in synthetic biology and seek to extend knowledge in different ways. Thus, translation is a multitude of deficits that different groups of actors can address. The *unfolding multiple* is a reflexive theory in that I identified a 'lack' in the understanding of translation and extended synthetic biology in particular ways. Specifically, in making new links between actors and positing social theory. Secondly, many proponents of synthetic biology *mobilise vulnerabilities* to argue that their field of research can solve problems in skin graft surgery, in university-industry collaborations and ameliorate the poor state of the national economy. But they also mobilise synthetic biology's vulnerabilities. Actors point to a

hostile public, sensationalist media and to other issues that threaten their emerging 'immature' science. Actors, then, mobilise vulnerabilities in multiple ways to obtain and maintain support and resources for their research. In closing, this raises a question of accountability: I suggest that reframing 'compelling start out stories' (Deuten & Rip 2000) in this way may impact the way proposals are assessed and grants awarded.

This thesis makes several contributions to knowledge. First, my thesis adds to collective understanding of bioscience by empirically examining translation in the emerging field of synthetic biology. By contributing detailed descriptions and analyses of the different practices that make science relevant to society other researchers may be able to identify elements of this research that apply to their own situations.

Second, in Section 5.2, I present an analysis of the enactment of 'gaps' between universities and industry in synthetic biology. These are consistent with some literature, but also offer new points that demarcate science, particularly between academic and commercial knowledge production. This work may be of use to actors in both academic research and partnership administration who are considering commercialisation or instigating collaborations with industry. Although this project is focused on translation in synthetic biology in the UK, I suggest some of the theoretical findings are generalisable to other situations.

Third, I offer a synthesis of STS theory to conceptualise synthetic biology. I argue that elements of post-ANT and post-social theory are needed to theorise the emerging field of research. This framework may provide a novel and possibly more satisfying way to understand how complex and abstract objects can be an important aspect of contemporary sociality.

Fourth, I present a reframing of expectations and innovation narratives. Engineers and scientists identify (and create) problems and tell stories to convince sponsors to invest in their projects (Deuten & Rip 2000). These start out stories change over time – the promises of innovations can change (Deuten & Rip 2000; Marris 2013). I argue that rather than think about 'getting resources to solve problems' it may be profitable, in a climate of increasing accountability and responsibility in research, to consider how actors identify weaknesses and deficits as a way to acquire support and assets. I suggest that thinking about 'vulnerabilities' may increase awareness of how researchers claim to tackle issues and the relationship between those claims and the resources they obtain. This could impact the assessment of proposals in both public and private funding regimes.

Chapter Two

Difference and Do-ability in Scientific Work

This chapter reviews the bodies of literature and concepts that are important to this study. Section 2.1 frames science as a topic that can be studied sociologically and details some of the findings from this approach with respect to translational research in biomedicine. I focus on translational research as there is a body of STS literature that is focused on the life sciences and these works include examples of applications of STS theory. The concepts in this section also provide an important starting place, particularly for the argument in Chapter 5. Section 2.2 covers theories and concepts that have emerged in the social studies of biotechnology and relates some of the contributions to understanding synthetic biology. In particular, I focus on the roles and realisations of hype and technological promises, and the way that biotechnology changes how actors understand life, which are particularly relevant throughout Chapters 4, 5 and 6.

In Section 2.3 I turn to reviewing methodological principles in STS including the development of *symmetrical* analyses. Furthermore, "translation" is itself a term of art in STS and I explore various meanings associated with the term. This leads me to a discussion of *co-production*, the idea that knowledge and social order are made at the same time (Jasanoff 2004). This is particularly relevant to this study because actors involved in synthetic biology promote their epistemic commitments and organise institutions, such as iGEM, to deliver on the promises of synthetic biology. Then, in Section 2.4, I concentrate on STS perspectives on ontologies because, if translation is partly about movement and change, then what is moving and

changing? This forms an important underlying concern throughout Part II of this thesis and to which I return in earnest in Chapter 7.

2.1 Science as Culture

One way to understand science is that it consists of a community of actors behaving in accordance with specific norms (Merton 1942). Merton argued that science has four main tenets:

> *Communalism* meaning the way researchers make findings available through publishing to allow others to build on earlier work.
>
> *Disinterestedness* where scientists do not allow personal concerns to affect scientific investigation, which should rule out fraud because that reflects personal goals.
>
> *Universalism*, which means research is subjected to common, external evaluation which does not depend on the identity of individuals.
>
> *Organised scepticism* where critique is encouraged and where new findings are treated with caution.
>
> (Merton 1942)

As a structural-functionalist theory, if science is working properly by actors adhering to these norms, then science will be able to fulfil its role in society – to extended certified knowledge (Sismondo 2010, p.23). Mertonian norms imply that science can be understood as a single culture with a unified ethic and that scientists who follow this ethic are rewarded. While this can be regarded as a "pure, untainted sociology of science", the emergence of studies of scientific practices, coupled with sociological reflexivity, led to new ways of understanding science (Knorr Cetina 1991, p.526).

Merton's sociology did not focus on the technical content of science. A social critique of the production of knowledge came later. *The Structure of Scientific Revolutions* (Kuhn 2012), first published in 1962, used a historical approach to challenge some assumptions about the progressive accumulation of knowledge. Kuhn argued that *normal science* happens when experimental and theoretical developments are articulated with one another within a larger conceptual framework. Kuhn called this overall conceptual consensus *a paradigm*. During a period of normal science, scientists engage in *puzzle-solving.* An example of *puzzle-solving* is when scientists, after Mendeleev proposed the overall theoretical system of the periodic table once, engaged in identifying specific elements to 'fill in the blanks'. Sometimes, Kuhn argued, there are problems that cannot be solved. These anomalies are 'parked' but, over time, they accumulate. Eventually, they become so numerous or problematic that a new overall theory is proposed and a new paradigm emerges in a process Kuhn calls a *revolution*.

One of the book's pivotal examples of a revolution compares Newtonian and Einsteinian physics. The meaning of "mass" as an absolute attribute in Newton's terms is *incommensurable* with the relative Einsteinian version. Therefore, for Kuhn, the new paradigm does not include all the knowledge and developments of the previous system. The upshot is that science, according to Kuhn, is not a continuous process of accumulating knowledge but involves jumps and disjunctures. Kuhn's main target was the idea of scientific progress as incremental accumulation of knowledge. It is also evident that at least two communities adhering to different scientific paradigms can co-exist and that science, therefore, is not necessarily unified or universal. Both Kuhn's and Merton's works form important starting places for this thesis, not least because they paved the way for STS more broadly.

During the 1980s, several studies were published where sociologists and anthropologists had entered scientific laboratory sites and closely observed the practices of scientists (Knorr Cetina 1983). Later laboratory ethnographies further elucidated the cultural disunity of science. For example, molecular biology is organised into smaller laboratories. Individual researchers engage in work at their bench, and their dexterity and physical skills are important as they conduct experiments and produce knowledge (Knorr-Cetina 1999; Myers 2008). On the other hand, the field of high energy physics involves large research groups, working in concert with large detectors and computers, organised around identifying very small and very fast particles (Knorr-Cetina 1999).

Traweek's (1992) ethnography contrasted high energy physics laboratories in the USA and Japan and found that – among other things – male dominated cultures excluded women by different means. In the USA laboratory, there was much phallic imagery and women tended to work in clerical roles. In Japan, it was not possible for women to become experimentalists because experimental work was often scheduled overnight, and until 1986 it was illegal for women to work at night in Japan. Thus, there are differences within disciplines.

While these examples have quite different emphases, they highlight the notion that science is internally differentiated along various epistemic, material and social axes. These further imply that science systematically violates the tenets of communalism, disinterestedness, organised scepticism and universalism. So, if not by following Mertonian norms, how does a culture of science value and reward researchers?

Scientific credibility and relevance

In different cultures people can gain forms of *cultural, economic, social* and *symbolic capital* in different ways (Bourdieu 1977). Scientists need to be funded to pay for equipment, staff, travel, consumables for experiments and administrative work and other things necessary to conduct their practices. In the ethnography *Laboratory Life* (Latour & Woolgar 1986) scientists gain access to funding by raising their status and respect in the *credibility cycle*. Researchers publish articles, get recognition, apply and win grants, buy resources, conduct experiments, produce data (Latour & Woolgar 1986, p.201). Then they publish their findings and begin the cycle again.

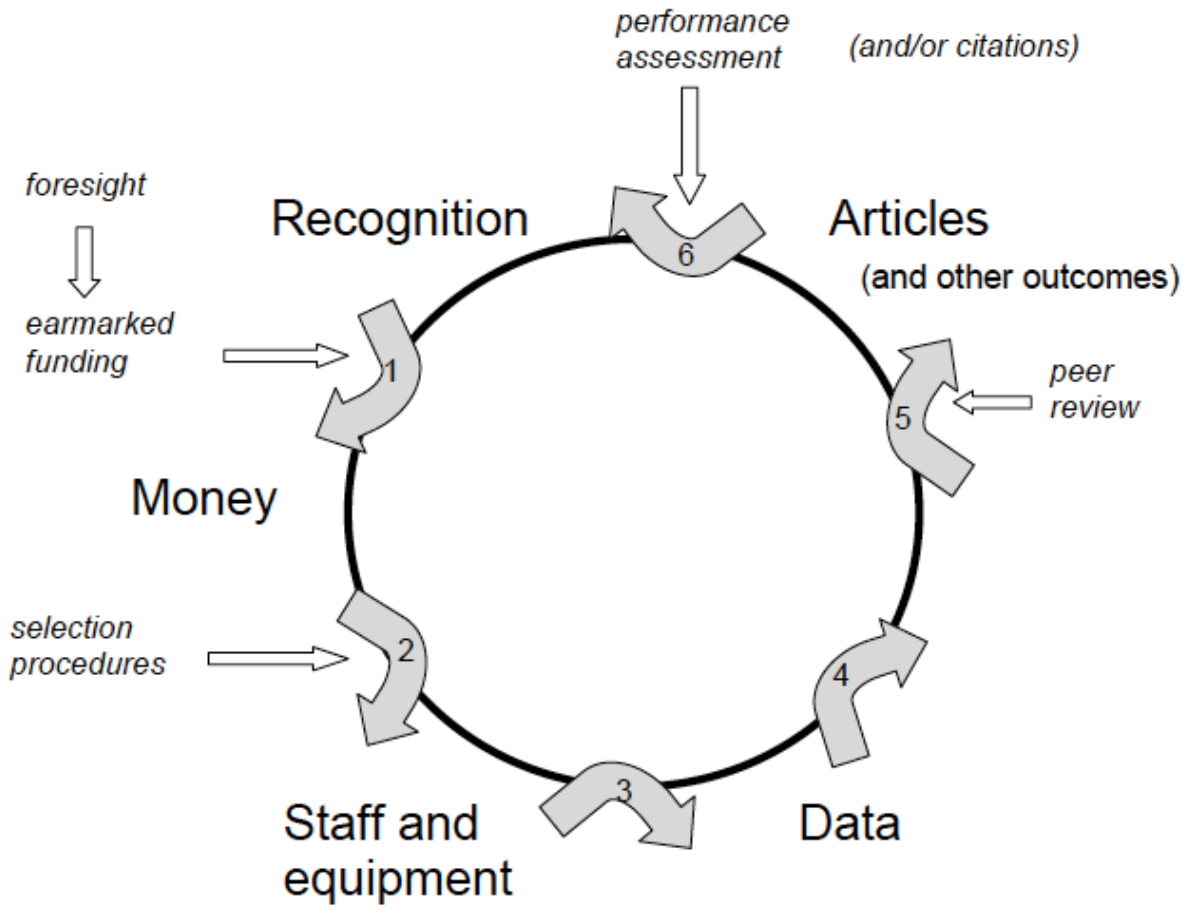

Figure 3. A credibility cycle (Hessels et al. 2009, p.396)

Further elaborations have emphasised the idea that contemporary science also derives credibility from demonstrating its *relevance* (Hessels & van Lente 2008; Hessels et al. 2009; Rip 1994). Thus various specific funding and intra- and extra- institutional forms of auditing affect the credibility of researchers (Hessels et al. 2009, p.396). Figure 3 on the previous page attempts to capture multiple influences on credibility.

This model acknowledges various ways in which scientists can get more resources to publish more, including how science is assessed and funded. Furthermore, as some scientists are increasingly expected to patent their findings as a way to attain status, 'patenting culture' means that researchers must attend to different modes of credibility in academia and industry (Packer & Webster 1996). Rip's (1994) model of various 'struggles' for status embeds the credibility cycle in a wider social milieu. This shows the interrelations of scientific credibility (facticity), funding, relevance to state and stakeholders, and legitimacy to research practices. See Figure 4 on the following page.

Following Rip (1994), it is possible to see the current emphasis on research translation as elevating the import of achieving relevance to sponsors' goals and legitimacy from expert and non-expert groups. In bioscience, for instance, recently neglected disciplines such as epigenetics and immunology are receiving greater interest since they better attend to biological complexity than the genetic determinism of the Human Genome Project (HGP) which, in a climate of an increasing audit culture in academia, has not produced the anticipated medical benefits (Rajan & Leonelli 2013; Kraft 2013).

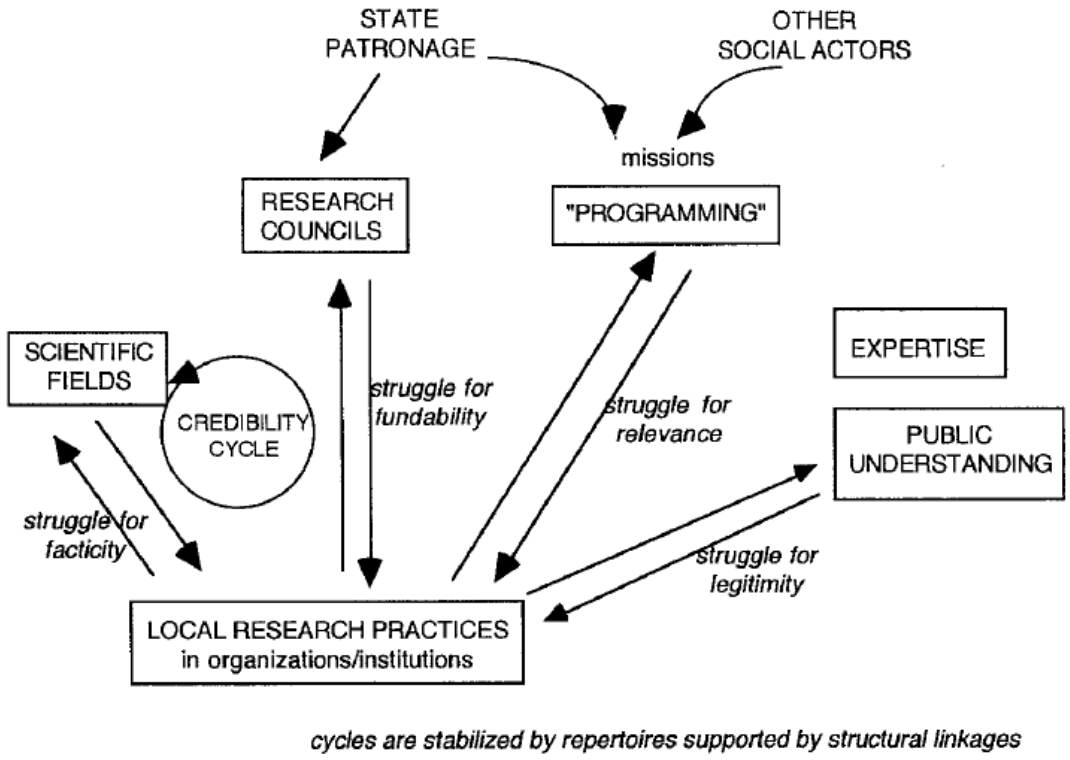

Figure 4. Struggles for funding and relevance (Rip 1994, p.10)

Furthermore, bioscience is shaped by other processes including capitalism and globalisation (Rajan & Leonelli 2013). So, the ways bioscientists achieve and maintain status is constantly shifting. Translation draws attention to some of these alterations, including which kinds of sciences successfully demonstrate their relevance.

Rajan and Leonelli's (2013) framework of epistemic and structural changes partly overlaps with STS discourse regarding the relationship of the shape of the knowledge economy. Thus, turning research into marketable products and services has emerged at a time when science is subject to other concerns:

> Interest in the commercialization of science has increased exponentially with the dissolution of the Cold War, the decline in military funding, hostility toward government interference, public skepticism about the telos of science, questions about the

> accountability of scientists, and the push to develop connections between business and science.
>
> (Mirowski & Sent 2008, p.673)

In the 1990s, two models of the changing relationships between academia and other institutions were proposed. The first suggested a shift from *Mode 1* knowledge production to *Mode 2* (Gibbons et al. 1994). Mode 1 research is what might be considered 'traditional' science. There are clear-cut disciplines with established hierarchies. Science is apparently autonomous. Mode 2 knowledge production, however, is marked by greater interdisciplinary working arrangements, distributed accountability and a greater emphasis on applied knowledge (Nowotny et al. 2001; Gibbons et al. 1994). Alternatively, these changes were expressed with the notion of a new *triple-helix* of industry, academia and government which was replacing the previous arrangement of industrial society which only involved government and industry (Etzkowitz & Leydesdorff 1997; Etzkowitz & Leydesdorff 2000; Leydesdorff & Etzkowitz 1996). The spreading agenda of translation, with its emphasis on multi-partnered knowledge making and the production of research relevant to industry and government, appears to be a manifestation of this more socially embedded science.

Shinn (2002) contrasted these two approaches siding with the *triple helix* on the grounds it was empirically grounded, global in scope, acknowledged differences in institutions while not advocating a wholesale shift from one to two and, finally, that it was clear where the authors derived their theoretical ideas. Following up on this, Mirowski and Sent (2008) argue that both *mode 2* and *triple helix* theories are too attached to a before-after notion of novelty and that both were guilty of overgeneralising the current structures, rather than emphasising plurality. Despite its limitations, *mode 2* is a framework of particular interest in science policy because it 'labels' an increasing concern, facilitates policymaking and "feeds the need for mimesis in science policy making" (Rip 2000, p.29). Though these theories have their

limitations they do appear to capture trends in the way that relationships are changing and the desire for coordinated action between different groups.

Thus, any study of translation needs to find a way to be aware of the broader academic and social changes. At the level of abstraction of *modes* and *helices*, the above concepts have left behind the idea of studying local scientific practices as pioneered by Kuhn and later ethnographic work. Translational research, though, has been analysed with an ethnographic approach, which attends to the need for specificity and plurality mentioned above.

Cultural differences between researchers

In biomedicine, translational research can be understood partly as a response to perceived differences between laboratory and clinical science practices and values (Kraft 2013). Stem Cell Research (SCR) has been a particular site in which to explore the differences of biological science and medical science. Medical culture, in SCR, prioritises finding the best outcome for patients and, as such, 'black-boxes' mechanisms of action or the 'way treatments work'. Meanwhile, scientific culture is marked by meticulous experimentation where understanding the underlying processes is a priority (Wainwright et al. 2006b). Thus, epistemic commitments can be problematic as researchers can disagree about what would be the best course of action for a particular project with finite resources – more fundamental knowledge versus patient trials.

Furthermore, SCR is often aimed at producing clinical benefit by eventually being used in transplantation procedures (Wainwright et al. 2008), such as tissue repair procedures I explore in Chapter 6. Instead, some researchers propose an alternative SCR where stem cells can be used to create an experimental model of a 'disease-in-a-dish' in order to test

potential therapies. This different future can be seen as a 'more realistic' goal for the use of stem cells partly because large drug companies appear reluctant to support the transplantation programme. Scientists can get more credibility, or *expectational capital*, by proposing a more plausible, or at least a less grand, future (Wainwright et al. 2008). Thus, the pursuit of credibility can affect how researchers try to make their science relevant to different audiences.

The emphasis on translation in SCR has affected the credibility and standing of other communities of researchers, too. Clinician-scientists, who play a pivotal role in conducting phase I and II clinical trials, have found a renewed status and professional identity as leaders of translational research (Wilson-Kovacs & Hauskeller 2012; Vignola-Gagne 2013). This appears to be a shift from what was once regarded as an unsure role in biomedical innovation to a more secure position. Their new hierarchical standing is partly due to their control and administration of randomised controlled trials (RCTs). Clinician-scientists' value relies on their breadth rather than their depth of knowledge and their ability to move between, and interact with, both laboratory or clinical professionals (Lander & Atkinson-Grosjean 2011). This is an example of how the translational agenda is reshaping professional identities and roles.

Furthermore, in recent years there have been increases in the number of actors engaged mediating knowledge between research cultures and other domains (Meyer 2010). In 2008 the MRC trialled a 'research translator' as a *knowledge broker* between scientists and clinician-scientists (Morgan et al. 2011). Part of their role was to encourage a 'translational ethos'. It appeared that the field of clinical science and the aims of the research translator were closely matched in the way that capitals might be accrued. The basic scientists, however, had a different cultural value system that perceived the research translator's strategies as risky to their own modes of accruing capital. These studies further

conceptualise the 'problem of translation' as differences between cultural reward and value systems. They also rely on the production and perpetuation of a boundary between different research cultures.

Maintaining boundaries

So far, I have focused mainly on the internal differentiation of research. But science is a part of society. How, if at all, is science separated from society? Since actors must interpret norms (e.g. Merton's) this makes it possible to study them as cultural resources (Sismondo 2008, pp.29–32). One research tactic is to chart how actors deploy norms in order to determine what counts as science to what shall be excluded, termed *boundary-work* (Gieryn 1983). This happens at specific instances in which science can be characterised in different, sometimes conflicting ways, depending on the argument being advanced. It also entails the characterisation, or differentiation, of science and pseudoscience, and is therefore aimed at maintaining authority, credibility and access to resources (Gieryn 1999; Gieryn 1983). This division is blurred and contingent. It means that science is actively defended and demarcated at specific points. There are at least three forms of *boundary-work:*

> *Expulsion* is an intra-scientific contest in which authorities battle for what counts as science and what does not and is often a new and radical proposition up against a traditional dominant paradigm.
>
> *Expansion* involves spokespersons for science versus those for non-science, such as religion, politics or folk knowledge, attempting to extend their claims to authority over a particular domain.
>
> *Protection of autonomy* is the third form of *boundary-work* where actors outside of science seek to maintain scientific credibility, but exploit research findings for market or

> political purposes. This form also extends to when scientists claim they are not responsible for 'downstream' consequences of research.
>
> (Gieryn 1999, pp.15–18)

Boundary-work can occur from inside and outside science. *Boundary-work* is pertinent to this research because of the increasing cultures of accountability in academia I have already mentioned. This means scientific autonomy is at stake as research scientists are encouraged to involve other stakeholders, such as industry, in the production of knowledge. The concept of *boundary-work* can also help analyse the formation of new disciplines (Lamont & Molnar 2002), such as synthetic biology.

A somewhat contested boundary in science is between notions of 'basic' and 'applied' science. Researchers deploy the term "basic research" in various ways to mean different things (Calvert 2006), which can change how science is made relevant. Thus, in SCR, boundary-work partly consists of framing research so it advances both 'basic' and 'translational' aspects of science by being both scientifically credible and because it begins the journey to the clinic, respectively (Wainwright et al. 2007). But, SCR scientists are wary of attempting experiments in humans, while doctors are keen to do their best for patients and yet are aware of the complexity and uncertainty in new, radical treatments (Cribb et al. 2008). These two institutional ethical positions are also reflected in the conflict between 'regimes of hope' and 'regimes of truth' in potential Parkinson's Disease treatments (Moreira & Palladino 2005). A 'regime of hope' focuses on future promises of medical intervention whereas a 'regime of truth' focuses on the production of knowledge. So, SCR researchers do 'ethical boundary work' (Wainwright et al. 2006a). Ethical boundary-work involves:

> both owning the ethical issues as a sign of responsible and thoughtful engagement in a highly contested domain, whilst concurrently devolving ethics to authorities outside science, especially those charged with regulation.
>
> (Wainwright et al. 2009).

This form of boundary-work involves researchers demonstrating that they do consider ethical issues and, at the same time, referring ethical decisions to other groups. Maintaining ethics then, just like maintaining authority, takes labour. In this case, ethical boundary-work can increase the status of non-scientific actors, such as regulators.

Translation draws attention to boundaries between different cultures. The studies show that researchers attempt to demarcate their own practices from other practices. However, boundary-work is material as well as rhetorical (Meyer 2006). In Section 4.2, I follow up the idea that synthetic biology is demarcated from GM science (Calvert 2013) and situate this in the context of gaining resources. In Section 5.2 I describe how an academic-industry divide is enacted at different points in time and space, which suggests translation is partly dependent on establishing difference.

Crossing boundaries

There is a large STS literature concerning ways that different groups communicate with one another. One concept, 'trading zones' (Galison 1987; Collins et al. 2007), suggests that different epistemic communities may develop pidgins and creoles in order to communicate. Others explore 'tacit knowledge' (Collins 1985; Howells 1996; Polanyi 2005; Collins 2010), which emphasises aspects of knowledge that cannot be articulated and need to be transferred in practice. Some of these concepts have been hypothetically applied to translating knowledge to build nuclear weapons (MacKenzie 1999) and so could be

profitably applied in empirical STS approaches to translation. However, I have selected to focus on a specific framework because it has been applied to studies of translation – *boundary objects* (Star & Griesemer 1989).

These authors were investigating how professional and amateur scientists worked together to make knowledge at Berkeley's Museum of Vertebrate Zoology from 1907 to 1939. Scientific work, such as collecting specimens, turns out to be 'heterogeneous' and requires the cooperation of different groups without, so Star and Griesemer claim, a clear consensus. The authors focus on the pragmatics of how "n-way translations" (ibid. p.412) between groups are coordinated. By comparing the 'visions' of scientists, collectors, trappers and administrators they argue that cooperation is achieved in part through the creation of boundary objects. They describe four types of boundary object.

> *Repositories* are collections of categorised objects like libraries and databases. These collections are modular and groups can access them without needing to address any differences of purpose.
>
> *Ideal types*, for example, diagrams of species. These facilitate collaboration by those allowing people with experience of many individual cases of a species to communicate.
>
> *Coincident boundaries,* which might be various maps of the state of California. These "have the same boundaries but different internal contents" and contain different information depending on whether they are used by scientists, collectors or government officials.
>
> *Standardised forms*. Amateur collectors were given standardised forms to document the specimens they gathered. The forms were unchanging and structured and formalised the way information was recorded and categorised.
>
> (Star & Griesemer 1989, pp.410–411)

This is not a complete list, but an initial taxonomy of boundary objects (Star 2010). The 'interpretive flexibility' (Pinch & Bijker 1984) of these boundary objects, the different ways of valuing and using them, facilitates the cooperation of different social groups.

Boundary objects has proved such a popular concept that there are more recent elaborations on what counts as a boundary object. They are objects of organisational scale and scope that exist between groups of people in specified contexts (Star 2010). While the initial formulation of boundary objects focused on the practical aspects organising different groups', later work, particularly studying the biosciences, examined the symbolic meanings of these objects (Fox 2011; McGivern & Dopson 2010; Swan et al. 2007). Many types of object can exhibit *interpretive flexibility* but many do not facilitate collaboration in the way the concept initially sought to capture. However, boundary objects and other related concepts may exaggerate the difficulties of communication between groups (Sismondo 2010, p.21).

With respect to translational research, human embryos can act as *boundary objects* that facilitate collaboration between SCR scientists and pre-implantation genetic diagnosis (PGD) laboratories (Williams et al. 2008). The interconnection was created by a difference: to PGD laboratories embryos are unwanted rubbish, but for SCR laboratories they are a valuable source of stem cells. The embryos became an object facilitating translation as the two different groups worked together to create human stem cell lines (Wainwright et al. 2009).

Translation has emerged as an explicit agenda in biomedical science, though, there was surprisingly little sociology investigating laboratory-clinic relations (Wainwright et al. 2006b). Furthermore, what there is tends to have been in situations of newer and potentially controversial science. Sociological research on translation in bioscience has, to date, focused mostly on stem cell science. However, it has demonstrated the successful deployment of analytical concepts including *cultures, credibility* and *boundaries*. These

studies have used a variety of methods, including historical analyses and ethnographic work predominantly based on observations and interviews. I have sought to outline how translation can be treated with STS approaches and now move on to literature on biotechnology and, more specifically, synthetic biology.

2.2 Promises and Products of Biotechnologies

Hype and expectations

An idea I mentioned in Chapter 1, and return to throughout the thesis, is that synthetic biology is a field of research that claims to be of great potential. This is despite a more critical position that there is a "myth of a biotechnological revolution" (Nightingale & Martin 2004; Hopkins et al. 2007). Even though there has been a large increase in possible drugs, there has been no sudden shift in the procedures and structures of industrial production and clinical practice, even perhaps a chance that "biotechnology has exacerbated the problems associated with drug development" (Hopkins et al. 2007, p.583). One of the authors' conclusions is that, if biotechnology has only had a limited impact on the sector so far, the hopes that biotechnology can bring about an increase in health and wealth is misplaced. Ultimately, the hype surrounding biotechnology exists precisely because it is having a limited effect, is not revolutionary, and instead "shared expectations are needed to co-ordinate the long-term, incremental process of technological accumulation" (Hopkins et al. 2007, p.586).

One of the key insights into the expectations and promises of technologies are their 'performative' effects (Michael 2000). Expectations about the future are active in the present: they can be used to mobilise resources and materials and shape the world to different extents (MacKenzie 2006; Pollock & Williams 2010). Expectations can have two

components. The way the future is constructed in the present and the way that past futures are remembered in the present (Brown & Michael 2003). But, predictions such as these place scientists' reputations at stake and therefore have implications for credibility (Brown 2003). So, the future of research is an important component in the organisation of biotechnology.

Returning to SCR innovations, the history of the translation of haematopoietic stem cell to therapy can be told, not as a recent "bench to bedside" initiative, but as beginning shortly after World War II and with many promises remaining unrealised (Martin et al. 2008). In this way scientists and entrepreneurs have long formed 'communities of promise' aimed at what is now being called translational research. In synthetic biology, this orientation to the future has been called a *community of vision* (Kastenhofer 2013).

The promises of synthetic biology are not static, either. The most visible 'success story' has been the production of semi-synthetic artemisinin, a potent antimalarial drug, using synthetic biology techniques to replace the extraction of the drug precursor from cultivated plants (Hale et al. 2007; Martin et al. 2003; Paddon et al. 2013; Ro et al. 2006). The Artemisinin Project was proposed as a solution to a crisis of malaria treatment. Over time, funding changed. The WHO changed their regulations and the price of artemisinin began to fluctuate. The promise of synthetic biology as producing a dependable, controlled amount of chemical turned to 'market stabilisation' (Marris 2013). It is therefore important to track who makes promises and how they are or are not realised.

Fulfilling promises

The proponents of synthetic biology are attempting to create an engineering discipline that "promises products rather than experiments" (Mackenzie 2010, p.194). The emphasis on innovation raises questions of how life can be researched and how those findings are applied to commercialisation and ownership practices such as patenting. Synthetic biology's reductive, Biobrick-type approach makes it particularly amenable to current ownership regimes because the novel discrete elements can be recognised by the patent system (Calvert 2008). There is a good deal of "bio-prospecting" – finding organisms which may have useful genes – in order to own tracts of 'genetic land' in the hope of future profit (Pottage 2006). Interestingly, the discourse of openness and sharing in synthetic biology appears to contradict the discourse of property ownership meaning it is an open question as to whether synthetic biology realises an idealised version of shared knowledge, or follows previous biotechnologies down a patenting route (Calvert 2012).

Perhaps, the main promise of synthetic biology is that "biology is technology" (Carlson 2010). However, the symbols of this promise such as biological oscillators, known as repressilators (Elowitz & Leibler 2000), can become integrated into networks of engineering developments.

> They signify iconically – through devices such as clocks and oscillators – that synthetic biology is a rate-controlled way of accomplishing change. Yet iconic forms become more infrastructural as they develop: they become more linked to other systems, and to complicated configurations of technical elements. At the same time, infrastructures are vital to realisation of the promise of synthetic biology.
>
> (Mackenzie 2013b, p.10)

This means objects can 'slip' between being symbols of the promise of synthetic biology and being the infrastructure on which synthetic biology is built. Thus, the specific realisations of

synthetic biology are partly dependent on which symbols of control and engineering move into infrastructural roles.

The emergence of synthetic biology depends on other factors as well as technical realisations. As the communities of synthetic biologists form they employ a range of 'devices' – journals, meetings, conferences, the international iGEM competition – to facilitate identification of, and identification with, the field (Molyneux-Hodgson & Meyer 2009). In the UK and US, the promises of applications and economic benefit have resulted in funding for specific research and institutional organisations (Schyfter & Calvert 2015). However, the funders have been more interested in the economic benefit and this has led to specific institutional developments which may have overlooked some key infrastructures required to realise synthetic biology, and may therefore forfeit subsequent profit (Schyfter & Calvert 2015). And, while it may be tempting to imagine that synthetic biologists adhere to a common future, they often have different versions of how synthetic biology might be organised and what it might contribute (Frow & Calvert 2013b). The creation of the Biobrick, for example, requires alignment of different values – academic, ethical, economic – in order to partially stabilise the concept (Frow 2013). The dynamics of expectations and realisations are complex and the interplay of different actors produces contingent instantiations of synthetic biology.

Furthermore, there may be 'barriers' to realising synthetic biology's potential. One study, concerning the collaboration of academic and industrial scientists in the water industry, argued that the water industry imagined a price sensitive and unaware consumer for whom access to water was a right (Molyneux-Hodgson & Balmer 2014). The upshot of this was that innovations suggested by the academics were not developed because the conservative water industry felt that consumers would be unhappy to pay for new technology. Another reflection on how the public was constructed in the discourse surrounding synthetic biology

argued that UK actors routinely imagine a public fearful through lack of education (Marris 2014). The public participation in synthetic biology operates in two modalities – validation and participation (Mackenzie 2013a). However, according to Mackenzie, most of the existing engagement either focuses on validation or assumes validation within the mode of participation. This relates to the earlier point that synthetic biology is actively 'struggling for legitimacy' (Rip 1994) by conducting public engagement aimed at ratification. This is despite a well-established line of publications in STS that there are still "misunderstood misunderstandings" (Wynne 1992) about why a part of society may question or reject scientific agendas and research.

There are more general theories for how biotechnology creates value rather than the realisation of promises. From her analysis of observations of 'the Visible Human Project' that created 'atlases' of internal images of people, Waldby suggests that,

> …biotechnology is a means of gearing the material order of living matter, and biomedicine in particular seeks to produce what I term 'biovalue', a surplus value of vitality and instrumental knowledge which can be placed at the disposal of the human subject.
>
> (Waldby 2000, p.19)

This imperial medical logic appropriates and alters things that are not, or not entirely, human (e.g. foetal matter, extracted cells, plants), for that which is deemed human in an attempt to increase longevity and health. This suggests that, at its heart, biotechnology is aimed at producing some form of surplus value. Synthetic biology fits this framework by combining knowledge to reconfigure biology for human ends.

Furthermore, *Biocapital: the constitution of postgenomic life* (Rajan 2006) explored the landscape of drug development and biotechnology companies in the US and India arguing

that biotechnology can be understood only in relation to the economic system in place. Neoliberalism and biotechnology are completely intertwined and developments include the outsourcing of drug trials to 'cheaper' places such as India (Cooper 2008).

These notions of increasing value may overgeneralise and oversimplify matters. The 'bioeconomic' notions of *biovalue*, *biocapital* and *life as surplus* were criticised for fetishizing the 'bio' and for not recognising the main change was from a commodity to a rentier economy (Birch & Tyfield 2012).

This section has covered some of the ways that synthetic biology is realised. The actualisation of synthetic biology takes many forms. It can be turned into patents to demonstrate value to potential investors. Synthetic biology can be turned into material forms, which can begin as symbolic advances, and its promises are turned into organisational and institutional developments.

Design changes life

Biotechnology does not only exploit that which is not classed as human for that which is, but it can also alter what "life" itself means. Starting a history of biotechnology, not in the 1970s but in the 1890s, Landecker argues that the emergence of various cloning techniques including freezing, amplification and synchronisation make 'life' a different entity:

> As a subset of this longer twentieth-century course biotechnology, the cloning story makes it matter differently to be composed of cells and cell cycles. Being a cellular entity after cryobiology and cell synchrony means being freezable and open to artificial synchronisation; any living thing made of cells, after these interventions, becomes an object that can be stopped and started, suspended and accelerated.
>
> (Landecker 2007, p.232)

Biology changes our concept of life. The interventions actors use to study an object changes the knowledge we have about that entity. In other words, the intervention in and manipulation of cells alters what we know of the 'bio-' in specific ways – life becomes something that seemingly can be increasingly controlled.

The main thrust of synthetic biology is to apply design principles to biology to make engineering life easier. Claims to biological design rhetorically function to separate synthetic biology from other trends in biotechnology (Calvert 2013). Design also does more. The computer software developments flatten the space and work of synthetic biology. This is accomplished by exhibiting a DNA design as a line of simple icons and eliding the various complex operations and techniques needed to assemble them (Mackenzie 2010). The agenda of standardisation is also altering biology. Planning the creation of Biobricks changes the way scientists engage with life by removing the 'artisanal' nature of molecular and micro-biology and encouraging knowledge exchange in a market-like environment (Mackenzie et al. 2013). As this work continues, what is 'synthetic' and 'natural' become defined at specific points, such as establishing novelty in a patent application (Calvert 2010). Synthetic biology, as it develops, changes the meanings of biology and biological work. As well as causing changes in the meaning of life in local practices, synthetic biology is also part of a wider discourse regarding the implications of science, to which I now turn.

Ethical and social implications

The first few years of synthetic biology saw the publication of many reports concerning the ethical and moral implications of the overall project (Nest High-level Expert Group 2005; Partliamentary Office of Science and Technology 2008; Balmer & Martin 2008; Royal Academy of Engineering 2009). The table on the next page summarises some main themes.

These concerns have given way to different interests. An new line of argument is that the worries about biosecurity are misplaced because they rely on the idea that the path from knowledge to material instantiation of weapons is linear, and simple (Marris et al. 2014; Jefferson et al. 2014b). The other is that, as synthetic biology emerges, how will it be governed? Earlier conversations were about the community's attempts to establish a self-governance structure based on the Asilomar conference in 1978 (Lentzos et al. 2008). The *Journal of Responsible Innovation* published a special issue following a workshop in 2015 to map out various lines of social enquiry in synthetic biology. One of these was that "translational governance research" was needed in order to make decisions regarding the global regulatory structures (Kuzma 2015). But, as with any science, synthetic biology knowledge will always be incomplete making risks unknowable and, at the same time, its multidisciplinary, multinational status meant that responsibility and authority will be divided and clear lines of governance may be impossible (Zhang et al. 2011). This means that self-governance, or external accountability, will be difficult to establish. In other words, the international multiplicity of synthetic biology makes management and regulation problematic.

Figure 5. Table of ethical and legal implications of synthetic biology

Theme	Commonly cited concerns
Biosafety	Accidental or intentional release of microorganisms into the environment could have unexpected consequences as synthetic organisms interact with surroundings and possibly evolve unpredictably
Biosecurity / Bioterrorism	The ability to construct new, modified or already existing microorganisms to use for malicious purposes is a threat. The increasing capacity to design and order DNA online from synthesis companies, in combination with a growing community of 'do-it-yourself biologists' practicing 'garage biotechnology' are a significant worry and difficult to regulate. A biosecurity threat is conceivable at both state- and individual- levels
Patenting: Commercial vs Public Good	The commercial potential of synthetic biology applications has led to concern that patents and monopolies could inhibit basic research and progress in the field. An 'open source' movement has responded to worries over burdensome patent thickets; for instance, the BioBricks Foundation (BBF) is a significant initiative working to facilitate an open research commons. Experts suggest both patent and open source frameworks are needed, but no uniform resolution yet exists
Trade and Global Justice	With the development of synthetic chemicals to replace cumbersome isolation and manufacture of naturally existing compounds (e.g. from plants), critics argue that synthetic biology could destroy local production in developing countries, thus maintaining the gap of health and wealth between rich and poor countries
Playing God	The promise that synthetic biology might create 'artificial life' or is about the 'design and construction of synthetic life forms' has evoked fears that practitioners of synthetic biology might be 'playing God'

(adapted from Cockerton 2011, p.24)

An interim conclusion to this chapter: synthetic biology and an emphasis on academic translation have emerged at approximately the same time. Social studies of translation have focused on new biotechnology, but they have tended to focus on the laboratory and clinic. Meanwhile, studies on synthetic biology have contributed much to understanding how a discipline can begin to form and how promises and value can be realised. The intersection of the drive for academic resources in synthetic biology, and the translation agenda for contextualised, realisable science that delivers societal and economic returns, make this project relevant to contemporary bioscience, academia and policy circles. I now move on from the conceptual apparatus relevant to translation and synthetic biology to the epistemological and methodological traditions within STS.

2.3 Producing Knowledge and Society

So far I have focused on understanding translation and synthetic biology as cultural phenomena. STS also has a rich history of methodological philosophy. In this section I review a selection of approaches to tell a particular narrative of conceptual developments. I begin by outlining approaches to researching the production of scientific knowledge and move on to discuss an attempt to combine different strands of STS research. This section is especially relevant to the principles I used to underpin the methodology of this project, covered in Sections 3.1, 3.2 and 3.4.

Symmetries and translations

Methodologically, Kuhn's *The Structure of Scientific Revolutions* focused on an historical analysis of the practices and meanings within science and related knowledge and social

order. This opened the door to examining science, not as a community of ideals, but as different communities specific to points in space and time. This approach to the sociology of knowledge production was extended in the 1970s by a group of scholars, based mostly at the University of Edinburgh, who developed an approach known as 'the strong programme'. Proponents advocated that sociology, rather than being focused on the context of knowledge, could raise its ambitions and "explain the very content and nature of scientific knowledge" (Bloor 1996, p.1). This programme was to have its own four principles:

> It would be *causal*, that is, concerned with the conditions which bring about belief or states of knowledge. Naturally there will be other types of causes apart from social ones which will cooperate in bringing about belief.
>
> It would be *impartial* with respect to truth and falsity, rationality or irrationality, success or failure. Both sides of these dichotomies will require explanation.
>
> It would be *symmetrical* in its style of explanation. The same types of cause would explain, say, true or false beliefs.
>
> It would be *reflexive*. In principle its patterns of explanation would have to be applicable to sociology itself. Like the requirement of symmetry this is a response to the need to seek for general explanations. It is an obvious requirement of principle because otherwise sociology would be a standing refutation of its own theories.
>
> (Bloor 1991, p.5)

The strong program explicitly emphasised the social factors that determine scientific knowledge. The explanations for 'truth' and 'belief', they argued, needed to be symmetrical in the sense that they should both be explained socially. Schaffer put the problem of asymmetry, by explaining 'truth' with reference to nature and 'falsity' with reference to the social, in an especially dry way in an interview for a Canadian radio series:

> It didn't look remotely plausible to say that Isaac Newton thought that there was an inverse square law of gravity acting instantly at a distance through empty space between the centres of distant bodies because there is an inverse square law acting instantly from the centre of one body to another. And Leibniz disagreed because he was German.
>
> (Schaffer 2009)

In other words, it was inconsistent to apply one set of explanations for one outcome and another set for a different outcome.

Scholars associated with the strong programme were able to describe the social processes of creating 'the scientific method' (Shapin & Schaffer 1985). They also described the processes in resolving the problem of regress, or how do you decide an experiment is right without doing another experiment, by showing how scientists invoke social arguments about competency and nationality rather than nature (Collins 1985). A related approach, *the social construction of technology* (SCOT), sought to apply similar principles in explaining how various technologies became stabilised (Bijker 1995; Pinch & Bijker 1984). However, the strong programme's acknowledgement that 'there will be other types of causes apart from social ones' created a blind spot that could be critiqued by other groups of scholars.

The strong programme was based on an identification and analysis of social groups' interests. Some scholars were unhappy with what they saw as the static sociological notion of 'interests' as used by 'The Edinburgh School' (Yearley 2005). Instead of competing interests they suggested that people tried to actively engage and enrol one another.

> [People] try to persuade by telling one another that 'it is in your interests to…' . They seek to define their own position in relation to others by noting that 'it is in our interests to…'. What are they doing when they so attempt to map and transform interests? Our view is that they are trying to impose order on a part of the social world.
>
> (Callon & Law 1982)

Social actors, in this line of argument, attempt to gather *allies* to their causes. However, a more radical proposition was to follow.

The authors continued to develop the idea of enrolment and proposed *A Sociology of Translation* (Callon 1986). The idea of translation as a way to unify or merge different meanings was borrowed from philosopher Michel Serres (Brown 2002) but also drew on earlier ethnographic studies of science, such as *Laboratory Life* (Latour & Woolgar 1986). *A Sociology of Translation* was an account of a group of marine biologists attempting to study scallops in St. Brieuc Bay and described the process of the biologists trying to build a network of relations between themselves, the scallops, the local fishermen and the scientific community. In his analysis, Callon described four stages of translation:

> *Problematisation* involved the actors (biologists) defining a problem, their own interests and the way their project might benefit other actors. The study, they say, may help the scallops to breed more successfully and will also support the fishermen, who want a bigger catch and sustainable income. The scientists position their work as the *obligatory passage point* (OPP) for the other actors to realise their goals.
>
> *Interessement* was when the primary actors tried to persuade others to join the project (or network) and interrupt the associations between other actors.
>
> *Enrolment* was when the other actors 'agreed' to participate.
>
> *Mobilisation* is the configuration of agreements that allow the project to move forwards. If any of the translations fail the whole network dissolves. Networks are tentative and ephemeral (Law 2009).
>
> (Callon 1986)

Translations are never perfect as translations also betray an original meaning or intention (Law 2009). However, translations are the way that a network can be established – by making one's own project a route through which people and things can achieve their own

goals. In this study the project was short lived. The scallops 'refused' to be anchored to the biologists' net and the fishermen went to sea on Christmas Eve to profit from a local Yuletide tradition. This paper was an early articulation of 'super' or *generalised symmetry*. This extended the strong programme's symmetry of using social explanations to explain knowledge and scientific belief to an analytical framework that claims, as a starting point, to treat all entities symmetrically. Rather than think of humans and scallops as essentially different, Callon used the same language to describe both human and nonhuman action.

The *Sociology of Translation* focused on the attempts at forming a largely stable network. Materially, scientists were using a net to fix scallops to the ocean floor to help them breed more effectively. And, metaphorically, scientific actors were attempting to position the actors, fishermen, scallops and wider scientific community in such a way that they were able to conduct their research. The *sociology of translation* became Actor-Network Theory (ANT) and was used in diverse ways by Callon, Law and their colleague, Latour.

Indeed, the primary methodological strategy of ANT was to *follow scientists and engineers* and to "make the list, no matter how long and heterogeneous, of those who do the work" (Latour 1987, p.258). ANT is therefore both a material and a relational theory.

> As a materialist theory it [ANT] explains intuitively the successes and failures of facts and artifacts: they are the effects of the successful translation of actions, forces, and interests. As a relationalist theory it suggests novel results and promotes ecological analyses: humans and non-humans are bound up with each other, and features on neither side of that apparent divide can be understood without reference to features on the other… it stands as the best known of STS's theoretical achievements so far.
>
> (Sismondo 2010, p.92)

However, ANT's status as a theory is complicated. Despite being a well-known theoretical contribution, and one that inspired much debate, one of ANT's most vocal proponents called

it a method not a theory (Latour 1999). Latour attempted to 'recall' his own conceptual technology the way one might attempt to call back a faulty product. However, he later reverted to his original position (Latour 2005). ANT seems to occupy a dual position as both method and theory.

Inscriptions and delegations

ANT scholars broadened the scope of STS to include physical matter in the analysis and explanation. This had its history in earlier work. Arguably, as important as Kuhn's work pioneered a mode of questioning, *Laboratory Life: the construction of a scientific fact* (Latour & Woolgar 1986) laid the groundwork for empirical observation of scientific practice. Latour entered the Salk Institute and "followed" (see Chapter 3) the scientists as they did their work of producing a particular fact, that a tri-peptide Thyrotropin Releasing Factor (TRF) is Pyro-Glu-His-Pro_NH_2. Latour, as the anthropologist, treated the scientists as a 'tribe' and asked 'naïve' questions about the practices he observed. From this perspective, the work of science seemed to be predominantly about writing. Scientists wrote on blackboards, prepared presentation slides, drew graphs and sketched diagrams. Furthermore, the machines that the scientists used turned materials into writing. The scientific apparatuses, composed of machines and techniques, were understood as *inscription devices* which work to "transform matter into written documents" (Latour & Woolgar 1986, p.51).

Later work in the ANT vein took the notion of inscription further. Whereas scientists assembled machines and techniques to produce writing, technologies had 'scripts' written into them to say how actors will use them (Akrich 1992). It was the analysts' job to "de-scribe" and explain the innovators' scenarios embedded in technological innovations.

Translation has also been deployed as the act of turning a large effort into a smaller one, such as using the technology of a hinged door instead of knocking down and re-bricking a wall (Johnson 1988). Translating and inscribing can be "delegating" actions and morals to technologies, like the Berliner Key, whose design guides a user to lock a door behind them (Latour 1992). It is the combination of these translations that produce "the durable and irreversible accomplishment" of a nature and a society (Latour 1993b, p.140). For Latour and ANT, translation has many meanings regarding the production of texts and technologies, and they are all intimately connected to the formation of networks.

Critiquing ANT

Since ANT has had an important impact on the way research is discussed in STS, I turn to some critiques. As a research method or methodology ANT has been debated and criticised for a number of reasons. Early studies tended to focus on a single actor or group (Restivo 2011). ANT accounts can be exclusive and warlike in their focus on human heroes (Star 1991). In response, later studies included more points of view such as taking the point of view of an electric train (Latour 1996). Furthermore, it is difficult to decide what is in and what is out of a network (McLean & Hassard 2004). The treatment of nonhumans also runs the risk of emptying humans of many qualities such as the capacity for emotion (Laurier & Philo 1999) and of raising the place of things above people (Collins & Yearley 1992).

Some of these criticisms have been discussed (Latour 1991). Perhaps the most difficult to defend is the idea that ANT is grounded on a mischaracterisation of SSK's 'interests' and is largely indistinguishable from SSK except for where ANT is confusing and unworkable (Bloor 1999). Similarly, the most damning is the accusation that ANT is a backward step in

understanding science as it is founded on naïve realism (Collins & Yearley 1992). In Section 2.4 I map out my position regarding realism in this thesis.

There were two additional problems with using 'early' ANT for this study. As I have already argued, 'translation' is used in ANT in multiple ways to capture the way people and things become enrolled into networks. It would potentially have proven confusing for multiple ANT 'translations' to be combined with the multiple empirical meanings of translation. A thesis on translational research replaced the ANT term translation with "transformation" (Rushforth 2012). This is itself a 'betrayal' as the metaphor of transformation does not have the linguistic connotations or conceptual flexibility as translation (see Chapter 1). In this thesis, I do not employ early ANT 'off the shelf', but instead I borrow some of methodological concepts proposed by Latour and other writers, including Bloor.

Secondly, this project was not concerned with establishing scientific facts, their resolution and the 'representation of nature'. The thesis is concerned with the constitution of 'translation'. This means the study is dealing with two concepts that are, at present, unstable – synthetic biology and translation – and therefore required a framework that could deal with this as early ANT explains facts as 'stable' networks. As I further explain in Section 2.4, later contributions following from ANT do attend to fluid and protean objects like translation and synthetic biology. Indeed, they have "succeeded in washing away a single crucial assumption: that successful translation generates a single coordinated network and a single coherent reality" (Law 2009, p.152).

Processes of co-production: accommodating nature and making doable work

The idea of co-production was proposed as an attempt to unify two broad strands of STS research (Jasanoff 2004). Research in the *constitutive* strand of STS includes ANT and

translations discussed above, theoretical work on agency and the emergence of science practice and knowledge over time. It is concerned with the way science makes new things in the world. The *interactive* strand is the way science and other institutions, especially politics, influence one another and can be represented by the strong programme and scholars such as Fox Keller and Haraway who critique science through gender.

> Briefly stated, co-production is shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it. Knowledge and its material embodiments are at once products of social work and constitutive of forms of social life; society cannot function without knowledge any more than knowledge can exist without appropriate social supports. Scientific knowledge, in particular, is not a transcendent mirror of reality. It both embeds and is embedded in social practices, identities, norms, conventions, discourses, instruments and institutions – in short, in all the building blocks of what we term the social. The same can be said even more forcefully of technology.
>
> (Jasanoff 2004, p.3)

Within the "idiom" of co-production there are four overlapping themes: emergence and stabilisation of phenomena; the resolution of controversy; the intelligibility and portability of knowledge; and the cultural practices and legitimation of what counts as science (Jasanoff 2004). Similarly, there are four overlapping sites of analysis: identities, discourses, institutions and representations. I did not use these categories in my analysis directly, because I was interested in actors' processes. However, whereas some ideas of 'making science relevant' imply a readymade society, following the *co*-production line, I take it that society is made relevant to science at the same time, and the processes produce both science and society.

The work of ANT was meant to undermine the 'modernist' viewpoint – that culture and nature were somehow separate. Analytically, non-ANT studies of the process of science often emphasise one of these two determinants. For instance, scientists' work involves

material interactions. Scientists plan their activities, build machines to do them, and respond to the results of their experimentation.

> As active, intentional beings, scientists tentatively construct some new machine. They then adopt a passive role, monitoring the performance of the machine to see whatever capture of material agency it might effect.
>
> (Pickering 1995, p.21)

Pickering names these alternating processes *accommodation* of actors' concepts and the *resistance* of nature, and coins the term "the dance of agency" to capture the way both humans and material world act towards each other (Pickering 1995, p.22). Pickering's overall metaphor is that reality is produced in 'the mangle' between social and material agency (Pickering 1995).

Pickering also draws a distinction between culture and practice:

> "culture" denotes the field of resources that scientists draw upon in their work, and "practice" refers to the acts of making (and unmaking) that they perform in that field. "Practice" thus has a temporal aspect that "culture" lacks, and the two terms should not be understood as synonyms for one another: a hammer, nails, and some planks of wood are not the same as the act of building a dog kennel – though a completed dog kennel might well function as a resource for future practice (training a dog, say).
>
> (Pickering 1992, p.3)

While there are differences here, Pickering's focus is on material, technical practices of knowledge production (Pickering 1995; Pickering 1992). Thus, in terms of co-production, 'the mangle' focuses on one determinant – the real-time interaction with nature.

Since science does not get done outside of society, actors make their work relevant to other social domains. One way to understand this achievement is that, rather than choosing to

undertake experiments that are just technically doable, researchers actively *align* their experiments with social worlds beyond their laboratories (Fujimura 1987).

> Scientists achieve alignment by articulating – considering, collecting, coordinating and integrating – tasks between these levels of work organization. That is, they make problems doable through the seemingly mundane processes of organizing and reorganizing their work.
>
> (Fujimura 1987, p.258)

The problems which scientists address are constructed through articulation. The patterning of tasks appears to be a mundane aspect but is an integral part of doing scientific problems. So, scientists (and non-scientists) have to actively re-organise their projects as knowledge changes and time passes. In her analysis, Fujimura (1987) considers three levels of organisation – the experiment, the laboratory and the social world. Using an example of a genetics project, she argues that, in order for an experiment to be done actors must organise equipment at the laboratory level. An experiment may require a centrifuge, and there may be one for ten people in the laboratory. Thus, there needs to be a system at the laboratory level to organise how people can co-ordinate access to the centrifuge. On the broader scale, laboratory work needs to be *aligned* with the social world in order to be relevant. This can involve changing the emphasis on research to, in her example, focusing on an interim target of a diagnostic test in order to preserve the company's interest in the project. Figure 6 below shows a model of this theory using overhead projector acetates to stand in for the different levels.

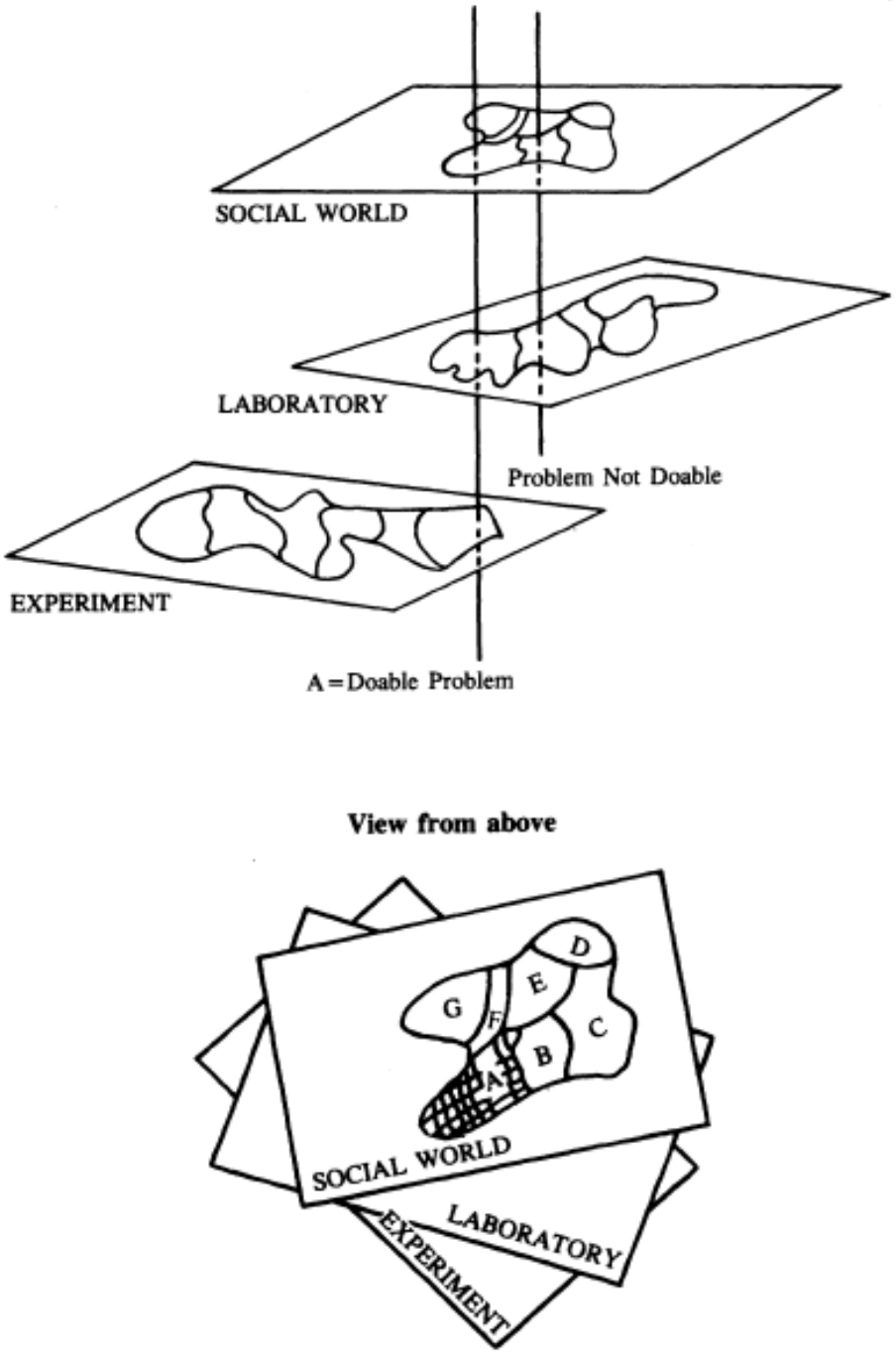

Figure 6. Articulating a doable problem (Fujimura 1987, p.259)

The reorganisation of work can take different forms. It might, for example, be the way that a contemporary scientific method was constructed by creating distant witnesses (Shapin & Schaffer 1985). The process of science is very much a social, historically contingent exercise that involves adaptations to forces in what might be termed the social domain.

Furthermore, this adds to the idea from Section 2.1 – attaining relevance is something that requires material as well as rhetorical work. I modified these 'levels' to fit with the data I generated in this project – Part II considers *alignment* and *demarcation* at the levels of state and science, domains of academia and industry, and the level of the laboratory.

A second use of *articulation* is from a small body of literature that does not reference Fujimura. Here, articulation is a rhetorical device which actors use to give meanings to their projects and argue their research is relevant (van Lente & van Til 2008; Bos et al. 2014).

Thus, 'umbrella terms' in policy (Rip & Voß 2013) like "sustainability" and "translation" are made into specific attributes of projects (Bos et al. 2014). In the sub-discipline of nanocoatings, sustainability:

> may refer to the coating itself or the product with its enhanced properties due to a coating. In our case 'sustainable' has been specified as (i) higher energy efficiency, (ii) higher quality, (iii) less material, (iv) reduced toxicity, or (v) higher durability.
>
> (van Lente & van Til 2008, p.975)

Thus, articulation of relevance to sustainability can be different things even within a single project. This means that overall policy agendas can be interpreted and specified in different ways even in the same field of research.

In sum, scientific knowledge is produced in dialogue with both the social and the material, depending on the emphasis of the critique. John Law (1993) introduced the term *heterogeneous engineers* to capture the way that engineering practices deal with the mechanical or material and also shape the social. Engineering involves arranging people and things and meanings. More recently, Jane Calvert reflected on her involvement with synthetic biology and argued that the iGEM competition was a particularly clear example of

synthetic biologists engineering, not just a biological order, but also the social order (Calvert 2013, p.416).

A starting assumption for the present thesis is that organising the social order and the production of knowledge are deeply intertwined. Throughout this thesis I use a broader definition of culture than Pickering and suggest that scientific practice is much more than technical work and organisation – scientists labour to make their research relevant and draw on a variety of cultural resources to do so. This thesis is concerned with both articulation in terms of organising work and with accommodation as scientists go about interacting with nature.

The aim of this section was to locate this thesis within a general overview of STS methodology. STS tends to look for complex socio-materiality, and to be qualitative and descriptive (Jasanoff 1996). Throughout the thesis I employed a hybrid methodology that draws on early ANT and the ethnographic approaches that are found in Pickering and Fujimura's analyses.

2.4 Objects and Ontology

The previous section discussed how to go about researching science, before moving on to ideas about scientific practice. Underlying those points, largely unsaid, was the question of how "reality" is understood by different STS researchers. The strong programme was relativist and focused entirely on social factors. By contrast, ANT was materialist and treated humans and nonhumans with the same vocabulary, at least at the outset. However, neither is incompatible with realism (Bloor 1999; Latour 1987; Williams & Edge 1996). I want to outline the key ideas that frame how objects and reality are treated in this study, which

stems from my rejection of the notion that science and technology are separate (Russell & Williams 2002b, p.51). This section lays the groundwork for the discussion in Section 7.2 by focusing on literature important to the overall conceptual framework for the thesis. Here I cover concepts of objects using examples ranging from a ball game through to more abstract and tricky objects like medical diseases.

Material-semiotics

The book *We Have Never Been Modern* (Latour 1993b) laid out the underpinning philosophy of 'early' ANT. Latour draws on the notion of quasi-objects, an idea Serres (2007) explains using the example of a ball in team sports. In his description the ball is a material entity, but that is not the totality of the object.

> A ball is not an ordinary object, for it is what it is only if a subject holds it. Over there, on the ground, it is nothing; it is stupid; it has no meaning, no function and no value. Ball isn't played alone.
>
> (Serres 2007, p.225)

There are two points here. The first is that the quasi-object gains meaning only when it is contextualised by a subject. The second is that the context, here a game, is social. The ball, in Serres' example, has corporality and meaning. It moves around during the game and can mean different things – a good team passes the ball quickly; one who hogs the ball is a poor player; one with the ball is attacking. However, the ball can slow a player down; it is cumbersome and difficult to run with it. It also marks out the possessor as the one who may be tackled. Paradoxically, that makes the player both an attacker and a victim (Serres 2007). In the practice of playing the game, the ball and the players inscribe one another with

meaning, all be it temporarily. The ball fits somewhere between the 'poles' of the physicality of nature and the meanings of culture. In Latour's words:

> Quasi-objects are in between and below the two poles, at the very place around which dualism and dialectics had turned endlessly without being able to come to terms with them. Quasi-objects are much more social, much more fabricated, much more collective than the 'hard' parts of nature, but they are in no way the arbitrary receptacles of a full-fledged society.
>
> (Latour 1993b, p.55)

A general theory of objects needs to account for all things, not just manmade articles. Considering synthetic biology for a moment, its status as an object is not clear. It is complex, and composed of practices. It is more complex and heterogeneous than a ball. Or even a ball game. So there is still work to do to begin conceptualising synthetic biology.

Hybridity

The world seems to be populated by individual objects, human and nonhuman. This is the modern perspective, so argue ANT theorists, which sees the world as made up of discrete and separate objects. Instead, says Latour, the world is made of "hybrids" constituted by their relations. The world is a "parliament of things" (Latour 1993b, pp.142–145). To see the world otherwise, as filled with independent entities, is a trick of perception that depends upon two processes: *translation* and *purification* (Latour 1993b, p.11). See Figure 7 below.

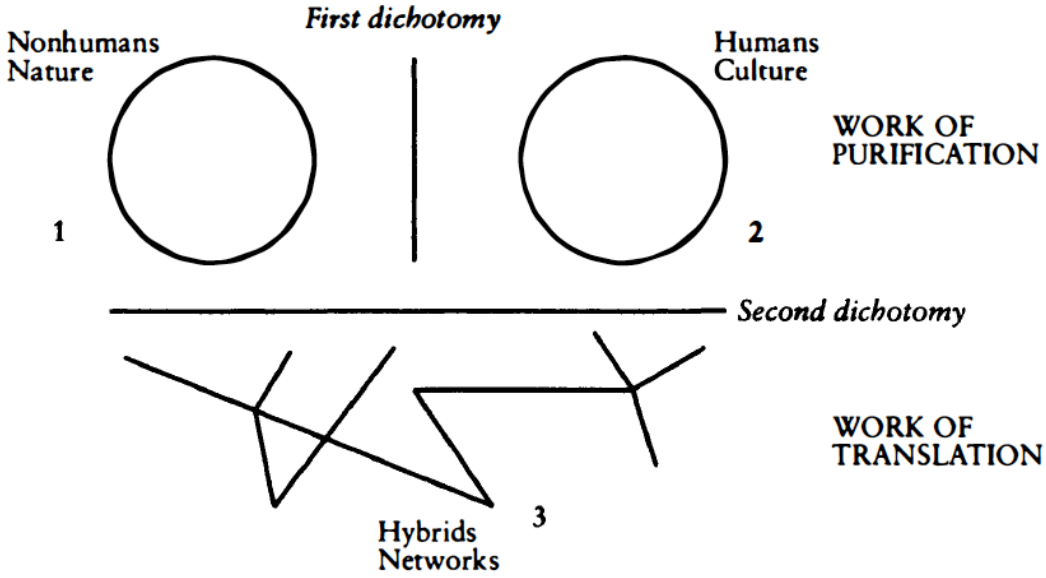

Figure 7. Purification and translation in actor-network theory (Latour 1993b, p.11)

Translation is a way we come to see networks of relations as individual isolable objects. As an example, the technique of vaccination was not a separate object as a technique waiting to be discovered and circulated throughout society. Instead, vaccination depended on 'capturing the interests' of hygienists, farmers, microbes and equipment and on 'a theatre of proof' that established its efficacy (Latour 1993a). Purification is the subsequent process by which categorises individual objects into humans and nonhumans, culture and nature. A related idea is explored in the metaphor of people as cyborgs – networks of humans, nature and machines (Haraway 1991). Hybrids or cyborgs, the outcome is that objects are better understood as products of relations.

Fluid networks

In ANT, every entity or actor is a network of relations. One of the ways that stability of networks can be achieved is through the circulation of special objects that can be transported with little deformation. These are termed *immutable mobiles* (Latour 1986).

Objects are “a more or less stable network of associations” (Law & Singleton 2005, p.335). For example, the printing press allowed ideas, which up until then had been transmitted verbally and changed as they went from person to person, to be concretised in text. Printed on paper, ideas could flow with more stability (ibid. 1986). There is a further example from the period of European imperialism where the success of the navies depended upon stable objects, ships, which could circulate unchanged (Law 1986). Should the ships become deformed, in other words wrecked, they would be no use and could no longer contribute to success. This example also highlights the labour that goes into maintaining an object. In its lifetime, a ship might have all its masts, sails and timbers replaced, new commanders and crew, yet will still go by the same name (Blackburn 1999). ANT considered networks as relatively stable though in no way permanent. Stability is therefore the result of continuous labour.

A later study took the *immutable mobile* concept and showed it was possible to understand apparently stable technologies to be more changeable, more fluid, than proposed by earlier ANT studies. Taking a Zimbabwean bush pump as their object of analysis de Laet and Mol (2000) argue that the technology is not fixed. The bush pump is a mechanical tool, which can be repaired, but it is also a community device and a nation-builder. Each of these identities has a different boundary. And, the success of the pump has many dimensions, too: it may give water, but not improve health; it may not help larger communities connect; it may develop a mechanical fault. The pump is fluid in the sense that the network sustaining it, the association of people and things, does not remain stable but the constituent parts and meanings, like the ship above, are slowly replaced depending on the context.

So far, I have largely left it unsaid that objects are made and stabilised in practices. I now develop this further.

Objects multiple

I have moved towards a view of the world constituted as dynamic networks. This means, for the purposes of this thesis, I assume there is a relational ontology. *Immutable mobiles* and their 'ecological' counterpart *boundary objects* (mentioned in Section 2.1) seem to occupy a key role in sustaining networks because of their interpretative flexibility. This leads to the idea, close to the alleged naïve realism of ANT, that these kinds of objects are an assemblage of various interpretations with a reality 'behind' them.

> It simply *mean*s different things to these different groups. Looked at in this way, then, messy objects are interpretatively complex objects, and if we want to understand them we need to take this into account. We need to *explain* (and in some cases explain away) the different perspectives, and so retrieve the real object behind the interpretations.
>
> (Law & Singleton 2005, p.334)

In contrast to this position, post-ANT theories are ontological, say Mol (2002) and Law and Singleton (2005), because they consider the constitution of objects, rather than interpretations of objects:

> The move, then, is away from epistemology. Epistemology is concerned with reference: it asks whether representations of reality are accurate. But what becomes important if we attend to the way objects are enacted in practices is quite different. Since enactments come in the plural the crucial question to ask about them is how they are coordinated. In practice the body and its diseases are more than one, but this does not mean that they are fragmented into being many.
>
> (Mol 2002, p.vii)

> The metaphor of construction – and social construction – will no longer serve. Buyers, sellers, noticeboards, strawberries, spatial arrangements, economic theories, and rules of conduct – all of these assemble and together enact a set of practices that make a more or less precarious reality.

(Law 2009, p.151)

This 'performativity' or 'enacted' version of objects interprets objects as being composed of multiple practices rather than as social constructions (Law 2009; Law 2002).

Possibly, the most well-known example of this move away from constructionism, epistemology and representationalism comes from a study of atherosclerosis (Mol 2002). Mol follows various patients, doctors, nurses, pathologists and physiotherapists and charts what they do when they practise the disease. She finds that the different groups do the disease in a different way and this, she concludes, means the object is singular in theory, but multiple in practice. It is an *object multiple* (Mol 2002). Patients practise atherosclerosis in a different way to physiotherapists, who do it in a different way to surgeons, who do it in a different way to pathologists. A patient may complain of pain in their legs and may (or may not) struggle to walk. A physiotherapist measures a patient's ability to walk a given distance. A surgeon may remove a bloody artery. A pathologist looks down a microscope at an occluded blood vessel prepared on a slide. In fact, some of the practices of atherosclerosis cannot be done at the same time:

> The practices of enacting clinical atherosclerosis and pathological atherosclerosis exclude one another. The first requires a patient who complains about pain in his legs. And the second requires a cross section of an artery visible under the microscope. These exigencies are incompatible, at least: they cannot be realised simultaneously.
>
> (Mol 2002, p.35)

Two 'strange consequences' of the turn to enactment are multiplicity (Law 2009), and the types of contradictions described by Mol above.

Furthermore, the turn to *performed* objects draws attention to how divers things appear to 'hang together'. Objects can be held together in *co-ordination work* (Mol 2002). Mol argues,

with reference to medical testing in atherosclerosis, that object features such as test results are *added up*, or hierarchically stacked if they conflict with one another, to form a composite. Secondly, test results can be translated into one another. Thus,

> The possibility to negotiate between clinical notes, pressure measurement numbers, duplex graphs, and angiographic images only arises thanks to the correlation studies that actively make them comparable with one another. The threat of incommensurability is countered in practice by establishing common measures. Correlation studies allow for the possibility (never friction free) of *translations*…
>
> (Mol 2002, pp.83–84)

This means that, for an object like atherosclerosis, there is labour involved in keeping the parts together, through organisational work.

Law and Singleton (2005) develop this notion even further in their consideration of alcoholic liver disease. They argue that the metaphors for objects reviewed so far: of as volumes in space, as networks and as fluids, do not account for an object multiple. They propose the metaphor of fire. Not a domestic fire but, following the fluid bush pump in an unremarked connection, a *bushfire*. Here is an extended quote explaining the concept with respect to alcoholic liver disease:

> So we have three fire objects, three versions of alcoholic liver disease. Each is made in a series of absences, but (and this is crucial) each is made differently. In the hospital, it is a lethal condition that implies abstinence. In the substance abuse centre, it is a problem that implies regulation and control. In the GP's surgery, it is a reality that is better than hard drugs. Each includes and relates to a different set of absent presences. Each is transformative and generative. Each moves the patient and the patient's body on: to abstinence; to family life; to alcohol rather than drug use. But this means that the pattern of absent presences over the three locations is itself a pattern of absent presence, of necessary otherness…

> … Alcoholic liver disease becomes an object that jumps, creatively, destructively and more or less unpredictably, from location to location. It is an object in the form of a dancing and dangerous pattern of discontinuous displacements between locations that are other to (but linked with) each other.
>
> (Law & Singleton 2005, pp.346–347)

Law and Singleton conclude that it is the multiplicity of alcoholic liver disease that makes it difficult to manage in medical administration. The quote above also draws out another important feature in these versions of objects. They are composed of things which are there, and things which are not. At the same time certain absences are made explicit, and others are not.

It is possible to conceptualise synthetic biology as a fire object. It is composed of different practices from different academic disciplines and those of non-scientific actors like administrators and policymakers. The post-ANT version of multiplicity therefore seems like a useful place to start conceptualising synthetic biology. Furthermore, patterns of absence and presence are, methodologically, also a starting point for the thesis.

Presently, this is as far as post-ANT thinking goes. Reality is performed by practices. Multiple practices in different sites perform complex objects. Objects create and destroy. There is, however, another line of scholarship that occasionally references the work above, but tends to focus on the ‘technical’ objects of knowledge and their role in science and technology.

Post-social theory

Knorr Cetina argues there is a "massive expansion of object worlds in the social world" (Knorr-Cetina 2005b, p.585) by which there is a proliferation of all kinds of technology, knowledge objects and information.

> What postsocial theory offers in the stead of the scenario of simple "desocialization" is the analysis of alternative forms of binding self and other, changes in the structure of the self that accommodates these forms, and forms of social imagination that subordinate sociality to new promises and concerns.
>
> (Knorr-Cetina 2005b, p.586)

According to post-social theory, objects result in new forms of sociality. *Objects of knowledge*, such as scientific concepts, computer programmes and technical equipment, are increasingly important as 'glue' that coheres the self and society.

When I use the term *objects of knowledge* I am paraphrasing another idea – *epistemic objects*. The concept of *epistemic objects* began to emerge with an historical analysis in the biological sciences in which experiments were comprised of two types of objects: *epistemic* and *technical* or *technological objects* (Rheinberger 1992; Rheinberger 1997). These are not fixed categories – an epistemic object in one *experimental system* maybe a technical object in another. A scientific or *epistemic* thing:

> … is not and cannot be fixed from the beginning, it represents itself in a characteristic, irreducible vagueness, which is inevitable since it translates the fact that one does not exactly know what one is looking for.
>
> (Rheinberger 1992, p.310)

Epistemic things "are in the process of being materially defined" (Rheinberger 1992, p.310) and as such they are not stable but pick up and lose characteristics. Knorr Cetina (1997) begins to refer to *partial objects* at the end of her article, broadening the concept beyond science.

Partial (epistemic) objects can be understood as having three features (Knorr-Cetina 2005a, p.193). 1) The unfolding character is the way objects are dynamic and continually 'opened up'. An example might be the understanding of the gene. As the human genome proved not to be as readable, predictable and deterministic as first thought, questions were raised about the milieu in which DNA sits. Then, as knowledge about epigenetics developed, what was understood as individual and deterministic "gene action" gave way to more integrated and responsive concept "reactive genomes" (Fox Keller 2014). Different sets of questions and lines of investigation arise with this new understanding: the genome unfolds. 2) The dispersed character is the way epistemic objects are constituted of other objects, some of which are themselves unfolding. Finally, 3) the signifying characteristic is the way that researchers identify lacks in their knowledge about the object, and this generates questions for further investigation, which produces new presences and new absences. A 'lack' of knowledge about an object results in new questions being asked. In turn, this generates more present knowledge, and further lacks. This is rather like the absence-presence in post-ANT (Law & Singleton 2005), and *accommodation* in 'the mangle' (Pickering 1995) that I mentioned in Section 2.3.

In terms of suggesting how these objects bind society, then, Knorr Cetina draws on psychoanalytic theory (Knorr-Cetina 2005a; Knorr-Cetina 1997) and uses a language similar to post-ANT. She argues that, as above, actors identify particular absences in objects. Actors then do work to 'fill in' these absences, which make realities. These then provide lines of extension, or 'chains of absences' that the actor identifies and which the object has had a part in signalling. This theory is explored with respect to 'the market' (Knorr Cetina &

Bruegger 2000). A financial market can operate as a binding object. Firstly, traders identify lacks in the market that they can exploit, earn status, and realise their own identities – to be successful and wealthy, for instance. Secondly, the traders operate at computer terminals that synchronise global participation in the market by their connection to one another. Thus, market provides a place to embed the self and coordinate society (Knorr Cetina & Bruegger 2000). This provides a different explanation to Mol's (2002) *co-ordination work* in how objects 'hang together' in that the self is intimately bound up in the extension of an object.

As I have argued, objects are not stable. One study, that took inspiration from the above 'object theories' (Engestrom & Blackler 2005; Star & Griesemer 1989; Knorr-Cetina 2005a; Rheinberger 1997), examined the life of an object in translational genetics (McGivern & Dopson 2010). The authors report of an 'inter-epistemic' battle between medical academics and government administrators in a genetics network. The academics were producing research and publications within their own domain, but this was not satisfactory for the administrators who closed the network by cutting funding. Following the closure some medical academics were able to "reincarnate" the object to create a genetics test that became a diagnostic technology in NHS practice. This specific study reveals some of the ways that institutions create certain type of objects. Here, the object is transformed from an epistemic object to a technical one.

What we find in these accounts is similarities and differences. Objects can be understood as generative, multiple and unfolding. This final section raises awareness of how objects can be transformed as they move from place to place. Or, as they are translated from one domain to another.

A turn to ontology?

The discussion, particularly in relation to the 'objects multiple' sub-section above, generated debate in STS over whether ontological questions have replaced epistemological questions, including a *Social Studies of Science* special issue (Law & Lien 2013; Woolgar & Lezaun 2013; van Heur et al. 2012; Mol 2013; Brives 2013; Marres 2013; Lynch 2013). There are two identifiable trends to studying ontology. The first is to understand objects as multiple realities proposed by post-ANT and the second is to study how identity and difference is done in specific cases (Lynch 2013). One option would be to call an empirical examination of things by a different name – *ontography* (Lynch 2013). This would mean, according to Lynch, that the analyst would not make an *a priori* decision that reality was composed of multiple objects. Instead, the analyst would approach the subject and decide whether ontology was an important aspect.

Furthermore,

> it remains unclear how claims about the ontological composition of the world differ from more conventional propositions about the social construction, co-production, or performative constitution of a certain reality.
>
> (Woolgar & Lezaun 2013, p.323)

Here, the reformulation of questions to be about 'ontologies' needs to be more clearly separated from other theoretical trends. The claims to greater political inventions have not been clearly demonstrated in the discussions (Woolgar & Lezaun 2013). An overall 'turn' seems unlikely since, although the use of the word "ontology" has increased, usage appears in disconnected discourses with different meanings (van Heur et al. 2012). The apparent shift to ontology is perhaps an outcome of the particular types of argument used by some researchers.

In approaching this research project, partly because I came from a positivist natural science background, I wanted to understand the objects that I had chosen to study within an STS framework. An important way to achieve this was to articulate them with theories of objects. So, my approach began somewhere in between ontology and ontography. On the one hand I was interested in the idea of a multiplicity and absences. On the other, I wanted to know how people defined and did synthetic biology, as the object to be translated, and how they defined and did translation. I therefore considered ontology as a 'sensitising concept' (Blumer 1986) in that I was aware of it as a possible line of analysis.

The aim of this section has been to outline the ontological position of the project. This is that an analysis of practices can yield insight into the constitution and roles of objects and associated concepts such as identity and institutions. From this perspective objects are material-semiotic, performed, multiple and generative. Section 7.2 returns to this literature to conceptualise synthetic biology as an *unfolding multiple* before discussing the 'absence' of translation.

2.5 Research Questions

First I give a brief conclusion before I state the research questions. Synthetic biology seems to throw into relief some of the trends and concerns that have emerged in contemporary life science. Section 2.2, while mainly focusing on the case of the UK, has covered some of the main themes identified in social research. Synthetic biology practices change the meaning and doing of biology and biological work; it raises awareness about ethical issues regarding the capitalisation and governance of designed life; and shows how promises and expectations can be realised in material and organisational ways. Thus, as actors translate

synthetic biology, there is a strong foundation of social research on which to build. At the same time, translation has been studied predominantly with cultural analyses relating to credibility, professional identity and the boundaries between laboratory and clinic. Therefore, there seems conceptual space to approach translation as an 'absence' in synthetic biology that different actors work towards addressing. This is a starting assumption. The STS concepts I have reviewed, analytical, methodological, epistemological and ontological, give a philosophical and empirical background to the remainder of this thesis.

The overall aim of this thesis is to understand how actors make synthetic biology translatable. This aim will be investigated by asking the following research questions:

1. In what activities do researchers, administrators and policymakers engage to address "translation" in synthetic biology?
2. What connections do researchers, administrators and policymakers make and unmake as synthetic biology emerges as a 'translational science'?
3. How does attending to translation shape the emergence of synthetic biology in the UK and, reciprocally, shape understandings of translation?

In the next chapter, I outline the processes I took to answer these questions and thus explain how I addressed the overall aim.

Chapter Three

Performing Research

In order to answer the research questions I took a qualitative research approach because my central concerns in this thesis are with actors' understandings, practices and ideas regarding translation. I planned to 'get a feel' for translation by conducting observations and reading documents, and further explore some points through a process of interviewing. I conceived of translation as an "umbrella term" (Rip & Voß 2013) that was flexible and enacted in local practices in different ways (Rushforth 2012; Bos et al. 2014; van Lente & van Til 2008; Mol 2002; Law & Singleton 2005). But things did not always run according to my plan and the research process was "messy" (Strauss & Corbin 2008, p.32). In this chapter I describe how I went about conducting the research, making decisions, generating and analysing data and, finally, writing an account.

The chapter title includes the idea of 'performance'. I use the word in its double meaning of both *doing* and *presenting*. This is consistent with the theoretical STS framework that I outlined in Section 2.4, and continue to develop throughout this thesis. The chapter is the presentation of some of the decisions I took while doing the research process and is an attempt to detail some of the experiences with which the reader might identify. For ease of explanation it is semi-chronological. It is also not possible to recount every consideration. I have taken a variety of strategies to try to explore selected issues in detail. These include taking illustrative moments and extreme cases (Flyvbjerg 2006) to probe some of the matters that emerged during this project. The issues that I raise in this discussion do not

necessarily have resolutions but they raised further questions and sensitised me to other situations during the research. I include them because they are important details of how I conducted the research. I narrate how the project took shape and how, by articulating and accommodating my research problem, I made my project doable (Fujimura 1987; Pickering 1995). In so doing, I aim to be transparent about the research process (Jenkins 2002). This is an important part of 'responsible speech' in sociology (Bauman & May 2001, p.8). This account is of how my performance of research practices, including writing, extended 'translation of synthetic biology'.

3.1 Action and Practice

I want to begin by adding a little practical detail to the ontological points I made in Section 2.4. Of key ontological importance in this study is my focus on action and practice. As reviewed in the Section 2.1, STS scholars have explored the ways scientists, laboratory technicians and assistants make decisions and articulate their findings with other scientists (Knorr Cetina 1983, p.169), with broader social worlds within and beyond science (Fujimura 1987) and with instruments and nature (Pickering 1995). More widely, social theorists and social researchers have become increasingly interested in practice in what has been called 'the practice turn' (Schatzki 2005). In some forms of ethnography, for example, action rather than belonging and biography has become the main question (Baszanger & Dodier 2004, p.21). Thus, my interest in action reflects a wider trend than just an STS imperative. In this thesis, I focus on the tasks, activities and practices that actors and I relate to translating synthetic biology.

Literature on 'practice theories' has emerged in philosophy and in studies of consumption (Schatzki 2002; Schatzki 2003; Reckwitz 2002; Shove et al. 2007; Hand & Shove 2007;

Hand et al. 2005). On these accounts, an overall practice is composed of all the specific instances of each performance. Each instance of a practice is specific and unique e.g. hammering a nail, taking a shower but together they constitute 'the practice'. There are then, according to Schatzki, two related concepts of practice: the overall practice and each instance of a practice as it is performed (Schatzki 1996). I have already argued, following Mol's (2002) case of atherosclerosis, that performing practices produces objects that can be understood as multiple *in practice*. Thus, an overall practice can be multiple. This allowed me to conceptualise translation in synthetic biology as a 'practice multiple' that did not privilege scientific work. This meant that various practices including research administration and policymaking could be relevant to translating synthetic biology.

Furthermore, a consequence of performance is that attributes are not an essential property of a thing, but are repeatedly enacted (like gender identity) (Butler 2010). This means that as new practices loop through and others fade out of an object, like synthetic biology, the properties of the object can change. Whereas 'social construction' implies building stability, the notion of performance lends reality a contingent and precarious existence (Law 2009). Specific properties of reality are attributed in specific reconfigurations, which can exclude other properties (Barad 2003; Barad 2007). Arising from this is the idea that reality is both dependent on the methods used to find out about it, and is inherently indeterminate (Law 2004). Thus, whatever methods I choose will generate some characteristics of synthetic biology and may exclude the possibility of knowing others. Focusing on actions of different social groups' practices will produce an 'object multiple', and may exclude possibilities of producing other characteristics of synthetic biology. But, because of the inherent 'mess' of (social) reality (Law 2004), it is not necessarily possible to know the specifics of these exclusions because it is not possible to isolate phenomena to make claims in the same way as with natural science. It is, however, my stance on how methods perform properties of objects.

In the introduction I quoted Strauss and Corbin's notion that research is messy. However, mess can apply to reality, rather than just research. John Law, in his 'attack' on social research methods (courses), argues for a discourse around teaching methods:

> that is broader, looser, more generous, and in certain respects quite different to that of many of the conventional understandings
>
> (Law 2004, p.4)

because:

> 'method talk' connotes something quite different – that is a particular version of rigour. This is the idea that it is important to obtain the best and technically robust possible account of reality, where reality is assumed… to be a pretty determinate set of discoverable entities and processes. That such is what the world is: a set of possibly discoverable processes.
>
> (Law 2004, p.9)

He goes on to challenge reality's *independence, anteriority, singularity* and *definiteness* arguing throughout the book that reality is multiple, indefinite, in flux and constituted at the point of performance.

A good example of dealing with mess is with Law and Singleton's (2005) methodological discussion of alcoholic liver disease (detailed in Section 2.4). In the article, the authors conclude that problems with researching alcoholic liver disease mirrored those of health administrators struggling to manage provision. As a messy object, the disease was different in different sites and slipped in and out of focus and morphed into other objects (Law & Singleton 2005). This was an effect I experienced in trying to fix on translation and, at times, synthetic biology. These comments foreshadow the discussion in the Section 7.2 where I

outline the concept of *unfolding multiples* and conceptualise translation, finally, as patterns of absences.

In terms of designing a project, it might be tempting to think of method in a messy manner, but this is not the case. I have, instead, taken the position that methods need to be explained systematically and the apparent mess justified and to some extent 'cleaned' for the reader, albeit through this semi-chronological narrative.

In sum, action and practice imply attendance to what people do and say, and the written and material paraphernalia required for these things. Multiplicity allows for various practices to count as, and constitute, a particular object. I discuss the reflexive and theoretical implications for this in Section 3.5 and Section 7.2. Methodologically, I needed to deploy a variety of data generation and analytic strategies to try to understand translation in synthetic biology. Finally, the specific methods perform specific characteristics of synthetic biology, and exclude other (unknown) possibilities.

Next, I begin to narrate how the project took shape. The contributions I have incorporated into the methodology, following the discussions in Section 2.3 are the ANT notions of *following the actors, symmetry* and the assumption of *hybridity*. I discuss these points with respect to doing the research in the next two sections.

3.2 Actor Networks

My PhD was funded by the ESRC. I was a member of the ESRC White Rose Doctoral Training Centre network "Rethinking the social production, locus and impact of bioscience", which consisted of three PhD students and their six supervisors. However, during the first

couple of months I was invited to join another PhD network called “synthetic biology for human healthcare”. The core of this network comprised one other social researcher and two candidates with molecular biology backgrounds. The initial supervisory structure of the network was the same as the WRDTC one I had already joined. However, over the coming years, additional people came and went. Postdocs and other supervisors dropped in for different meetings. Several other PhD students from chemical and biological engineering were regular visitors. My affiliation with the synthetic biology network was a springboard for this project as it facilitated my access to laboratories as research sites. Furthermore, in 2014, five of us from the network collaborated to recruit undergraduates to form an iGEM team for the 2014 competition (more about this later).

There were a range of synthetic biology projects in the network – creating biological fuel cells, pathogen detection systems, and a collaboration aimed at destroying biofilms. I was particularly interested in one project tackling problems in skin-graft surgeries. There were two sister projects – a PhD project and a postdoc project, that were funded by the institution and BBSRC, respectively. The project appeared to have some of the elements I was looking to explore. Although the project was not explicitly funded as a ‘translational’ one, the aim was to use synthetic biology techniques to produce a novel protein for tissue engineers to improve the adherence of skin cells in grafts or surgery. This meant that it was a) positioned as synthetic biology b) concerned with moving knowledge between disciplines c) innovation and market orientated d) easy to negotiate further access as I was already partially integrated e) nearby and convenient. Bearing in mind the literature reviewed in the previous chapter, it seemed like a conceptually rich site to investigate the topic. The laboratory spaces of the student and postdoc became key field sites. This project is the focus of the analysis in Chapter 6.

In some senses, because I had already been invited to an academic network and I was already regularly interacting with actors in synthetic biology since November 2012, negotiating initial access was unproblematic. The laboratory observations mainly involved visiting laboratories and snowballing other data sources. I visited three laboratories in two departments and shadowed researchers at their benches, computer stations and lunchtimes. During this time I identified a range of relevant workshops and conferences and, while I did not 'follow the actors' from the network to these events (since I think of my method as 'following translation'), I saw at least one (usually more) at each site.

Curiously, although in its infancy, synthetic biology had an ambivalent status at the institution. The institution had hosted one of the first seven BBSRC funded Networks in Synthetic Biology (NSBs). Yet, momentum seemed to be stalling. One administrator commented on difficulties in securing further funding for synthetic biology:

> But there is kind of an overall feeling… that we've kind of missed the boat a little bit in that area. BBSRC have just awarded three research centres in synthetic biology, um, we didn't go into that call first time. We're hoping to look to develop it for a second call.
>
> (Research administrator 2 interview, 18th February 2014)

The institution did submit a proposal to the second call for SBRCs. It was unsuccessful. So too was a collaborative proposal for a doctoral training centre in synthetic biology. The idea that the institution was not at the centre of developments in synthetic biology was put in a different way by another researcher:

> something that had always been interesting is the peripheral status of this institution in the development of the field. So, [X] is reasonably well known. And is one of the relatively few proper, in scare quotes, engineers involved in it. So [they're] actually quite important. To the field. Nationally… But but for some reason [the institution is] actually excluded from a lot things. [The institution is] definitely not in the core… very much in the periphery.
>
> (Social researcher 2 interview, 2nd July 2014)

This quotation is an example of a local sense of exclusion. The institution is portrayed as having a good record of research in synthetic biology and that it believes itself to be of import given the expertise of one its key players. Although these seem to qualify the institution to be central to developments in UK synthetic biology, actors felt they did not hear about some key decision-making meetings.

On the other hand, the institution funded the PhD network. It has also hosted researchers who have moved on to take up prestigious places in synthetic biology at other institutions. This suggests that, in some ways, synthetic biology was and had been well supported. Furthermore, following the initial NSB funding, there were good collaborative relationships between social, biological and engineering researchers. This had been a main goal of the NSBs (Molyneux-Hodgson & Meyer 2009). The ambivalence, while not central to the analysis in Chapter 6, does give some important background in terms of other factors that may influence the projects I describe.

Community membership

Due to my involvement on the network, I was invited (and expected, I think) to get involved with iGEM. This extended my time in the field beyond what I had originally planned by about two months. Discussions about recruiting undergraduates for iGEM took place from Christmas 2013, with recruitment in the spring. The project ran through July and August 2014. This culminated with trip to Boston, MA at the end of October 2014. While this was not a core part of my data collection, the supervisory role, development of the project and trip to the iGEM Giant Jamboree in Boston were all informative and helped develop some of the general feel for synthetic biology.

Importantly, though, there were ways in which it was possible to gain trust in the different sites I visited. One way that I was able to build trust was through demonstrating competence in laboratory techniques that I had learned as a biomedical scientist at university. When we were training the iGEM team the microbiologists set up a small test to check the students' ability to pipette liquid. The aim was to pipette two samples of distilled water into two Eppendorf tubes and weigh them to see if there was a difference in mass. I rolled up my sleeves, flexed my thumb and relied on the thousands of similar actions I had performed over a decade ago. After we did the test, one of the microbiologists used my masses as an example of accuracy and precision. By demonstrating my technical ability, I felt I was able to gain a little credibility in the field. This is a rather specific example. The effect likely extended more generally into the language and 'way to be' in a laboratory setting. Thus, although I did not conceive of my involvement in iGEM as key to my interest in translation, I felt it was important to my role as a researcher (see Section 3.5).

There is debate in social research about the effect of a researcher's membership of the communities they study. Sharing some social experiences and a common language can be ways of understanding membership and there is a possibility, in this way, to generate material of greater depth because participants may share more with the researcher (Adler & Adler 1987). From this position, being an insider to a community has certain advantages. On the other hand, researching as an outsider, such as Latour and his naïve, "anthropological probe", may sensitise the researcher to elements of their research site. Elements an insider may overlook.

The insider-outsider formulation seems the type of dualism that poststructuralist and postmodernist scholarship has challenged. One way to treat this dichotomy is to focus on the hyphen as a space in which researchers can be both inside and outside (Corbin Dwyer &

Buckle 2009). In the idiom of this thesis, these boundaries are performed. To the reader, I typically refer to participants as “actors”. When I talked with participants, or presented to them, I typically said “we”, including myself. Thus, I did the boundary of inside and outside at specific points (Gieryn 1983).

Observations

There were three issues that arose during observations that I want to discuss. The first is what can happen when a researcher intervenes; the second is what can happen when a researcher is already familiar with their site; the third is what can happen when a researcher discovers that access is limited, in my case, by time. What I do not have space to explore here is the huge amount of relational groundwork done by other researchers, and the emotional labour (Hochschild 2003; Wharton 2009) that goes into maintaining research relationships.

Reactivity. I was visiting an engineering department. I had been talking to a researcher in her ground floor laboratory (Field notes, 28th January 2014). She was preparing cell culture media. This involved collecting and weighing small masses of various salts and checking her calculations and previous mixtures in her lab book. Then noting down what she was making on this day. After this, we climbed back up the stairs to the PhD room in the building. A whole cross-section of biotechnology, bioengineering and molecular biology PhD candidates had their desks there. About thirty or so.

This particular lunchtime, the room was quiet. Some had gone to buy their food, or moved to one of the building’s more public spaces to eat. There were four of us left. Two of the others dashed to the windowsill to grab a mini fuss-ball table. One shouted, first to three! They

quickly scored the goals. Afterwards, one of the candidates commented, it's not always like this when you're not here. Yeah, said another, we seem to be more chatty when you're in.

Entering or leaving the field are perhaps the largest interventions a researcher can make (Burawoy 1998). The 'novelty effect' is a form of reactivity that can mean the presence of a researcher can produce untypical results (Bryman 2012, p.715). Although I had anticipated that my presence as a researcher would have an effect, it came as a surprise that participants, some of whom were of no direct interest to my project, would perform 'fun, exciting science'. Furthermore, the participants were aware of my presence and reflexively commented on their behaviour. As this happened at a relatively early stage in the research I was more aware of my presence in future situations, particularly during later interviews, participation at events and visits to other field sites.

Familiarity. When I was at conferences and meetings I was able to sit and make notes. Most of the other delegates did the same. At other times, for example, during refreshment breaks, I was able to have conversations with other actors and, later on, record these in my notebook or type them into my tablet.

In contrast to the flow of recording at these field sites, field notes for the laboratory visits were more problematic. Physically, I was always moving out of the way of researchers, or trying to find a space they were not using. It was difficult to rest my notebook anyway as the benches were filled with apparatus and running experiments. More importantly, I found it difficult to 'see' translation, so I was not sure where to look. As I followed the researchers carrying racks of Eppendorf tubes and well plates from bench to bench and, in some cases, between laboratories, I was not sure of the overall relevance of these activities to 'translation'. They had *something* to do with it, but the connection was unclear. This was coupled to my own history of being at the bench: I had spent two years doing this form of

work and had seen colleagues performing these techniques. My sense was that my field notes were somehow missing the point, that my "familiarity may be in tension with inquisitiveness" (Bauman & May 2001, p.10). Would a researcher unfamiliar with laboratory science have felt the same? I was, however, able to interpret my laboratory field notes in a meaningful way after I had generated some analytical insights from the interviews and other observations. The final conclusion to Chapter 6, explicitly linking time and skills to points in earlier chapters, came late in the writing.

A dead end? A comedic yet disappointing development concerned the skin graft project's timespan. The network to which I had been invited consisted of three doctoral projects funded from 2012 to 2015, with submission slated for sometime in early 2016. I never specifically asked about the length of the postdoc component. Then, in November 2013, I recall a comment to the effect of, "you should catch so-and-so before they leave after Christmas". Leave? I remember thinking. I was completely unprepared for a part of the project to end. Despite this surprise, I was able to organise an interview. Also, the final meeting for that element of the project, which took place in January 2014, proved to be a very useful point as it involved a presentation of the overall project and much discussion of the project work, the current status and possible next steps. Perhaps, because it was my last chance, I was also particularly alert. It therefore ended up being a crucial series of events for that particular site, even if they appeared to come prematurely.

In reconstructing these events, the experiences of doing observations appeared to catalyse two things. First, I decided that I was not getting at translation on these laboratory visits. I wondered if it was something that emerged in a different organisational or practice-context. Had I wasted my time? Second, I set about writing up my observations and experiences and generated a chapter. But it did not work. I dismantled it and peppered rewritten paragraphs throughout this thesis. While it had always been my plan to interview actors, and the

observations were crucial to identifying actors to interview and deciding what kinds of questions I might ask, I found the experience of trying to write desperately frustrating. It was only after beginning to analyse the interviews that I felt I was able to 'read back through' the observational data and interpret it what I felt was a more satisfying and convincing way.

3.3 Hybridity and Mess in Practice

An artefact of the narrative so far implies that I ceased observing, attempted writing and then began the process of interviewing. It was not nearly so tidy. By April 2014, I had conducted four formal interviews (in that I had prepared questions and digitally recorded them). I had also made numerous field notes of conversations from my observations, visited several events and made notes regarding Internet sites, films and publications. From my initial analyses of observations in laboratories and at events I had some ideas to pursue in the first interviews.

Interviews

The main interview stage took place through the summer of 2014. I began creating a list of possible interviewees in May and had a total of twenty-eight interviews by 2nd of September 2014. I prepared a set of questions so that I could guide each interview – they were semi-structured.

I selected interviewees via a variety of mechanisms. My initial strategy was to identify interviewees by getting referrals and suggestions from the synthetic biology network contacts. Using this method, I conducted interviews with two research administrators, two

postdocs, a PI as well as informal interviews with various academic participants during lab visits. Through attendance at conferences and general reading of policy and scientific literature I identified a range of further potential participants. A number of them were named co-investigators on the grant application for the Innovation Knowledge Centre for Synthetic Biology – The *Synthetic Biology Commercial and Industrial Translation Engine* (SynbiCITE). The SynbiCITE proposal was important for two reasons. Firstly, it was funded as an institution that contained "industrial translation" in its name. Secondly, it was a large proposal in terms of the number of co-investigators. The proposal listed thirty co-investigators and twenty-eight 'other partners' (academic and commercial institutions) (Engineering and Physical Sciences Research Council 2015a).

After Easter 2014 I had assembled a list of interviewees from around the UK and contacted them. I had a regimen of: email approach, telephone call, and follow up emails or calls. I was surprised at the conversion rate – my experience in marketing and business environments did not prepare me for 'yeses' to come quite so quickly. From my list of potential participants, I selected the final sample by their agreement to participate. The interview sampling was therefore, at various times, different combinations of:

- *Theoretical* sampling when looking for cases where I could test ideas
- *Purposive* sampling, for example, to select interviewees who would be able to 'articulate' translation because they were associated with it
- *Snowball* sampling where sources such as interviewees or documents refer to further sources
- *Opportunistic* sampling such as being directed from one interview to another potential participant 'down the hall'

(Miles & Huberman 1994, p.28)

Before the interviews I planned a set of questions. There were around twenty prompt questions on various themes, which were related to the research questions and which I

could tick off during the interview. A single question would often result in a conversation that covered multiple prompts. Also, the interviews tended to come in bunches, often because they were organised around a visit or event. This meant that, although I prepared a set of questions unique to a particular participant, the ones in each bunch tended to be more similar. In small font in the top right corner of the question sheet I typed core theoretical concepts and themes generated from recent analyses typed. These were part of my preparation and a way of checking that my questions were relevant rather than anything I actively referred to during the interview.

The interviews took multiple forms (see Figure 8 below). I attended many sites in person. Often, these included some kind of tour – I was 'shown around' RCUK in Swindon and parts of the Universities of Newcastle and Sheffield. However, in order to access some participants more quickly and cheaply, I agreed to some interviews over the Internet and telephone. Five of the interviews took place via online video, though one was sound only, and two were on the telephone (though these were with the same participant). Several of the interviews took place during other events – a meet-up for iGEM, a launch event for an academic network. I recorded twenty-four interviews on a digital voice recorder.

Figure 8. Table of interviews

Participant Code	**Interview date**	**Mode of interaction**
Academic Researcher 2	28th July 2014	In person; unrecorded
Academic Researcher 4	4th December 2013	In person
Academic Researcher 5	7th May 2014	In person
Academic Researcher 6	5th February 2014	In person
Academic Researcher 7	28th July 2014	In person
Academic Researcher 9	28th July 2014	In person

Academic Researcher 10	1st September 2014	In person
Academic Researcher 11	29th August 2014	In person
Academic Researcher 12	15th July 2014	Telephone
Academic Researcher 14	19th August 2014	Video internet call
Academic Researcher 15	28th August 2014	Video internet call
Academic Researcher 18	28th July 2014	In person
Academic Researcher 19	28th July 2014	In person; unrecorded
Social Researcher 1	1st July 2014	Video internet call
Social Researcher 2	2nd July 2014	In person
Research Administrator 1	19th August 2014	In person
Research Administrator 2	18th February 2014	In person
Research Administrator 3	3rd March 2014	In person
Research Administrator 4	16th July 2014	Voice internet call
Research Administrator 6	19th August 2014	In person
John Collins	3rd July 2014	Video internet call
Research Administrator 10	18th August 2014	In person
Research Administrator 12	19th August 2014	In person
Research Administrator 15	19th August 2014	In person
David Willetts	2nd September 2014	In person
Industry representative 1	1st September 2014	In person
Industry representative 2	10th September 2014	In person; unrecorded

The process of interviewing raised some important issues in the production of knowledge and below I consider *rapport* and *power*.

Rapport. One of the aspects of being in the field is that I wanted to develop relationships with participants so that they would be at ease and feel free to answer questions, and thus

generate higher quality data. One way to approach building rapport is for researchers to be aware of the characteristics of both actors in the interview (Aldridge 1993). Aldridge notes that, in his research with Anglican clergy, because the appointment of women to the Church was a concern at the time, gender was a particularly important consideration. In my research many of the actors I spoke to already had further degrees, making them academically 'elite'. Indeed, many were in positions of authority, too. There was then an interesting dynamic between me as a PhD candidate and their having passed through an academic system and, in some cases, moved into administration. However, because of my interest in translation I seemed to be asking questions that appeared timely to many actors. Several participants, for instance, had experienced research in academia, industry and worked in administration. So, my tactic of preparing individual interview schedules for each person in each role was one way of being aware of the participants' relevant features.

When I was transcribing the recordings (see Section 3.6) I was able to identify my laughter in a lot of the dialogue. For the most part I thoroughly enjoyed being in the interviews and I think this had an impact on how ready people were to talk. A problem follows from this, though. In particular, one of the early interviews ran for an hour and fifteen minutes and I found it difficult to end it. This was for two reasons. One, it was early in the research process and so I had not begun to refine what was important. Two, I wanted the participant to feel at ease and, even when they were talking about things that seemed irrelevant to my research questions, I let them run with their own line of thinking. Sometimes, this felt like they were reassuring themselves of their own worth: arguing for their own expertise (academic researchers 4 and 6). The steering and ending of interviews therefore presented a problem for maintaining rapport.

Also, I noted a difference in how it felt to conduct interviews face to face in comparison to telephone or video. There are a range of differences when interviewing in different modes

including: *interruption, topic control, lack of visual communication, articulation, holding the telephone, bringing preparatory materials, recording the interviews* (Stephens 2007, pp.209–211). In some cases, interviews using telephones do not generate different findings to interviews conducted face-to-face (Sturges & Hanrahan 2004). That said, my experience was that there was a qualitative difference between the interview modes. This is by comparison of the 'feeling' of conducting interviews face-to-face, via video conferencing with and without pictures, and via the telephone. I found it more difficult to maintain rapport in the absence of physicality and images. This is because microphones often transmit more background noise and there are no ways to communicate nonverbally. In fact, in one interview, the participant said they could not use the video because they were using their tablet. I got the sense they were referring to official documents as I was asking questions (research administrator 4). Another, who also opted for sound only, then proceeded to make coffee away from the microphone and then, I think, repeatedly bang a paperweight on the desk (academic researcher 14). The recurring jarring knocks, extra loud in the headphones, made transcription a painful experience. In this project rapport, access and data quality were all bound together.

Power. Two interviewees, who were senior research colleagues, agreed to have lunch with me but suggested that I would not get 'good data' if I recorded them. As they were more senior, and I wanted to maintain rapport, I accepted. We dined in a café and I struggled to change between my pen and fork quickly enough. After lunch, I scribbled as much as I could recall as I was waiting for the next interview. I was conscious of their unease, my desire to make notes and my own need to act in a polite manner at the dinner table. Thus, I felt that resulted in a much lower quality of data, mainly because I had not felt able to defend my need to record them.

A related point arose from my interactions with government. I decided, because of his connection to synthetic biology, it would be relevant and interesting to attempt to recruit David Willetts to the study. He had been minister of state for universities and science from May 2010 to July 2014. Surprisingly, he agreed. Despite some difficulties with scheduling, including a rearrangement, it so happened that we were able to find a date that was the day after two other interviews and an iGEM meeting in London.

I was nervous about the interview and had attended a daylong research course “conducting elite interviews”. I also sought advice from a scholar in the Politics Department for whom interaction with ministers was commonplace. My anxiety began to increase during the trip across London from the conference to the Houses of Parliament. This was exacerbated by the police presence at the gate where there was a jarring contrast between modern security technologies and the 14th century roof. I was directed to a high-ceilinged antechamber to wait. I was half an hour early. I watched people rush around and greet one another and loiter on the uneven stone floor. Later, in a clip on YouTube of a BBC interview, I saw the comedian Russell Brand make a comment that stuck in my mind:

> What I noticed when I was in the Houses of Parliament... it's decorated exactly the same as Eton, it's decorated exactly the same as Oxford, so a certain type of people go in there and say 'this makes me nervous' and another type of people go in there and go 'this is how it should be'.
>
> (Brand 2013)

The process and environment were nerve-wracking. I came away from the interview and could not recall any words we had exchanged. Only that at one point I had completely lost my train of thought mid-sentence and the minister had reassured me. Yet I can still recall his restless fidgeting in the first part of the interview, and our walk to the London underground exit. I felt deeply embarrassed and delayed transcribing the recording.

When, several days later, I listened to the audio recording I was struck by how quickly David Willetts was satisfied with his answers. Most of the other interviewees talked around their subjects, almost circling points. He, however, gave an answer quickly and precisely. This gave the interview a real pace that I had not experienced – all the others seemed leisurely in comparison. Listening back I was also able to identify the point at which he relaxed – as I was explaining how, in my research, the *Roadmap* (Technology Strategy Board 2012b) seemed to have a broadly positive image. At this moment I remember he leaned back on his sofa. I got the feeling I was not a threat.

This extreme example highlights some key elements of power in elite interviews, partly "because the typical or average case is often not the richest in information" (Flyvbjerg 2006, p.229). This case then is a discussion of issues that were present in different forms in other interactions, including nervousness, the buildings and environment, my thoughts about the other's status, approaching the recordings and reinterpreting the situation during transcription.

My aim in this section has been to give a sense of the process of observing and interviewing people in the course of this project. These points and considerations are made as adjuncts to the arguments regarding integrity, validity and ethics in Section 3.4. I found the processes of data generation to be frustrating, fun and even physically painful.

Documents and Websites

I aimed to collect various documents and representations of 'translation'. I used a computer to generate data from my desk. This included searching for "translational research" and

employing other terms and Boolean operators to explore documents and websites with related terms. This yielded a lot of data on how translational research was discussed in biomedical and medical science and formed the bulk of my initial reading. I began narrowing searches of "translation" with "synthetic biology", "UK", "government", "funding" among other terms. Perhaps the first piece of 'grey literature' was the policy-informing *A Roadmap for Synthetic Biology in the UK* (Technology Strategy Board 2012b). This was reassuring in the sense that the word "translation" occurred several times in the text. Furthermore, several of the searches specific to synthetic biology produced the same documents as the "translational research" searches. The *Roadmap* has an interesting status in this project as several of my participants had contributed to its text.

When I was attending field sites, such as interviews and meetings I gathered other documents. This was opportunistic. I filed conference programmes after attendance. I also found that various website searches would yield interesting publications, by TSB and RCUK, or by BIS and other government departments. Three particularly interesting documents, other than the *Synthetic Biology Roadmap*, are worth mentioning. The *Bioengineering* Report (House of Commons Science and Technology Committee 2010), the *Bridging the Valley of Death: Improving the Commercialisation of Research* (House of Commons Science and Technology Committee 2013) and *Emerging Biotechnologies: Technology, Choice and the Public Good* (Nuffield Council on Bioethics 2012). Each came about by a different search – one on the government website, one in Google and one from a participant interview.

Websites also turned out to be a useful source of information, particularly for checking funding details of projects such as the NSBs or SynbiCITE. Moreoever, they formed important sites for testing ideas because I could easily find them during the interview analyses, a point I return to in Section 3.6.

Multiple and hybrid sites

What I hope is apparent from the discussion so far is that I was collecting various forms of data by being involved with different, heterogeneous communities. This study is not an ethnography in the anthropological sense in that I have not committed to generating accounts from only the participants' viewpoints. Indeed, ANT-inspired studies are not typically ethnographic (Bruni 2005). Researching 'translation' I also had in mind that I would attend different sites. So, although a traditional, dominant form of ethnography locates research at a single site there is an increasing tendency towards "multi-sited ethnography" (Marcus 1995). Marcus, following Latour, suggests there are different ways of making different objects central to multi-sited ethnography by "following people, things, metaphors, plots, biographies and conflicts" (Marcus 1995, pp.106–110). At some points I followed actors. At others, I followed the absence of translation, a 'chain of absence' (Knorr-Cetina 2005a) dictated partly by my own plans, partly by disciplinary and methodological affiliations and partly by what the world allowed me to do.

Multiple sites are not necessarily different geographical locations. They also imply multiple forms of data, for instance, analogue and digital. A "virtual ethnography" is both almost ethnographic and takes place both online and offline (Hine 2007). The contemporary pervasion of internet and mobile communication meant that I was able to research via websites, internet searches, contact people via phone and email and so on. One example of a 'hybrid' research site in this study was a webinar launch of new funding stream. I was in virtual attendance, while others were present in a room in London, and I had the facility to conduct 'chats' with other online observers via instant messaging.

Multiplicity also took a temporal form regarding the SB 6.0 conference, held at Imperial College, London. I attended the conference 9th – 11th July 2013. Later, the organisers published videos of the main sessions (BioBricks Foundation 2013). I was therefore able to 'revisit the past' in a way that I was not expecting – it was not a recording I had planned or made. This meant I was able to transcribe specific talks that I knew were of interest.

One of the features of practicing multi-sited research is that it makes connections between various individuals, organisations and entities. In its process, multi-sited research makes a new space:

> The multi-sited ethnographer can be viewed as an embodiment of the middle range: it is not that the study contributes to bridging a pre-existing middle range, as much as that ethnographers bring it into being through the territory they map out whilst attending to the diverse accountabilities which they experience. Multi-sited ethnographers craft field sites with an eye to producing appropriate accounts for heterogeneous audiences comprising diverse sets of peers, policy makers, funders, bosses and research contacts… the ethnographer seeks out resonances, finding audiences for whom the study will be recognized as having an adequacy to connect with their concerns. Rather than being inherently recognizable as timely, a study finds an audience through a much more active process.
>
> (Hine 2007, p.657)

By travelling to different participants I was making an audience for my findings (see also Section 3.5 for how the findings might travel beyond the project). Perhaps others had not thought of translation as something that would, or could be, a topic of sociological research. This study highlighted 'translation' for some of the participants. More importantly, I was performing my own research object of translation. I was asking questions and following lines of questions that unfolded translation, and synthetic biology.

3.4 Doing Ethical Research

In this section, I deal with ethics in the broadest sense – not only to participants, but to funders, the academic community and wider society (Berg 2001, p.39). Thus, doing 'good' research has broad implications for practicing and communicating research (Jenkins 2002, p.13). As such, I cover the ways that I related to the participants and the ways I aim for this to be quality research for social researchers and wider society.

There are a variety of ethical considerations when approaching research. These are both "consequentialist", in ensuring that participants are protected from harm and that research promotes some benefit, and "deontological" in the sense of ensuring others' rights to equal and respectful treatment (Murphy & Dingwall 2007, p.339). Though, as Murphy and Dingwall (2007) go on to point out, these conceptions are problematic as they exist in a specific time and place (now, in Western society) and their specific enactments may create particular issues. With their caveat in mind, I now discuss how I designed and did ethical research in this project.

In Western society there has been a proliferation of guidelines and laws regarding the generation and use of personal data (Berg 2001, p.39). These include guidelines such as the ESRC *Framework for Research Ethics* (Economic and Social Research Council 2012) and the *Statement of Ethical Practice* (British Sociological Association 2002) and laws such as the Data Protection Act (1998). Furthermore, the research project was formally granted ethical approval by Department of Sociological Studies, University of Sheffield (see Appendix II). This project adheres to these various stipulations.

In terms of approaching and recruiting participants I provided an explanation of the project and a participant information sheet for them to read. I would then ask participants if they had

any questions and, when that had been addressed, asked them to sign a consent form (see Appendix II for information sheet and consent form). All except one of the participants were either studying for or had been awarded postgraduate degrees and none of the participants would normally be considered vulnerable in this context. The conversations could be on the phone, email or in person. Signed hard copy consent forms were stored in a lockable cupboard in the department to which only the department manager and myself had keys. The electronic versions were stored, as with all the digital recordings and transcripts, on the University's password-protected 'cloud'.

Following the guideline documents above, I take the view that ethics operates beyond bureaucratic procedures and formal structures. In some indigenous communities, research ethics means making meaningful, mutual and requited relationships (Smith 2005). This model places the emphasis on process, maintenance and care. For me, outside of the ethics forms and ethics committees, I worked to establish a respectful rapport and I followed up meetings with thank you emails with the hope of initiating future contact to share findings. I also aim to write in a style that is accessible, yet still expresses the details of the field research and nuances of theory I cover (Jenkins 2002, p.13). For more on the production of this thesis, see the final Section 3.7: *A Genre Account*.

Two points require further mention. First, one participant, to whom I had been directed, seemed edgy in the interview. I realised this when I produced the digital recorder and they were unusually hesitant. We agreed that any quotes I used would be sent them for agreement and all data would be destroyed at the end of the project. This was despite the steps taken for anonymity. After I left the interview and puzzled over the issue I came to the conclusion that a factor had been an assumption I had made. Because of the route of the referral and the actor's position I had thought they would be familiar with social research techniques and strategies, such as recording. I now think that they were taken somewhat

off-guard by my whipping out of a digital recorder. With the remaining few interviews I was mindful not to make assumptions regarding interview practices.

The second point involves the style of writing, to preserve anonymity and communicate clearly. Chapter 6 focuses on the 'bioglue project'. This was a small project and so there were a small number of key actors. I have had to take care in use of quotes and descriptions to ensure that the small number of people could not identify one another. Thus, the ethical approach has had an impact upon the final shape of this report.

Integrating methods

The ontological and epistemological position described in this chapter meant study design needed to attend to heterogeneity, practice, multiplicity and complexity. As such, I opted for using multiple techniques to generate data. Using multiple methods brings to the fore how different methods are validly integrated.

Validity, for the purposes of this discussion, means the soundness of the project, its coherence. There is a central problem of validity in interpretivism – we cannot know for certain what happens in another person's mind. However, there are alternatives to ensuring validity of a study such as conducting *sensible, comprehensive, transparent and sceptical* research (Jenkins 2002, pp.98–104). I think of this as producing coherence (see Section 7.3 for how coherence of a multiple object can be achieved with narrative work).

There are different ways to ensure valid integration of research methods. One way is to check that there is 'complementarity' between the ontologies and epistemologies facilitated by the different methods (Mason 2002, pp.35–6). I have taken care to outline the ontological

and epistemological foundations of this project in Sections 2.1, 2.2 and throughout Chapter 3. I applied this throughout as a form of theoretical integration. Furthermore, the notion of symmetry means that all materials can be treated the same in the first instance, be they field notes, transcripts or documents. Indeed, ANT-type studies acknowledge that objects are partly constituted by discourse (Sismondo 2010, p.150), though in this project I take discourse to include material as well as textual practices (Barad 2003). There is no internal conflict between using observations, interview and documentation in terms of giving an account of the constitution of translation. Indeed, it would be difficult to generate data on specific people's thoughts and beliefs without some method directed at soliciting information from people regarding their perspectives (e.g. interviews). Likewise, data on organisational representations of 'translational' would be challenging to acquire in the absence of websites and documentation. The treatment of objects, and how to find out about them within a messy world, is consistent throughout all the work in this research. In other words, the project methods were aligned in terms of their ontological and epistemological assumptions.

A second way, relevant to qualitative research, is to be flexible in the process of the doing the work to make sure the methods are sensitive to the context (Mason 2002, p.3). Research methods, to be coherent with the philosophy I have laid out, need to adapt to the unfolding nature of the world and the object of study. Unlike quantitative research, where the method is structured for the purposes of representative generalisation, flexibility, here, allows for 'depth'. This is a part of Latour's dictum to 'follow the actors' (Latour 1987). The ability to be flexible was built into the project because I was able to respond to different avenues throughout the investigation. It is the case with semi-structured interviews, too: while I had prepared questions and themes to follow, there were several times when the interview was outside of my topics but I followed the interviewee to see where they went. Sometimes this was fruitful, sometimes not.

A third way to integrate methods is to ensure they 'mesh' in explanations. This means attention to the style of argument. In terms of offering a convincing argument, I draw on data generated from the multiple methods throughout the thesis. I do not, however, offer generalisations based on representation. The argumentation is based on evoking and illustrating elements of translation in synthetic biology. In giving an account of a messy, decentred object one needs to deploy different metaphors and conceptual apparatuses (Law 2002). As I said at the very start of the thesis, I use a variety of concepts to analyse the data. In giving the account, then, I follow Jasanoff in that I am "against reductionist story-telling… causes are heterogeneous and hard to pin down" (Jasanoff 1996, p.413). It is possible to enact the complexity of the social world by using data from different methods and connecting them with various concepts in the explanations.

This brings me, finally, to the issue of interpretive validity. This means that the interpretation I offer is convincing. As well as using theory generated from other research, I concentrate my claims to interpretive validity on reflexivity (see Section 3.4) and transparency.

> The basic principle here is that you are never taking it as self-evident that a particular interpretation can be made of your data but instead that you are continually and assiduously charting and justifying the steps through which your interpretations were made. If you do this effectively, it should enable you to show both that you have understood and engaged with your own position, or standpoint, or analytical lens, in a reflexive sense, and also that you have tried your best to read your data from alternative interpretive perspectives.
>
> (Mason 2002, p.192)

I have demonstrated a clear engagement with the theoretical lens(es) through which I have generated interpretations. I have detailed in Section 3.6 the analytic processes by which I have come to conclusions. It is through this practice of 'laying out in detail' that I aim to create a convincing argument.

A study for others

This thesis is, in part, concerned with academic research and the production of knowledge with 'impact'. Here, I describe two points about the way I intend that this research might be transferrable to other sites and cases. One of the ways to achieve this is through detailed description of the empirical sites. In this mode, it is for others to decide the value of the account in understanding their matters of concern (Hammersley & Atkinson 2007).

A more satisfying contribution for me is to be able to make a theoretical contribution. This means creating abstractions. Abstractions are mobile. Indeed, abstractions are the key to sociological inquiry (and human society, more generally) and as such there "isn't a no theory option" (Jenkins 2002, p.32). So, creating theory is a way to abstract from this project and suggest that phenomena may be a part of a pattern outside of the specifics. My overall strategy of multi-sited ethnography was meant to attend to generalisation and the concepts I have developed are likely to be mobile because of extended case study design (Burawoy 1998) where I have connected translation in synthetic biology to other entities. Furthermore, I chose the skin graft project because it incorporated many of the issues that I hoped to explore (Flyvbjerg 2006), and that were already noted in other literature, which I highlighted in Section 3.2. Thus, I made theory at a local level, in the laboratory. But I also made connections between that data, interviews, national policy, and what other actors did and said at other points. Therefore, I contend that I offer 'connected concepts' that other researchers, and some of my participants, may be able to apply to their own situations.

3.5 Reflexivity

I have been emphasising that this research project was done by me, so this is an appropriate time to bring up reflexivity in this thesis. The idea of reflexivity is related to the capacity of people to be both subject and object of action. In the sentence, “I free myself”, the speaker is the subject and the object of the verb. When this point is extended to social research, in that people can refer to and be aware of themselves and their relationships, it has implications for conduct in the social sciences and especially studies of science and any interest in the co-production of knowledge. It can be a way to develop convincing arguments and perform ethical research (see Section 3.4).

In this study, I followed the actors through their everyday working life. As I did this, and they interpreted the world, I interpreted their actions and their interpretations. This produced information, but “what we call our data are really our own constructions of other people's constructions of what they and their compatriots are up to” (Geertz 1973, p.9). Giddens calls this “the double hermeneutic” (Giddens 1984). The thoughts and theories that I have, and share with actors or disseminate at a later date, then can ‘loop’ back into actors’ understandings of the world and alter their practices and their understandings of their own positions (Hacking 1995). An example of this is Merton’s (1948) *self-fulfilling prophecy* whereby unfounded claims about the weakness of a bank resulted in depositors withdrawing their monies and the bank getting into financial difficulty. The upshot is that, as a researcher, I need to be aware of my own position within a “research assemblage” (Fox & Alldred 2015).

Reflexivity, for some writers, is a key part of STS scholarship (Jasanoff 1996). However, certain positions do receive critique. Quite rightly, and in keeping with the positions taken elsewhere in the thesis, reflexivity is neither a special academic virtue nor does it facilitate privileged knowledge (Lynch 2000). The reflexivity of this thesis rests on the notion that

integrity and quality can be achieved by demonstrating how the position of a researcher affects the knowledge production process.

With these points in mind, I attempted to address the issue of reflexivity in various ways. I discuss the specifics in the research processes throughout this chapter and how, possibly, I affect/effect the findings of this study. To be theoretically reflexive, I applied the concepts I generated back into this study. This aided my own understanding of the research process and role in extending an object and I describe this in the *self-test* subsection coming up. Finally, I wrote a brief account of my own history and considered how this may have implications for my research practice. This comes next.

A partial presentation of self

Work in STS has emphasised science as a local achievement – specific material cultures that produce facts – rather than finding universal truths.

> Relativism is the perfect mirror twin of totalization in the ideologies of objectivity; both deny the stakes in location, embodiment, and partial perspective; both make it impossible to see well. Relativism and totalization are both "god tricks" promising vision from everywhere and nowhere equally and fully, common myths in rhetorics surrounding Science. But it is precisely in the politics and epistemology of partial perspectives that the possibility of sustained, rational, objective inquiry rests.
>
> (Haraway 1988, p.584)

What Haraway argues for is an epistemology where all knowledge is understood as located in specific times, places and practices. Barad has extended this possibility of partial knowledge to the idea that knowledge is created by intra-action between phenomena (Barad 2007). In other words, partial knowledges cannot be aggregated to some complete whole.

Instead, knowledge is created by specific configurations of materials and meaning. People, as phenomena, produce knowledge in locations. In light of this, I introduce myself as a 'partial connector' – a specific person who intra-acts with other phenomena through different practices at different locations and who enacts a partial self, and partial knowledge, at each site:

I was born in Leeds, UK to a teacher and doctor. We moved to Manitoba. Later, we settled in a large village on the border of Buckinghamshire and Oxfordshire. Formally, I hold a degree in Biomedical Science and a certificate and a diploma in Education. I have worked as a research assistant in a bioscience laboratory, as a teacher of science, as a confectioner making sweets for customers' entertainment, as an account manager for a marketing firm.

There are a couple of points I want make about this biography. One, people can be struck by my accent – I pronounce "castle" with a flat "a", yet to some people I sound posh. I play on this a little and normally introduce myself as "born in Leeds, raised near Oxford". Thus, I can be from the North and South of England. As a general rule, I give a narrative in a way that I hope people will find something that they connect with. Also, I present some information and explicitly omit others – gender, race, age.

Two, I began to address the issue of access and trust in Section 3.2. My bioscience training meant I was able to gain credibility and trust by demonstrating a technical competence – pipetting. As I said, this small example may reflect a larger effect of professionally working in science and having an idea of how academic research proceeds. However, this meant that access was bound up with participation.

One typology of researcher roles outlines a spectrum of four different roles (Gold 1958). At the one end of the spectrum, *complete observer*, there is no interaction between researcher

and participants. The other roles, *observer-as-participant participant-as-observer* and *complete participant,* involve progressively more interaction and immersion in the research sites. Although this relies on an unfortunate dualism, between researchers and researched, it does offer me a place to acknowledge the multiplicities of 'presenting the self' (Goffman 1959). As I moved among the different sites I took on different roles, different levels of participation. I transitioned from *complete participant* (peer/colleague) in the PhD network, to *participant-as-observer* in the laboratories and conferences, back to *complete participant* (as iGEM advisor) and to *observer-as-participant* during interviews. I wanted to be seen as a competent and sensitive social researcher and also, as part of the network and iGEM team, as a hard-working contributor. However, this seemed to be an effective strategy to maintain access, at least to the synthetic biology laboratories and iGEM.

The idea of roles extends to my participation in STS communities. Reading about the development of ANT is a route that, retrospectively, allowed me to gain in confidence and legitimise my increasing participation in academic STS (Lave & Wenger 1991). The development of 'super symmetry' to include objects, the critiques with respect to 'flattening' and power, and the emergence of what is sometimes called post-ANT, gave me an understanding of how STS had developed and kinds of critiques that had been historically successful, and the shift in emphasis from epistemology to science and society. In terms of 'getting' STS, the knowledge of ANT's key papers gave me access to community in-jokes, including the tongue-in-cheek use of hyphens after Latour's critique where he problematized "the word 'actor', the word 'network', the word 'theory' and the hyphen!" (Latour 1999, p.15).

For me, knowledge of ANT facilitated my increased participation in several ways. It gave me a conceptual tool that challenged my assumptions about the structure of the world, a case study of how STS academics critique and develop theory, and a point of reference to talk to members of the community, a 'language'. Thus, the participatory roles I took through the

research had implications beyond the project itself (see Appendix III for how my participation in academic communities increased over the course of the PhD).

Self-test

The strong programme (see section 2.1) advocated a reflexive approach in that "its patterns of explanation would have to be applicable to sociology itself" (Bloor 1991, p.5). One criticism levelled at the strong programme was that its style of explanation did not accomplish reflexivity because the programme did not treat its own explanations symmetrically (Woolgar 1981). In other words, in parallel to the ways that scientists construct elements of the natural world, social studies construct elements of the social world. The ANT version of symmetry was one attempt to remedy this problem. In this study, I systematically applied the emerging concepts to the study itself. For example, the notion of the *unfolding multiple* (Section 7.2). This study performs multiplicity and is a part of the 'unfolding' of translation and of synthetic biology.

Whereas one thesis is a construction (Meyer 2006), this one is a reflexive performance.

3.6 Analysis

The act of breaking up concepts, 'loosening' them, and subsequently ordering them is a means of describing components in a logical way. One of the problems with doing this, though, is that it can make the process appear sequential. I cannot stress enough that this was not the case with this project, and often is not the case with qualitative research more

generally – making sense of a messy world is a messy process (Law 2004). As such, I did analytical work throughout the project and the loosening up took different forms.

A second point is that this is a PhD thesis. I placed emphasis on my own development. I approached the project with an ethic of experiential learning. I had to *do* research. I could, and indeed did, err. The analytical systems emerged through doing. The practice of analysis and synthesis was perhaps where the greatest practical learning occurred. It is where many of the concepts and terminology discussed in Chapter 2, and some of the methodological theory discussed above, came to mean something. Sometimes this led to ideas that faded away. For example, most of the diagrams depicting translation involve a linear diagram usually progressing from science on the left of a page towards market, product or society on the right of a page. Early on, I felt that I wanted to challenge these diagrams. Then to say that the models were performed in the way that institutions were funded. However, as I read literature regarding linearity, I felt it would be difficult to say challenge this in a novel way (Godin 2013; Godin 2006; Edgerton 2004; Balconi et al. 2010; Williams & Edge 1996; Sorensen & Williams 2002). Indeed, the appearance of linearity is the product of a multi-authored innovation story (Deuten & Rip 2000). Over time, as I was able to refine concepts in writing, the thesis emerged. Therefore, the process of analysis was laborious as it involved both *learning to do* and *doing*.

Transforming data

The human senses focus on specific ranges of the world in terms of wavelengths of light, frequencies of sound and so on. Our perception is already concentrated on certain types of events at particular scales so that we can make sense of our environment. The very act of ‘sensing’ data involves a reductive transformation. Collecting data for others, by writing or

recording in some way, eliminates further elements of the world. This section explains some of the transformations that the data underwent in this project.

The process of qualitative analysis can be broken down into reduction, display and conclusions (Miles & Huberman 1994, pp.10–12). Furthermore, the process of analysis is intertwined with the way data is managed (Miles & Huberman 1994). My data consisted of documents, handwritten notes, typed notes on a tablet, and a computer, recorded interviews, videos of speeches, photographs and so on. One transformation is the data undergoes 'processing'.

> The raw data requires some sort of organizing and processing before it can actually be analyzed. Field notes, for example, may fill hundreds of pages of note books or take up thousands of megabytes of space on a computer disk. These notes need to be edited, corrected, and made more readable, even before they can be organized, indexed, or entered into a computer-generated text analysis program file. Recorded interviews must be transcribed (transformed into written text), corrected, and edited…
>
> (Berg 2001, p.34)

In order to demonstrate the kinds of work that gets done in 'cleaning up' data, and in keeping with the overall epistemology of the thesis, I have chosen to focus on the details of acts of transcription. I experienced comparable processes and effects to the ones described below in generating and readying field notes, diagrams and videos.

In this project I decided to transcribe the interviews myself. This was to revisit, recall and to become more familiar with the interview data. The process of transcription is an active part of the research process, with interpretive and analytic decision-making (Tilley 2003). Transcription is also an iterative process that facilitates an engagement with data construction where "analysis takes place and understandings are derived through the process of constructing a transcript by listening and re-listening, viewing and re-viewing"

(Lapadat & Lindsay 1999, p.82). I had found that steering the interviews meant that I focused on guiding the conversation to topics that I wanted cover. I made a few notes, but relied on the 'memory' of the tape recorder. Through re-listening, and typing, I returned to the sites of interviews, albeit in digital form. This is in contrast to many events during the observational data collection that I could revisit only by reading my scratch notes. As explained in Section 3.3, the SB 6.0 conference was a notable exception as the organisers subsequently posted videos online.

Listening to some sections of recordings over and over, the interviews became much longer and more nuanced. Instead of a forty-minute conversation, progressing through time, I also used a media player to slow the recordings to about 30% so I could closer match my typing speed. Thus, rather than technology facilitating a *compression* of spacetime, the process of transcription expanded the object (Engestrom et al. 2003). Transcribing changed my sense of time of the interview, extending and drawing out the experience and interaction.

I went over and over certain sections in recording, usually because it was difficult to hear the exact words for some reason. One interview took place in a café (industry rep 1, 1st September 2014). The repeated hissing of an espresso machine was very disruptive to the mic's pickup. I tried to transform the recording using a computer program to limit background noise and focus on human speech. This meant I was able to transcribe some words warped by the interference.

There are, then, many choices to make during transcription (Hammersley 2010). At one point, for example, I experimented by reformatting some of the transcripts into screenplays to enhance the notions of performances and actors. Initially, I opted for as naturalistic a style as I could. I also chose to type the mutterings, stutters, repeats and other non-speech elements. I tried to punctuate little and included as many vocal noises as possible – we give

off signals intentionally and unintentionally, and both can be 'received' differently in interaction (Goffman 1959). Occasionally, I added relevant comments on gesture or expression. All these different processes and different choices mean that the "transcription of tapes can be done in many ways that will produce rather different texts" (Miles & Huberman 1994, p.9). As I was writing up, though, I began adding punctuation and, by using square brackets, correcting quotations to make it easier for the reader to understand them. The interview data were transformed right up to the last.

Coding

The generation of codes is one way to compare 'horizontally' between different sets of data (Mason 2002). There are different ways to approach coding so I will describe the way I coded the transcripts. In an analogous way, I wrote memos and notes with respect to observations and emerging findings. I have chosen to keep this discussion to the interviews to be consistent with the previous section on transcriptions and explore specific processes in more depth.

The first interview I analysed line by line with no prior categories. This closely resembles 'open coding' (Strauss & Corbin 2008). My aim was to begin to generate ideas directly from the data with the aim of refining them later, both in comparison with other data and with the literature. This generated a lot of themes. As I coded subsequent transcripts I referred to, and adapted, the categories from the previous ones (Glaser 1965). Many of these categories were irrelevant to my research questions. In the later transcripts, I generated codes that were more descriptive and contained more data.

I copied text into new documents with theme headings. This generated eighteen new documents. The sections of transcripts that covered multiple themes were present in the new documents – some sections doubled and tripled. Some of these documents such as "defining Synthetic Biology and Translation" were comparatively large – more than ninety pages. "Scientific scepticism" turned out to be only a page long. By reading through these I then generated new documents by writing brief statements about what each segment covered. I highlighted these with different colours to create what I imagined were going to be four discussion chapters.

What emerged from coding the interviews were theories about performances of translation. I tested these by comparing between interviews codes and memos on the field notes and documents. What then came from coding and memo writing was still not finalised. As the next Section 3.7 explores, the act of writing was an important part of the analytical and research processes as it formed a way, albeit temporarily, to crystallise the findings.

3.7 A Genre Account

The process of doing academic social research is, like laboratory life, very much about producing texts. As Latour writes:

> See? That's again why I dislike the way doctoral students are trained. Writing texts has everything to do with method. You write a text of so many words, in so many months, based on so many interviews, so many hours of observation, so many documents. That's all. You do nothing more.
>
> (Latour 2005, p.148)

The requirements of the final text, in this case a thesis, function as a method as it limits and facilitates what can be described and explained. The university faculty suggested the final thesis should be 75 000 – 100 000 words noting that "brevity achieved without sacrifice of clarity is a virtue much appreciated by examiners" (The University of Sheffield 2015). The thesis also needs to be so many chapters and to address certain issues. This forces the writing into certain conventions, such as divided sections. In this thesis, writing was constitutive and I now explore how writing as method influenced the analytic and concluding processes.

In order to make some decisions about academic writing, and presentation of data, I read *Clear and Simple as the Truth* (Thomas & Turner 2011). The authors argue that "even the best educated members of our society commonly lack a routine style for presenting the result of their own engagement with a problem to people outside their profession" (Thomas & Turner 2011, p.10). It is to meet this need that clear prose in 'classic style' was developed.

I chose not to use 'classic prose' throughout the thesis because it explicitly 'hides labour' (Thomas & Turner 2011, pp.194–5). In a practical writing exercise, the authors explain how to hide the labour of observation and begin adding inference to a perceptible observation. By presenting an interpretation as 'transparent' it hides the action that goes into interpretation. In contrast, what I find particularly attractive about the Latourian approach – the explicit and playful use of metaphor – is that it facilitates 'obvious' reinterpretation. The labour is laid out for the reader. A second reason was because 'classic prose' assumes "thought precedes writing" (Thomas & Turner 2011, p.11). To follow a 'classic' course of presentation would therefore be at odds with one of the fundamental assumptions of this thesis. That is, dualisms like thought and action are ways to understand a problem that already rest on processes which mask hybridity (Latour 1993b).

Rather than present this thesis in ‘classic prose’, I used it as an analytical stratagem. When I struggled to write about something I would try to approach it with the ‘plain for all to see’ way of describing. This ‘loosened up’ my writing, and often allowed me begin writing about my research without trying to use STS concepts.

The first attempt at writing an empirical chapter resulted in me concluding I did not understand ‘translation’, at least in the laboratory. But it was an important process to go through, and much of that attempt has found its way into other sections, particularly Chapters 1, 3, 6 and 7. Even towards the end of drafting the thesis, I was still developing new connections, new points of coherence. In so doing, I was doing more ‘cleaning’. These exploratory writings were a form of research, discovery and analysis where:

> I made accidental and fortuitous connections I could not foresee or control. My point here is that I did not limit data analysis to conventional practices of coding data and then sorting it into categories that I then grouped into themes that became section headings in an outline that organized and governed my writing in advance of writing. Thought happened in the writing.
>
> (Richardson & St. Pierre 2005, p.970)

I have been over and over the writing in the thesis. Editing, rephrasing, deleting and substituting different words and paragraphs. Over time, the final argument, the final connections emerged. For Glaser (1965), writing comes after theory. I think of writing as an analytical, iterative process of ‘layering’.

Some scholars have commented on how some sociological scholarship is poorly written (Richardson & St. Pierre 2005; Becker 2007; Wright Mills 2000; Jenkins 2002). There are non-academic influences on my writing, particularly minimalism, which influenced my style in Chapter 7. Minimalism is a sparse style of writing that encourages the reader to slow down. I use minimalism to recall the earlier points throughout the thesis and create a synthesis:

> In minimalism, every story is a symphony, building and building, but never losing the original melody line. All characters and scenes, things that seem dissimilar, they all illustrate some aspect of the story's theme.
>
> (Palahniuk 2004, p.143)

I think it may be suited to some sociological description and analyses in order to limit longer sentences and sensitise the acts of both reading and writing on representation. Furthermore, minimalism seems an appropriate style with which to describe "a fractionally coherent subject or object" (Law 2002, p.3) (see Section 2.4) because minimalism is additive – each element adds to the whole. Chapter 7 is my first experiment in a writing style that might be termed "academic minimalism".

It is sometimes difficult, however, to balance minimalist sentences with the detail and depth required by some academic explanations. Therefore, I instituted a set of mediating principles. In 1946, George Orwell suggested some guidelines for writing accessibly and without ambivalence. I often think of these when writing academically because they are concerned with ethical communication in politics:

1. Never use a metaphor, simile or other figure of speech which you are used to seeing in print.
2. Never use a long word where a short one will do.
3. If it is possible to cut a word out, always cut it out.
4. Never use the passive where you can use the active.
5. Never use a foreign phrase, a scientific word or a jargon word if you can think of an everyday English equivalent.
6. Break any of the rules sooner that say anything outright barbarous.

(Orwell 2004, p.119)

Although these rules are formulated for writing in general, I have tried to produce a thesis that is readable and clear in style. That is my hope – that the thesis is a convincing account, but one that reminds the reader it has been crafted.

Indeed, the final thesis is a 'cleaned up' representation of the process of research. In so doing, I aim to connect my thesis with a broader research 'genre' in STS where:

> … the approaches taken by SSK scholars, and by science studies more generally, have tended to be qualitative rather than quantitative, thickly descriptive rather than thinly reductionist or model-dependent, deconstructive rather than paradigmatic, and self-consciously, often ironically, narrative.
>
> (Jasanoff 1996, p.411)

These four points form a framework to summarise this chapter and connect this research project to some of the common features of STS scholarship. This includes some general comments about the methodological, sociological, anthropological and postmodernist influences that have inspired the shaping and concerns of this project. I have not 'blindly followed' other scholars so I will say a little more about how I take each of these points and justify their use in the research.

Qualitative and descriptive research

Science tends to present its method in a way which removes the complexities, difficulties and realities of practice (Latour & Woolgar 1986). In contrast, STS researchers often tend to give accounts of science in the anthropological mode of 'thick description' (Geertz 1973). This is an account whereby the words and terminology used to describe action also work to frame the context of that which is being described. For example, to describe someone as

hitting a small wooden ball with a wooden stick through metal hoops on a patch of grass is 'thin' compared to saying someone is playing croquet on a lawn (Maxwell & Mittapalli 2008, p.880). This is particularly the case in my use of acronyms and biological terminology (in Chapter 6) and so I have included a glossary of terms to aid the reader.

However, any description is already interpreted:

> A purely objective description is not possible, because the social world is always already interpreted and because what we see is shaped by how we see it.
>
> (Mason 2002, p.149)

This means that every description and methodological choice is 'doing work' to interpret the world and is not a reflection of an external reality. However, this interpretive labour is a way to explore a phenomenon, or case, in depth.

The questions that I presented at the end of the literature review are concerned with changes. Changes in qualities. It is not, for the most part, concerned with numbers and measuring. Indeed, this is a problematic and artificial distinction, not least because quantitative data are based on categories qualitative in nature (Douglas 2002). Broadly speaking, qualitative research aligns with an interpretive epistemology, constructionist ontology and inductive theory-making (Bryman 2012, p.380). There are caveats to these broad-brushstrokes. As I have detailed, there is not necessarily a clear distinction between deductive and inductive research. Although this thesis has produced some theory in an inductive way, I have used other social theory to guide this research. This has aided the interpretation of some of the data in that I used other theories as "sensitising concepts" (Blumer 1986). These are concepts marked by an absence of clear specifications and benchmarks. Instead they offer general suggestions of content. For instance, *articulating alignment* became an important analytical framework during the writing process. However,

other notions, particularly the 'imaginary' first outlined in Section 4.3 and the ideas of 'contours' described in Section 5.2 were more inductive.

Deconstructive narrative

Narratives are ways of telling a story. This involves putting together an account to connect elements in the account. They can, but do not have to be, chronological. It is possible to see the overall shape of the thesis as a narrative funnel guiding the reader from a nation state perspective to the view from the laboratory bench. An example of self-conscious narrative description concerns the way researchers embody protein structures (Myers 2008).

Furthermore, my narrative attempts to convey complexity by being deconstructive. This is an approach to analysis most associated with Jaques Derrida. There is a problem with trying to give a brief account of deconstruction that is well articulated in the 'deconstruction' entry in the *Sage Encyclopaedia of Research Methods*:

> An encyclopedia is designed to enclose, encapsulate, reduce, and simplify its subject matters, whereas deconstruction is oriented toward opening, expanding, amplifying, and complexifying them.
>
> (Gough 2008, p.203)

Gough goes on to offer a 'performed' entry – rather than explaining deconstruction, he does it for the reader. Deconstruction reverses the common-sense idea that signs represent an objective reality and treats the iterative use of signification as the cause of belief in, rather representation of, an objective reality (Carspecken 2008, p.171). Theory associated with STS has broadened deconstruction from a focus on language and text to material matters (Barad 2007; Barad 2003; Pickering 1995; Pickering 1992).

Furthermore, one of the central projects of STS is to suggest that 'things could be otherwise' by showing the contingent nature of reality, even its singularity (Woolgar & Lezaun 2013). One way is to offer a different account that runs against the expected, or assumed, (grand) narrative.

> The alternative is to imagine, reflexively, that telling stories about the world also helps to perform that world. This means that in a (writing) performance reality is staged.
>
> (Law 2002, p.6)

Thus, the accounts I present in this thesis *participate* in the world (Law 2002, p.6). I aim for it to participate in STS, too. Woolgar (2014) gave a lecture on provocation and irony at the Centre for Science, Technology, Medicine and Society at UC, Berkeley. He argues, among other things, that irony is subversive and is performative because it potentially splits its audience into those who get the joke, and those who judge the representation to be sincere. Thus, in retelling the data collection and analysis in a narrative style, I aim to perform an STS version of irony, and account for the complexity of doing research.

To summarise – in the project I am interested in exploring quality rather than measurement, emphasising depth of investigation, opening up and complexifying and, lastly, proposing alternative accounts of 'translation'.

3.8 Conclusion

In this chapter I have outlined the process and considerations for performing this research project. Ontologically, I have assumed a position of relativism in the sense of 'non-absolute realism' or 'relativist realism' (Bloor 1999) in which reality is not entirely singular, antecedent,

definite or independent (Law 2004). This means, epistemologically, that reality is produced and known through specific 'intra-actions' between phenomena, which include interpretive schema, research methods, material tools, natural and manmade materials (Barad 2003; Barad 2007; Law 2004). The upshot of this is that there is no complete knowledge. Instead, partial knowledge in the double sense of incomplete and biased (Haraway 1988) is performed and inscribed at specific points. Methodologically, I have selected an approach that will capture performances of making synthetic biology translatable in different sites. Thus, I followed (Latour 1987), observed and 'interrogated' human and nonhuman actors in a multi-sited ethnography (Marcus 1995; Hine 2007). I have explained the ontology, epistemology and methods and described how they are all interrelated in theory and practice. The matter of ethics is related to writing and representation as well as the conduct of research, as well as the self. In so doing, I have articulated the alignment of this thesis with STS communities, research participants and wider society. In the next three chapters I describe the analysis and findings I created in the approach I have outlined.

Part II

Articulations & Contributions

Chapter 4

States of Synthetic Biology

In this chapter I explore how actors align synthetic biology with other entities. The level is similar in scope to the “social world” beyond the laboratory (Fujimura 1987, p.258) that includes the work of research administrators, scientists and policymakers. In Section 4.1, I detail how synthetic biology is performed as a precarious yet potent solution to state economic recovery. Proponents of synthetic biology, actors from various academic disciplines, biotechnology industries, government and research funding, make synthetic biology into an entity that can realise the UK state’s identity as a global leader of bioscience. However, there is much debate as to what constitutes synthetic biology and what novelty synthetic biology offers. In Section 4.2, I explore the messy and local processes of demarcating synthetic biology from other biotechnology and bioengineering. I situate this discussion in the context of actors attempting to preserve their access to resources, particularly funding. Finally, in Section 4.3, I analyse the way actors cite various influences that shape the establishment of a UK synthetic biology industry. I argue that a particular kind of industrial manufacturing is imagined and this affects how synthetic biology is emerging: a particular commercialisation narrative enables some actions while constraining others (Deuten & Rip 2000).

4.1 Towards Global Leadership

UK science, health and wealth: policies and reports

In this section I show how a range of governmental reports describe the UK research system as globally competitive in terms of fundamental science yet lacking an ability to turn these into applications and economic gain. I situate this narrative in relation to the promises and potential of synthetic biology and argue that these technological promises of the field are turned into organisational responses. I begin with three documents, selected because of their importance to UK policies relating to bioscience research. These are a *Review of Health Research Funding* (Cooksey 2006), *The Life Science Strategy for the UK* (Department for Business Innovation and Skills 2011) and a government report into different biotechnologies called *Bioengineering* (House of Commons Science and Technology Committee 2010). Each of these documents adds to setting a scene in which synthetic biology can realise its translational potential.

The UK government has produced policies to lay out the future of research investments and commissioned various reviews of publicly funded bioscience research. The *Cooksey Review* (Cooksey 2006) focused on health research in the UK and claimed that the UK has a history of notable biomedical science.

> The Review found that the UK Health Research system has many strengths. It has a long tradition of producing excellent basic science, with the Medical Research Council (MRC) funding 27 Nobel prize winners since its establishment in 1913. The quality of the health research base, combined with a national health service, creates a major selling point that attracts R&D investment from the pharmaceutical and biotechnology industries, which form a major part of the UK knowledge economy.
>
> (Cooksey 2006, p.3)

The report draws explicit links between the state's economy, bio-industry and scientific knowledge. According to the review, the National Health Service (NHS) is a specific feature of the UK that combines with the research activities and appeals to industrial investors in biomedical sciences.

Despite this history and these features, the *Cooksey Review* concludes that there is not enough conversion of biomedical knowledge to health and wealth benefit and that:

> …the UK is at risk of failing to reap the full economic, health and social benefits that the UK's public investment in health research should generate. There is no overarching UK health research strategy to ensure UK health priorities are considered through all types of research and there are two key gaps in the translation of health research:
>
> - translating ideas from basic and clinical research into the development of new products and approaches to treatment of disease and illness; and
> - implementing those new products and approaches into clinical practice
>
> (Cooksey 2006, p.3)

The report recommends the "the government should seek to achieve better coordination of health research and more coherent funding arrangements to support translation" and that "other institutional changes are necessary to maximise the economic and health benefits arising from a single health research budget" (Cooksey 2006, p.4).

The government, in one response to the *Cooksey Review*, created the Office for Strategic Coordination of Health Research (OSCHR) which was tasked with setting the health research strategy and coordinating the budgets for DH and MRC. The MRC website states the OSCHR:

> … has demonstrated a powerful capacity to work across government through collaboration, addressing many of the issues required to ensure a comprehensive health research environment and leading to improved health outcomes and economic growth.

> The OSCHR process has helped to focus on the development of better NHS electronic data capabilities for research; create a research programme for public health and greatly enhance translation science.
>
> (Medical Research Council 2015b)

In the view of MRC, the *Cooksey Review* of health research resulted in successful institutional change and new funding arrangements that prioritised translational science. In this way, the MRC also constructs the view that the UK is 'good' at basic science but 'bad' at creating clinical applications and that what was required was "cultural change among public funders of health research to address the barriers to research collaboration and to support the application and translation of basic research" (Medical Research Council 2015b). These comments legitimise the institutional and cultural changes meant to ensure the realisation of health and wealth benefits.

The UK contribution to global bioscience is also a feature of the Introduction to the *Strategy for UK Life Sciences* (Department for Business Innovation and Skills 2011). In contrast to the Cooksey Review, where the conversion of 'basic' science to clinical application is identified as being deficient, the ministerial foreword to the *Strategy* suggests the UK is a place that can support discoveries that turn out to be medically beneficial.

> The UK has long been a world-leader for innovation in life sciences. That is why many of the most talented scientists from other countries come here to research and develop innovative drugs and technologies. It is also why so many of the great breakthroughs in this field – like Sir Alexander Fleming's discovery of penicillin and the discovery of the structure of DNA and antibody therapies – have happened here.
>
> We want that enviable record to continue into the future, strengthening our life sciences industries and helping to build a sustainable economic recovery.
>
> (Lansley & Willetts 2011, p.2)

The above quotation connects scientific discovery, industry and state economy. The UK is presented as a place for advancing basic science and that successful conversion of knowledge will produce income for the country. Towards the end of the document there are two and a half pages of 'actions'. The first two actions are:

> - We will invest £310m to support the discovery, development and commercialisation of research. This covers £130m for Stratified Medicines and £180m for a Biomedical Catalyst Fund.
> - We will commission an independent panel to develop a technology roadmap that will propose actions required to establish a world leading synthetic biology industry.
>
> (Department for Business Innovation and Skills 2011, p.31)

The *Strategy* mobilises a history of successful innovation to justify spending on developing technologies and industries in order to support the UK economy. In particular, the *Strategy* publicly announced the process of changing funding arrangements (see Section 5.1 for a detailed description of Catalyst funding) and for developing synthetic biology within the UK to become a world leading industry.

In 2010, The House of Commons Science and Technology Committee produced a report into three areas of bio-scientific innovation – GM crops, stem cells and the 'emerging' field of synthetic biology. In constructing the report, called *Bioengineering*, the committee solicited evidence from a wide range of stakeholders, including representatives from academia and industry. The executive summary reads:

> We found that the UK has an excellent research base but is still failing to maximise its potential by translating research into wealth and health. Considering that the UK is emerging from a recession and a difficult economic climate still prevails, this is worrying. The road to economic recovery will depend, in part, on exploitation of the UK's research base, which in turn requires efficient translation to generate returns on investments.
>
> (House of Commons Science and Technology Committee 2010, p.3)

The report emphasises the recessive state of the UK economy and argues that translation is "still failing". Basic life science or knowledge is seen as a state resource generated by public funding and which can be converted to a financial surplus. This, according to the report, requires improvements in the processes by which science is converted to profitable and marketable products and services.

These documents do a number of things. They connect the production of knowledge to state economic benefits, a particularly salient argument within a narrative of austerity and recession. They present the UK state as a space for world-leading bioscience and that this should continue. In this way, they perform the notion that "the modern state is a scientific state" (Sismondo 2010, p.191). They identify cultural and institutional changes as key to realising the promise of bioscience. They prioritise technological development in the name of economic recovery and health benefits. Thus, some areas of research are selected as more important than others. Finally, the arguments presented in the documents make connections that serve to legitimise some kinds of activities and investments in bioscience and de-prioritise others. This will be further explored in the upcoming sections.

While much STS work has argued for an integrated and networked understanding of the character of production of knowledge (Knorr Cetina 1981; Latour 1987; Gibbons et al. 1994), the policies described above appear to argue that individual discoveries can be located within the borders of the UK: a discrete space for science. It is onto this stage, of a UK

absence of or weakness in translational bioscience, which synthetic biology and its proponents have stepped.

Funding potential

Some of the research councils responsible for administering public funds for research made synthetic biology a funding stream in 2007 and funded seven academic networks that ran between 2008 and 2011. Five networks were in single universities (Bristol, Edinburgh, Nottingham, Oxford and Sheffield) and two were collaborations, one between the universities of York and Durham and one between Birkbeck College and University College London (UCL). The funding for and interest surrounding UK synthetic biology increased. In 2010, RCUK awarded Imperial College a 5-year grant for the Centre for Synthetic Biology and Innovation (CSynBI).

As explained above, the *Bioengineering* report solicited information from a range of stakeholders in bioscience and innovation. Evidence submitted by CSynBI presents synthetic biology as having revolutionary potential. The memorandum is worth quoting at length because of the way CSynBI connects the potential of synthetic biology to the realisation and failure of other technologies.

> The last half of the 19th century and the first years of the 20th century saw scientific and technological discoveries that created the basis of wealth generation by means of major new industries— petrochemical, automotive, aircraft, electronics etc. SB [synthetic biology] has the potential to create another group of major new industries with profound implications for the future of the UK, Europe and other major economies…
>
> Unlike synthetic chemistry in the 19th Century, the UK essentially "missed the boat" on the commercial potential of the microchip revolution and lost the opportunity to participate

> in any significant, commercial way in what is now a major global industry. The UK writes significant amounts of commercial software, but the US dominates the sector (eg Microsoft and Google). In the opinion of The Royal Academy of Engineering Inquiry into Synthetic Biology's working party, one of the key reasons for the UK's relative failure was because the UK professionals did not undertake an effective campaign to inform decision makers about the potential significance of the microchip…
>
> If the promise of SB is realised, it could form the basis of a new industrial revolution based on the confluence of biology with engineering. The UK has little in the way of natural resources but a major asset is human resource in terms of a strong science base. It is therefore important to build the capacity to exploit the science base in SB to create the new technology and companies that can create employment and economic benefits to the UK.
>
> (House of Commons Science and Technology Committee 2010, p.Ev 1)

CSynBI's evidence to the committee positions synthetic biology as having an economic and technological potential similar to some of the most recognisable and commonplace industries in contemporary society – planes, cars, computing and so on. CSynBI argue the UK 'lost out' during the computing revolution, partly because proponents did not make their case for support clear. Finally, the human capital of the UK, rather than its natural capital, is suggested as a key area for building capacity to build a profitable technology. The expectations of synthetic biology are equated with a history of successes and failures of other more well-known technologies. By presenting synthetic biology in this way, the memorandum aligns synthetic biology with other technologies, and a 'fear of loss'. It also argues that the new technology could produce various benefits to the UK economy. Thus, the quotation performs an alignment of synthetic biology with UK needs as identified by government.

The idea of an industrial revolution invokes ideas of moving from craft production to standardised systems. Professor Freemont, co-director of CSynBI with Professor Kitney, said:

> Before the industrial revolution most items were made by hand, which meant that they were slower to manufacture, more expensive to produce and limited in number. We are at a similar juncture in synthetic biology, having to test and build each part from scratch, which is a long and slow process. We demonstrate in our study a new method that could help to rapidly scale up the production and testing of biological parts.
>
> (Freemont & Kitney quoted in: Smith 2013)

Ad-hoc building is time-consuming. The acceleration of testing and development is one of the promises of the synthetic biology approach. This quotation argues that the work being done to improve the speed of scaling up and testing of new parts will mean that manufacturing can happen more quickly. Overall, the idea is that investment in synthetic biology will speed up translation of science to the bioeconomy.

In 2012, the Chancellor of the Exchequer George Osborne gave a speech at the Royal Society. He spoke of how science was a driver of economic growth. He made several announcements, including additional funding for UK space technology and the publication of *A Synthetic Biology Roadmap for the UK* (Technology Strategy Board 2012b). In his speech, he used some of the hopes of synthetic biology to justify increasing government investment in the field:

> Synthetic biology has huge potential. Indeed it has been said that it will heal us, feed us and fuel us. The UK can be world-leading in this emerging technology. That is why we are backing it with further investment today.
>
> (Osborne 2012)

The chancellor pointed out that synthetic biology offers something else to the state besides improvements in medical, food and energy technologies. The state can establish itself as a world leader. This connects the way that synthetic biology is funded, the types of research

avenues that might be pursued, and the way the UK state imagines itself within global bioscience.

The proponents of synthetic biology are active in creating grand expectations. In these documents and speeches "the future is mobilised in real time to marshal resources, coordinate activities and manage uncertainty" (Brown & Michael 2003, p.4). However, particular kinds of futures are invoked. The overall goal of making biology an engineering discipline is reinterpreted in these examples to align synthetic biology with state needs and legitimise government backing of the field.

Before moving on, I want to acknowledge that the promises of synthetic biology are not necessarily orientated to health and wealth. There are high-profile researchers in synthetic biology who emphasise the transformation of biology into an engineering discipline rather than focus on state economic benefits. One researcher pointed out that synthetic biology is founded upon epistemic, rather than commercial, principles:

> The idea of synthetic biology is not driven by "we need to build these foundations to have innovation", I mean, that's it's sort of a given that that will happen… It's more we need build these foundations so that the experiments and the building and doing becomes much more routine and quicker and faster. Scalable. Predictable. Modelling. Just to take away the huge amount of time and money that is spent on experiments that basically don't go anywhere.
>
> (Academic researcher 10 interview, 1st September 2014)

The quotation illustrates how some researchers are orientated towards innovation: the main goal for this researcher was to improve the engineering of life and to make biological science generate more verifiable knowledge per unit investment. If biology is made easier to engineer by applying the design principles of abstraction and modularisation and standardisation then that will somehow, inevitably, produce innovation.

This epistemic focus on synthetic biology does not appear to be the case for some of the more public proponents and supporters in the UK. They argue for funding and infrastructural support to realise the promise of innovation, rather than of engineering. In the science funding narratives described above, the UK is a state with a good science base, but a state in which technological innovation is precarious and vulnerable to failure because of lack of support from the state or lack of coordinated action from proponents. With support, so the story goes, synthetic biology can flourish to address state needs.

Realising promises by funding re-organisation

Synthetic biology is presented as having the potential to deliver a return on life science investment, which would see benefits for the UK. RCUK has continued to invest in Synthetic biology following the initial networks and research centres such as CSynBI. The funding has come predominantly from a pair of the quangos that make up RCUK: the BBSRC and the EPSRC, reflecting the disciplinary combination of biological and engineering research. Other councils, including AHRC, ESRC, MRC and NERC have also made contributions to greater or lesser degrees to various forms of grants and other forms of support. However, towards the end of the NSB funding period the government became increasingly involved in the emergence of synthetic biology. This included synthetic biology being one of eight technological areas highlighted by the chancellor during his talk at the Royal Society in 2012 (Willetts 2013a, p.9; Osborne 2012).

The links between RCUK, UK government and synthetic biology were then particularly visible at SB 6.0, the sixth international conference of synthetic biology. This was held in 2013 at Imperial College, London. There were over 750 delegates from around the world.

Predominantly, the audience consisted of synthetic biology researchers. The three-day conference was structured into four main sessions each day. Three of the four daily sessions were plenaries held in The Great Hall and featured a panel of speakers.

One morning David Willetts, then minister of state for universities and science, was invited to address the whole conference audience at the beginning of the *Translating technology, transcending industrialisation* track. Professor Kitney, a director of CSynBI, used the opportunity to highlight the minister's endorsement of synthetic biology.

> We are particularly pleased that David has been able to come this morning because he has been a great supporter of synthetic biology in the United Kingdom as I'm sure he will tell you in a very modest way.
>
> (Kitney, 11th July 2013)

In Willetts' speech at the synthetic biology conference, he explained that the chancellor's analysis of emerging technologies had taken a strategic view to invest in those that some think will have worldwide significance and in which Britain already had strength. Willetts stated that the current policy was to "reinforce academic work with practical measures to help take it further" and that the *Eight Great Technologies* report had prompted the Chancellor, George Osborne to announce an extra £600m government investment in those areas of technology (David Willetts speech, 11th July 2013). Of that, £50m was to be invested in synthetic biology over the coming two years. This was in addition to the on-going RCUK investments.

Willetts had previously argued that there was a particular role for government in making strategic decisions regarding science funding:

> One reason science in Britain is so excellent is that Ministers do not interfere in the allocation of funds for particular science programmes – the Haldane Principle. This principle covers current expenditure science which is within the ring-fenced £4.6bn annual resource budget. Governments do however have a more direct role in deciding on the allocation of major science capital spending. And there is also a role for government in deciding broad areas of technology to support through the Technology Strategy Board before they have reached full commercialisation.
>
> (Willetts 2013a, p.8)

The document states that approximately a third of the science research budget comes from government, a third is allocated through RCUK and universities allocate the remaining third, after they have received their block grants from HEFCE and its devolved counterparts. Accordingly, government can make an impact in steering capital investment and support for commercialisation without contravening the Haldane Principle (for a discussion of The Haldane Principle and its shaky historical grounds, see Edgerton 2009). During an interview conducted for this research project, Willetts said:

> Politicians tend to get involved more when there is a big new capital decision to be taken. Those are the strategic kind of things are legitimately for ministers. I think that with synthetic biology, increasingly, the need will be for larger scale plants. Kind of places where you can produce on a sort of intermediate scale and show the process can deliver tonnes for that product. So I think there will be more [of those] types of decisions.
>
> (David Willetts interview, 2nd September 2014)

The role of government, then, is to make larger, strategic decisions regarding the allocation of public funds in science and technology. In other words, government can steer the overall direction of the state's research programme by earmarking portions of finite resources. Government has specifically backed infrastructure for fundamental research and translation of synthetic biology. According to David Willetts, the next phase in translation is for academia and industry to negotiate and agree on how to establish a synthetic biology manufacturing industry. This positions responsibility for translating synthetic biology outside

of government. I return to how responsibility for translation comes to academics, and explore it in more detail, in Section 4.3, Section 5.1 and Section 5.3.

During his conference address, the minister gave a narrative for the way he had become involved in synthetic biology and some of the organisational developments that had occurred.

> It began with a roundtable I chaired back in October 2011 considering the possible role for government in providing more support for synthetic biology. That resulted in the formation of a working group chaired by Lionel Clarke of Shell that produced a Roadmap for synthetic biology in the UK and I pay tribute to Lionel's work and this roadmap has been an invaluable guide to public policy since it was produced. We've now created a leadership council on synthetic biology co-chaired by Lionel Clarke and myself which brings together both representatives of the academic community and from the business community as well.
>
> (David Willetts speech, 11th July 2013)

This brief account of the developments gives a sense of growth to synthetic biology. The discussions started 'around a table' and produced a document for technological development, which has informed research funding. The *Roadmap* (Technology Strategy Board 2012b) included five recommendations for state policy:

Figure 9. Recommendations from *A Roadmap for Synthetic Biology in the UK*

(Technology Strategy Board 2012b, p.5)

These recommendations, as discussed throughout this thesis, serve as an important guide to the dimensions of the emergence of UK synthetic biology.

The synthetic biology leadership council (SBLC), identified in the fifth recommendation, had its inaugural meeting in November 2012. The SBLC, as explained in Willetts' quotation above, was originally co-chaired by the minister and Lionel Clark, an industry representative. The SBLC included various invited members of academia, industry, RCUK and other institutional stakeholders. The SBLC was set up as a steering group for synthetic biology in the UK and, with the co-chairing arrangement and non-elected council members, also enacted a relationship between academic synthetic biology, UK industry and the UK government. The formation of the SBLC institutionalised ministerial and industrial involvement in the steering of UK synthetic biology.

As well as acknowledging the roadmap and SBLC, Willett's SB 6.0 speech included a series of funding announcements relevant to the other four recommendations and signalled the "start of a new wave of investment supported by the British government in translation of and research in synthetic biology" (Willetts, 2013). In the order of the speech these were to:

- Contribute to the world effort in synthetic biology by creating an innovation knowledge centre (IKC) to bring together academics and people focused on applications of synthetic biology with the aim to accelerate the translation of research to application. This was to be based at Imperial, led by Professor Kitney, with a five-year grant of £10 million
- £1 million to collaborate with USA, China and India on a project aimed at producing a fully synthetic yeast genome. The UK component was to be led by Dr Tom Ellis and Professor Paul Freemont
- £20m for synthetic biology research centres (SBRCs) to generate research relevant to one or more industrial sectors
- £10m synthetic biology seed fund for companies and pre-companies "to help bridge what's called the Valley of Death between pure research and commercialisation"
- £18 million for DNA synthesis technologies
- £2 million to train young academics
- This was in addition to £65 million already committed by BBSRC and EPSRC

These commitments perform how the promises of synthetic biology are to be realised in institutional ways. The synthetic biology IKC, called the Synthetic Biology Innovation and Commercialisation Industrial Translation Engine, was funded in 2013. This long title has been abbreviated to SynbiCITE (pronounced "Syn-bee-city"). The establishment of six SBRCs, SynbiCITE and the seed fund divide the labour of innovation into different institutions. The SBRCs are to generate industrially relevant knowledge. SynbiCITE is to

identify opportunities from synthetic biology research and match them to industrial partners or back the formation of new companies with support from the seed fund. The international projects are a 'signal' of the UK's commitment and leadership, underlined by the announcement being made at the international conference. Many of these developments are discussed in more detail in Section 5.3.

For the purposes of this argument, the alignment of the expectations of synthetic biology with UK state needs legitimised government investment and facilitated actors' access to increased commitments. Public and ministerial announcements are a mixed blessing: they simultaneously raise the stakes for innovators while making it more difficult for funders to renege on their commitments (Deuten & Rip 2000, p.80). Furthermore, Schyfter and Calvert (2015) have begun to explore the way the expectations of synthetic biology have been realised in different institutional formations in the UK and USA. They argue that some of the organisational developments ignore the infrastructural requirements needed to realise the promise of an engineering discipline. In other words, there is a tension between realising economic gains and realising engineering benefits. Whether or not this turns out to be critical tension, synthetic biology is an academic field where governmental and industrial affiliations are presently realised in institutional formats.

A global synthetic biology leader

In 2010, the UK was presented as a world-leader in synthetic biology basic research. Professor Richard Kitney is quoted as saying, "as far as the academic research side of synthetic biology is concerned we are number two in the world at the moment, the US being the leader" (House of Commons Science and Technology Committee 2010, p.13). The roadmap recommended the UK "assume a leading international role" (Technology Strategy

Board 2012b, p.32). The earlier quotations from policy documents present a history of world-class bioscience and innovation from the UK. This is nuanced as actors make international comparisons and shape the global leadership that the UK could achieve.

Although the UK is second to the US in terms of research output, the UK is a leader in terms of funding in Europe.

> So the UK has really taken a leadership role in that aspect and we've also funded an awful lot of synthetic biology so when you look at the portfolio of funded grants, for example, between the UK and the the rest of Europe, the UK makes up maybe about a third of the funded portfolio. So we're quite considerably ahead of the next highest funder of synthetic biology in Europe, which I think is Switzerland.
>
> (Research administrator 4 interview, 16th July 2014)

Establishing UK synthetic biology means the state can be enacted as a leader of some form. Although the US is a leader of research output, there is a sense that the UK was leading the US in some of the practices that were being undertaken. The *Roadmap*, in particular, seems to be a part of a strategy that the UK is pioneering, which participants felt is recognised by actors in Europe and the US.

> It's quite nice now that you know people all over Europe and other countries are saying well wow look at the look at what the UK are doing in synthetic biology, isn't it great? We need to do that. We need a roadmap. So one of the recent talks I was at, there was someone from the NSF in America [who] was giving a presentation and her finishing slide actually was: So now we're quite agreed in America that what we need is an American roadmap. And they had a picture of our roadmap with the UK crossed out and USA written on it. And bearing in mind that that's the country where synthetic biology really started. It's quite cool, actually, that everybody's looking to the UK and they think that politically and organisationally and funding wise we've kind of got all that done.
>
> (Research administrator 10 interview, 18th August 2014)

Here, the administrator acknowledges a playful rivalry between the UK and US. This is coupled with the sense that the UK 'does better than it should' in biological research output, given its size:

> I think the UK punches, probably punches above its weight in terms of the number of academics here. Probably perhaps. Biology. So it's somewhere where we can take the lead… And the US, the US are definitely um, not jealous but they look to us, I think.
>
> (Research administrator 6 interview, 19th August 2014)

Thus, the UK is a successful place for synthetic biology. The notion that the UK has successfully organised synthetic biology plays out in the *Roadmap,* which envisions the kind of leading role the UK might take:

> Whereas the UK is considered to lead synthetic biology in Europe, our total research funding is significantly lower than in the US. On the other hand, overall research effort across Europe including the UK is comparable to the US, placing the UK in a prime position to continue its leading international role, for example in helping to establish international standards, both technical and regulatory.
>
> (Technology Strategy Board 2012b, p.32)

In interview, David Willetts presented the UK as a leader in standards and regulations because there are difficulties in innovation funding and in how much scientists value their work.

> I think we can innovate in other ways. I mean, I accept that shifting to mass production is something that we find tricky in the UK. Because science overestimates it's significance and there isn't public funding. But there are other forms of innovation that we may be better at. For example innovation in standards and regulation.
>
> (David Willetts interview, 2nd September 2014)

The differences alluded to here, between academia and industry, are covered in more detail in Section 5.2. However, this perceived position as a leader of European research policy has been enacted by the UK's principle role in developing the *Strategic Vision* for the European Research Area in synthetic biology (ERASynBio 2014). This document bears striking resemblance to the *Roadmap* in terms of the themes and development opportunities. The point here is that, the perceived successes in policy may generate work in other policy areas.

While the *Roadmap* appears to be particularly important it is not the only work that contributes to the UK as a policy leader.

> The UK is really leading the world in some of the policy aspects. So, the UK did the synthetic biology dialogue. We published a report on the social and ethical implications, erm, we published the UK synthetic biology roadmap. So we've been involved in a whole range of different policy activities and yeah, even the US is now getting to the point where its starting to want to do some of those activities.
>
> (Research administrator 4 interview, 16th July 2014)

Both the report, the *Synthetic Biology: Social and Ethical Challenges* (Balmer & Martin 2008) and the reported findings from public workshops of the *Synthetic Biology Dialogue* (TNS-BMRB 2010) contribute to the performance of the UK state as a global policy leader. Broadly, while the US is understood to have the highest national investment in synthetic biology in this narrative, the UK is thought to be in a position that it could lead the international policy developments and shape the biological and innovation standards concerning synthetic biology. Thus, it connects some kinds of policy work in synthetic biology with the status of the UK State.

This section has explored how the promises of synthetic biology – that it could form the basis of an industrial revolution and support the UK economy and society – have been

turned into funding commitments to support certain kinds of institutional developments. The alignment of synthetic biology and the UK state has involved the creation of various organisational structures including the SBLC, the SBRCs and SynbiCITE. These relationships bring with them pressures and uncertainties. They also perform the UK, not as a global research leader necessarily, but as a leader of standardisation and policies. I have shown how the alignments and connections between state and science are contributing to the shape of synthetic biology in the UK. The next section begins to explore the importance of, and labour that goes into, maintaining synthetic biology as a new field capable of novel contributions.

4.2 Demarcating Synthetic Biology

The above discussion appears to treat synthetic biology as a single object. However, as I explore in this section, synthetic biology is generally understood as a range of approaches and techniques rather than as a single thing. The appearance of an identifiable object, synthetic biology, is achieved in local specific contexts. Furthermore, how synthetic biology is demarcated conceptually and in practice has implications for the way resources are allocated and for what might count as translated research. That is, what counts as successfully commercialised or industrialised synthetic biology. This section examines *demarcation* as a sister process to *articulating alignment*. *Alignment*, so far, has been concerned with connecting entities and tinkering by reorganising institutions. *Demarcation*, in this section, is mostly concerned with dissociating and distancing.

Defining synthetic biology

There is not a single and unanimously agreed-upon definition of synthetic biology. The definitions of synthetic biology are multiple and contested (see Section 1.2). Actors do identify synthetic biology practices, as multiple as they can be, and these form local boundaries around what synthetic biology is, and what it is for. For many actors, the moves towards commercialisation and markets bring to the fore particular kinds of statements about what synthetic biology *is*. Statements about what constitutes 'proper' synthetic biology.

Actors including researchers and administrators talk about synthetic biology as a diverse field composed of various subtopics and research interests. Synthetic biology was referred to as a "broad church" (academic researcher 4, 4th December 2013) and was described as "many things to many people" by one primary investigator (academic researcher 15, 28th August 2014). Smirking, one participant said, "I expect you'll spend the first few chapters of your thesis trying to define synthetic biology… which there's a lot of debate about at the moment" (industry rep 1, 1st September 2014). In other words, it is not contentious to say that synthetic biology is not singular since the actors are well aware of how contested the definitions are; there is already awareness of non-unity and diversity in synthetic biology. These points also form a starting place for the argument in Section 7.2.

There are a number of schematic representations of synthetic biology that circulate in academic and policy discourse. The *Roadmap*, for example, includes a diagram showing how synthetic biology is translational. Academic disciplines contribute to understanding; synthetic biology then converts the knowledge into industrial and market applications (see Figure 10 on the next page).

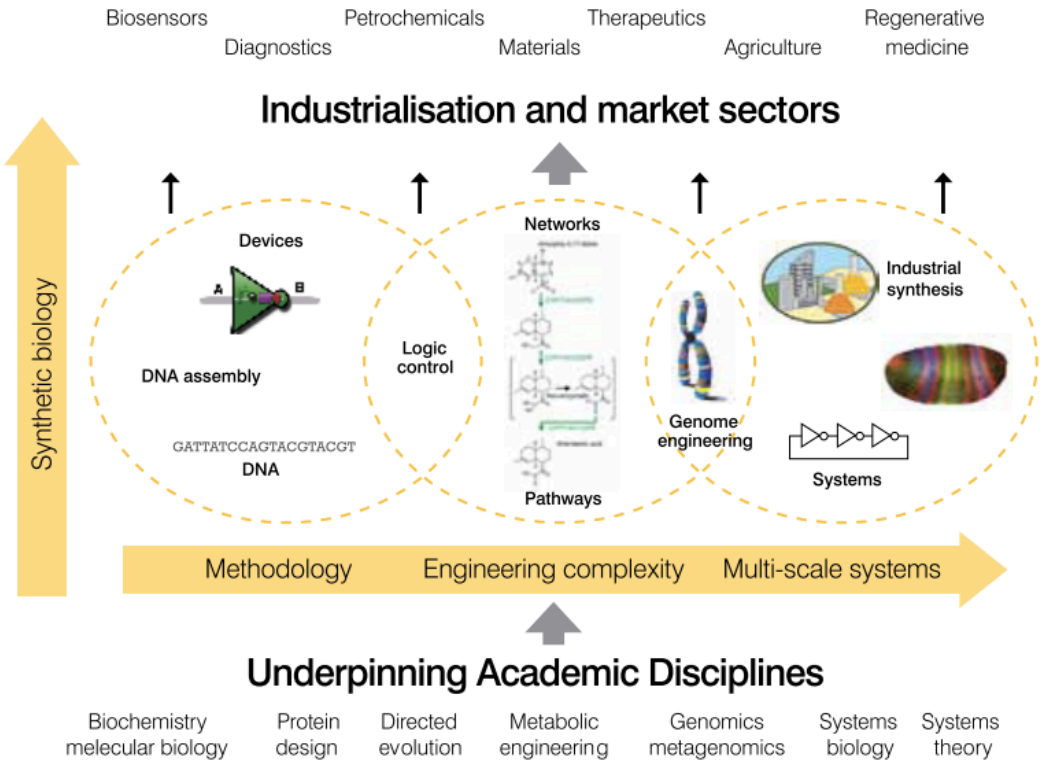

Figure 10. Synthetic biology as a translational field of science

(Technology Strategy Board 2012b, p.13)

The diagram is a representation of the diversity of synthetic biology. Here, synthetic biology is positioned above of academic disciplines and below market sectors. Various mathematical and biological sciences and different scales of investigation are orientated to different market sectors. It draws a boundary around synthetic biology by showing which disciplines are legitimately involved and the kinds of process that convert knowledge to application.

Administrative practices are also an important set of activities that produce versions of synthetic biology. For instance, in funding decision-making, defining synthetic biology can take a different form than a diagrammatic representation. I briefly describe how these funding processes contribute to forming synthetic biology.

One way researchers can get money is by applying to RCUK for grants. RCUK has two main streams of funding. Responsive mode is the standard route for gaining funding while a parallel mode, special opportunities, can include 'hot' areas of science, strategic longer larger awards (SLoLa) for experienced academics, career development grants, business opportunities and so on. A researcher, or group, fills out a proposal form online and submits through the Joint Electronic Submission system (Je-S). Application forms include mundane criteria such as selecting a research council to which to apply, the type of scheme and completing the form correctly. These are submitted by a deadline and are sent for review by an expert panel of peers – 'excellent science' is the main criterion for RCUK. The proposals are ranked by the panel and monies distributed accordingly.

At the time of the interviews, synthetic biology was a funding priority for RCUK and so there was a specific allocation for proposals. This means a particular area of science has a specific funding code. The administrator quoted below decides that because synthetic biology has its own funding code, RCUK understands it as a discipline.

> I think I do see it as a as its own scientific discipline but there's definitely something that… So when [RCUK] code grants there's definitely an approach that we look for. So does it have an engineering spirit? Is it using mathe-model, math, you know, modelling to ensue, to inform the biology that they're going to influence? All of the, is it modular?
> ... in terms of [RCUK] I don't think we really don't define it… But I mean we code it. So when we get all of our responsive mode grants in we then go through and and we code the grants according to what scientific areas they fall in. And synthetic biology is one of those so we obviously see it as a discipline in its own right.
>
> (Research administrator 10 interview, 18th August 2014)

The blurry line between discipline and approach is captured by the quote. Synthetic biology in funding administration, is text and diagrams on a form, written by an academic, that can be identified on an application by administrators, and coded so it goes to the correct panel

for review and funding is allocated from the correct stream. This is a set of practices from which laboratory work is absent. Instead, it is a bureaucratic object that can be used to contain applications and is transported between researchers, administrators and review panel.

These practices function to assign some projects to synthetic biology, and not others, and therefore contribute to synthetic-biology-as-a-thing. The object of synthetic biology is done differently by different groups (Mol 2002). This means the synthetic biology is shaped by the way funding bodies process grant proposals as well as the way researchers align their work. Furthermore, the way industry define synthetic biology has implications for what counts as translated synthetic biology and for the way synthetic biology is treated outside of the academe.

The stakes

In the summer of 2014 the international company Ecover, a 'green' producer of soaps and detergents, announced they were replacing palm oil in their products with an oil produced by algae. It quickly emerged that the algal oil was produced by a San Francisco biotech company called Solazyme. This led to a "furore" including reports in national newspapers like *The Guardian* (UK) and *The New York Times* (USA) (Ginserg 2015).

One participant suggested what the implications could be of defining synthetic biology in different ways.

> I think the problem as I just alluded in synthetic biology is two, really. One, is there's a bit of stress at the moment between academics particularly in the UK who want to be very very broad in the definition of synthetic biology so they slip under the funding wire. On the

> other hand, industry who are being attacked by activists who want largely want to rerun the GM debates, which again I participated in when I was in industry. They want [the definition] to be incredibly tight so they don't fall under the wire. So there's this kind of odd dichotomy of people being very specific. As [in]: oh, of course my my molecular biology is a synthetic biology. I made these oligos, didn't I? And, yeah, and you get kind of companies who have effectively built an organism from scratch who say, oh no no no no no no no no no. And I didn't use engineering principles. We just damn well did it. And so, you know, there's a there's a difference there.
>
> (Research administrator 12 interview, 19th August 2014)

This quotation is about how synthetic biology is interpreted and used. Academics want to be able to apply for grants and so the broadest definition works for them because it is the most inclusive. Meanwhile, industry want a restricted definition so they can control whether they align themselves with synthetic biology or not. This point was made in *The Guardian* by the ETC group arguing that Ecover exploited the confusion of what constitutes synthetic biology to claim they were not using novel biotechnology (Thomas 2014). This highlights how difficult it might be to anticipate what will happen as synthetic biology moves from academic science to industry. What counts as synthetic biology may change as it is translated from one domain to another one.

These sections have described some examples of the material practices involved in 'bounding' synthetic biology (Meyer 2006). In the next section, which explores *boundary-work* as a rhetorical practice of demarcation (Gieryn 1983), proponents attempt to separate synthetic biology as a novel contribution to science.

Beyond craft science

For many involved in bioscience, the difference between synthetic biology and other contemporary biologies, comes down to purpose. For them, synthetic biology is about using microbiology techniques to create a system, device or biological part that would solve an identified problem. One PhD student referred to this as doing "closed" as opposed to "open" science (field notes 13th January 2014). Another PhD student contrasted their "discovery-based project" generating knowledge about algal communities with, perhaps only half-joking, the "saving the world" synthetic biology project of their colleague (field notes 13th January 2014). These statements enact a boundary between applied synthetic biology and basic science, though "basic" research is produced in various contexts with an array of meanings (Calvert 2006).

One of the ways that synthetic biology is distinguished from other bioscience is by articulating microbiology as a 'craft' science that is inconsistent from context to context. For some actors biology is not reproducible because "it can be demonstrated on occasion in the lab… 85% of all biological research reported is not repeatable" (John Collins, SynbiCITE, interview 3rd July 2014). They also argue that as biological properties change at increasing size, there are problems with scalability. These two points, reproducibility and scalability, can be seen as heuristics that are imagined to guide the application of an engineering approach. This means standardisation is an integral activity that would solve some of the problems actors identify with other bioscience.

Metrology and standards are central to the project of synthetic biology and apparently crucial to the coordinated industrial commercialisation of biological knowledge. From this point of view, synthetic biology solves issues based on manufacturing since biological functions

need to be repeatable. The lack of reproducible results also has an impact on the acquisition of funds for 'translational' projects:

> The trouble is, you look at the returns of VC industry in this sector and it's extremely poor. I mean, who would put the money in? It's extremely high risk. The attrition is very high. Oh, did I say that you know that ten per cent of biological research is reproducible? No wonder it's high.
>
> (Industry rep interview, 1st September 2014)

> (Transcript note: earlier in the interview they say, "it's estimated that only 10% of that work is reproducible" and this quote has been edited to fit with their own and other circulating numbers.)

The industrial representative argues that investment is problematic because the reproducibility of biological results is poor. Knowledge, on this view, cannot be increased if the results of experimentation cannot be repeated and so investors are unlikely to come forward because of the risk. The role for synthetic biology, and for the participant's company, is to increase the reproducibility of biological research.

The commercial director of SynbiCITE made the point that turning biology into a reproducible science was a way to enable translation to industry and create wealth:

> Effectively [to] use different tools or different toolkits with the same design to produce the same output, and you can verify, that you corroborate, you can model it. You can simulate it and you can reproduce it. But it sounds easy. But actually that's what translation is. Reproducibility. Sustainable reproducibility. And ultimately profitable reproducibility.
>
> (John Collins interview, 3rd July 2014)

These comments present synthetic biology as the solution to commercialising biology in different ways. They draw on the epistemological goals of synthetic biology and argue that

they facilitate gains, not just in knowledge production, but also in creating industrial applications from biology. This is in addition to the way that synthetic biology 'fits' with ownership regimes that appeal to industry (Calvert 2012). *Demarcation* draws on problems actors identify in biology and argue that synthetic biology will be able to convert knowledge to products by changing the reproducibility of biological experiments, which will facilitate manufacturing and increase confidence for investment.

Cynical alignment

An overall project for some synthetic biologists is to work towards the standardisation of biological parts. Standards are a key point of differentiation in the argument for a distinct synthetic biology. Standards are therefore a key resource for articulation and demarcation. It is through standardisation that reproducibility is to be achieved. This section explores how proponents of synthetic biology argue that some researchers are 're-labelling' their existing work. Then, in the following section, I show how researchers, particularly molecular biologists, suggest that synthetic biology is merely a 're-badging' of their established research programmes. *Cynical alignment* can work in both directions.

Standardisation is both a key defining feature of synthetic biology and essential to fulfilling its promise. One research administrator said:

> There are certain things you can standardise easily like data and the way you work with the data. More difficult is actually when you talk about standardising life, so making a real toolkit of biological parts. And that is incredibly difficult but it's really essential if yeah, if synthetic biology [is to] fulfil its potential then there's a whole load of activities that really need to be standardised. And that is a giant technological problem. Which no one has really worked [out] a solution to yet. And that'll require, not only investment in

> infrastructure, but also just for the scientific community to sit down and say, you know, what are, what's gonna be our standards and how we're gonna work in the future.
>
> (Research administrator 4 interview, 16th July 2014)

This quotation illustrates the notion that standardisation is not a purely technical problem. It involves social changes, too. This is despite standardising and modularising life being problematic in that advancing engineering often requires bespoke rather than standard parts (Calvert 2013). Consensus about the kinds of biological tools that will be in the kit also means people agreeing to standardise the ways synthetic biology work can be done. This is the central goal of the Flowers Consortium, a group of five UK universities attempting to create an infrastructure in the form of standards for synthetic biology (The Flowers Consortium 2015).

The fundamental work in synthetic biology can be understood as the construction of standards, modules and registries. For instance, the iGEM competition has a track for "fundamental advance" (field notes, iGEM, 1st November 2014). This still leaves applications that need to be developed and translated; there is a balance between developing standards and generating new products:

> The scientists at [X] were kind of really annoyed because [another institution] were not doing proper synthetic biology… they were going for the low hanging fruits of application. Commercial application. So, for example, [another] centre was considered to be one where they were just doing industrial biotechnology or biofuels or whatever just because that would be a quick win. That when people who are trying to do proper synthetic biology, trying to develop standardised parts which can be used in many different contexts, were penalised because of their lack of kind of speed of application.
>
> (Social researcher 1 interview, 1st July 2014)

Here, a boundary is established between "proper synthetic biology" and scientists doing "quick win" work which does not contribute to the community ethos of standardisation. For

some researchers, there is a distinction within synthetic biology: the 'fundamental' work being the creation of standards and parts, orthogonal DNA and so on, while the 'applied side' is about developing the specific product or service. Yet, some funds go to groups who are not in the core group of scientists, and sometimes these researchers are seen as not contributing to the overall programme of synthetic biology. This means those researchers working on 'fundamental' projects can feel as though they are punished because the creation of infrastructure is time-consuming. Thus, by promising speedy applications, other researchers were thought to be able to access resources and reduce core funding.

The demarcation of synthetic biology is far from straightforward. Actors who were particularly invested in the success of synthetic biology raised the issue of 'rebadging'. For them, people who were realigning their work without making significant contributions were risking the whole project:

> If you then open the door and welcome in things that were existingly done, that were not taking into account any of those standards and not putting any efforts into modularisation, and building the foundations, then it kinda dilutes the whole thing. It's like, I dunno, having a Lego set and then allowing your friend to come along with Meccano and… It'll end up a mess, right?
>
> (Academic researcher 10 Interview, 1st September 2014)

This suggests that synthetic biology needs borders to preserve the founding principles. This is in direct tension with research administrator 12's thought that academics want a 'loose' definition (see subsection *The stakes*). According to academic researcher 10, if anybody can get funding for synthetic biology work then there is a possibility that this will result, not in a standardised approach to biological engineering, but in an ad hoc discipline. In this view synthetic biology, as a codified and systematised science, is vulnerable if funded research is not committed to contributing to the specified engineering approach. This version of the rebadging argument puts synthetic biology itself, all its potential, on the line.

However, any separations between basic and applied bioscience can be problematic. In their introduction to their overview of STS, Bauchspies et al. say:

> We can already see in fields like biotechnology that the distinctions between pure and applied science and between science and technology are no longer viable
>
> (Bauchspies et al. 2006, p.9).

For the case of synthetic biology, it is not so much that these distinctions are not viable so much as they are remade and enacted at specific points. They are also dependent on the perspective of the observer – fundamental synthetic biology to one person might be another's applied molecular biology.

Resisting a Revolution

While synthetic biology attempts to distinguish itself from other biological sciences (it does not appear to need to be distinguished from, say, engineering or mathematics), there is a trend among 'classical' microbiologists to view synthetic biology as offering nothing new. This could occur in different ways and these are explored below.

RCUK and UK government funding policy identified industrial biotechnology as an area of investment. Thirteen networks in industrial biotechnology and bioenergy (NIBBs) were funded in 2014. I 'followed' synthetic biology researchers to a launch event for one of the NIBBs. The event was a two-day meeting which involved various sessions and presentations aimed at fostering collaboration. (A more detailed description can be found in Section 5.1.) On the first morning I was one of the first people to enter the conference room. There were large round tables, around ten chairs each, and a projector screen at the far

end. A couple of event organisers handed out name badges. I sat down and introduced myself to neighbours as the room filled up. A senior academic scientist joined me. When I explained I was interested in synthetic biology, she leant over to me and, in a hushed yet forceful tone, explained synthetic biology was 'just molecular biology' (field notes 9th September 2014). Despite synthetic biologists being at the meeting, synthetic biology was not a high profile feature of the event. The main references were during a plenary where a "synthetic biology type approach" was written on a whiteboard as part of a cluster of ideas aimed at solving particular problems. This had the effect of reducing the status of synthetic biology, graphically making it one of a number of allied approaches in industrial biotechnology, despite the claims that synthetic biology could create an industrial revolution.

Similarly, another senior researcher found synthetic biology to be something which had a long history under other names. They concluded that the name is irrelevant and that the outcome is key.

> I argue again that actually that sort of things been done under different badges for many many years. So as you can see I'm slightly more regressive in terms of synthetic biology and you know, at the end of the day, the important thing is the outcome, whether there is an improvement in our understanding of processes… or whether you end up with a strain that has improved industrial performance, ok? So the net result is the same.
>
> (Academic researcher 18 interview, 28th July 2014)

Here, the process, whether synthetic biology or otherwise, is less important than the outcome. However, as alluded to previously, even though formal definitions and representations of synthetic biology circulate participants often commented on the difficulties of defining synthetic biology.

One of the issues, then, concerns novelty. One administrator working in innovation said:

> I think for me, for my definition of synthetic biology is, is new biology. You know, is it a biological system [that's] fundamentally new? Not rearranged in a way that would achieve in a, it's something fundamentally new.
>
> (Research administrator 12 interview, 9th August 2014)

This type of novelty, voiced primarily by those with microbiology training in interviews and meetings leads to the conclusion that synthetic biology is not new. Synthetic biology uses the same techniques as 'classical microbiology' and some of its products are so similar that the two are indistinguishable when using the definition "making new forms of life". Academic researcher 15 described how they had been working on protein synthesis for years and now their research seemed to align with some of the "synthetic biology from the USA" (Academic researcher 15 interview, 28th August 2014). Thus, different participants granted synthetic biology more or less novelty.

A second way the novelty was challenged was related to the idea that synthetic biology is an extension of other techniques. Academic researcher 4 described their synthetic biology project as using "classical microbiology" techniques (interview 4th December 2013). However, they found it very difficult to explain how the synthetic biology project they were involved in could be distinguished from previous work they had done in microbiology. In other words, synthetic biology, for some researchers with micro and molecular biology training, is simply a rebranding of biological techniques that were already well developed. These resistances connect synthetic biology to this history of microbiology. Microbiology has long employed the techniques that the actors feel are appropriated by synthetic biology. This could be seen as a form of boundary work based on intra-scientific *inclusion* rather than expansion, expulsion or protection of autonomy (see Section 2.1). This is because it negates the idea that synthetic biology is new and may work to retain access to some of the resources that actors feel are being diverted to synthetic biology.

Synthetic biology is constructed as the solution to the UK bioeconomy, given that it aims to improve the reproducibility of biological research. To highlight 'trial and error' methods of biological research as being irreproducible happens to be the inverse of the way that, in 19th century England, John Tyndall separated science from mechanics:

> Scientists acquire knowledge through systematic experimentation with nature; because mechanicians and engineers rely on mere observation, trial-and-error, and common sense, they cannot explain their practical successes or failures.
>
> (Gieryn 1983, p.786)

The argument made here about mechanicians, particularly the ad hoc and iterative nature of engineering, are almost exactly how actors in synthetic biology criticise other biological science. On the other hand, engineers are not interested in explanation and are 'happy if it works' (field notes, iGEM meet up, 18th July 2014). The contributions of synthetic biology, and problems of biology, are deployed in ways to discredit claims to novelty or to justify support for different areas of science. Since "novelty is a requirement for marketability in science" (Fujimura 1987, p.282), this affects how actors can make their research relevant and secure access to resources.

This section has explored the ways in which the boundaries of synthetic biology are performed with respect to other biology, and that even the notion of basic and applied knowledge exists within the 'translational' field of synthetic biology. Establishing synthetic biology's boundaries is a messy process with actors deploying engineering principles as distinguishing features. On the other hand, some actors dismiss synthetic biology because it relies on well-established biological techniques. The credibility of synthetic biology, and proponents' access to resources, are at stake. The next section charts another strategy for enhancing credibility – creating a plausible future.

4.3 Imagining an Industry

This section explores the ways that a future synthetic biology industry is being shaped in the present.

Supporting Industry Creation

One institutional enactment of the roadmap's recommendation "to invest to accelerate technology to market" has been the establishment of SynbiCITE, the synthetic biology IKC. There are currently seven IKCs in different technological areas. These are centres of expertise and:

> Are a key component of the UK's approach to the commercialisation of emerging technologies through creating early stage critical mass in an area of disruptive technology.
>
> (EPSRC 2015)

The case for an IKC is usually created following consultations with stakeholders. The act of establishing an IKC in synthetic biology aligns synthetic biology with other emerging technologies.

The purpose of SynbiCITE is to support the establishment of commercial technology. One research council administrator said:

> And my view on why we have an IKC rather than just say the TSB [technology strategy board/Innovate UK] doing a call is that the businesses based on the technology are not established enough to collaborate in that way… they need other types of support as well and there isn't an established industry and they may be facing particular challenges in obtaining funding. So, you know what catapult centres are, I presume, but they're much

> more industry led. [In the case of] the IKCs I don't think the industry has developed to a point where they can lead… the TSB and BBSRC are looking for a new industry coming of this not, not an incremental innovation, although that may happen. I think… we'd be underwhelmed if, you know, we improved process efficiency by 5% in an existing industry…
>
> (Research administrator 1 interview, 19th August 2014)

SynbiCITE has been funded because there is not yet a UK industry. In its absence there needs to be some kind of work that creates the shape of an industry. The expectation of some funders is that a synthetic biology industry would offer something more profound than 'an efficiency increase' to current production lines.

The government's support for synthetic biology has had an impact on the way decisions about the allocation of funding are made, and the identification of organisational needs. There are currently seven IKCs in the UK. All of them, except for IKC for synthetic biology, have been created following consultation with industry and academic experts.

> I think the one thing that I'd just mention and it may make may not be relevant to you at all… but is on my mind… is that for synthetic biology IKC is the first IKC that we've awarded in a top down way. So, but it was, we want an IKC in synthetic biology and it's in the roadmap… but previous IKCs have all been as a result of an open call where people came in and said, you know, you could have an IKC in this area or this area or this area so we've been choosing between different areas… So, you know, when I talked about panel meeting we were looking at three IKCs in synthetic biology. Previous panel meetings have um… been reviewing the case for the IKC as well as the ability to deliver it. If you like.
>
> (Research administrator 1 Interview, 19th August 2014)

The case for SynbiCITE was not in competition with IKCs in other areas. For synthetic biology, there was going to be an IKC. The question was, "to whom would it be awarded?" rather than "does the UK *need* an IKC in this area?" Uniquely, SynbiCITE was awarded in a

'top down' way (research administrator 1 interview, 19th August 2014). The initiation of SynbiCITE is part of the process of creating a UK synthetic biology industry in the absence of companies with the ability to develop products and services into a market. In imagining an industry, actors refer to other entities to shape a future for synthetic biology. The next three sections consider the character of the future industry of synthetic biology.

Science for the Public

The public is frequently mobilised in discussions about the future of synthetic biology. One research administrator presented the public as the ones who would need to be satisfied by innovation:

> I think another big potential challenge for synthetic biology is around delivery. So, we spent a hundred and eighty million pounds on synthetic biology in the UK. When are we gonna see the, you know, when is the public gonna see a return of that on that investment?
>
> (Research administrator 4 Interview, 16th July 2014)

'The public' is high on the agenda for funders and researchers alike. In interview, the commercial director of SynbiCITE said, "I think there's gonna be a major hurdle with the public acceptance of this because too many have for too long tied it to GMO" (John Collins interview, 3rd July 2014). A related concern is that even the language used to describe the microbes – as 'bugs' – might put off the public and exacerbate ill feeling towards synthetic biology (field notes, 7th May 2014).

Another participant put this in stronger terms (he was irreverent throughout our interactions – his choice of words seemed deliberately crude and comic):

> I think one of the aims… of the synthetic biology community was to set things up so that they didn't run into the same problems as genetic engineering did. So the lobby, the antigenetic engineering lobby in Europe is, to a greater or lesser extent, idiotic and caused by failure of the public to understand and lack of desire of the public to understand what's really going on… I think people [supporting synthetic biology] are very keen not to repeat that mistake.
>
> (Academic researcher 14 Interview, 19th August 2014)

Proponents of synthetic biology are consciously attempting to avoid their version of what happened with GM crops, in particular, a public rejection. The areas of genetically modified (GM) crops and organisms are known to be a significant feature in debates about the future of synthetic biology (Marris 2014). I argue that distinguishing synthetic biology from the history of GM decreases the possibility of releasing synthetic organisms outside of laboratories, perhaps related to concerns about cross-pollination between GM and non-GM crops.

The interaction of science and the public can be imagined as some form of trial. A point when synthetic biology comes to the attention of the public.

> [Synthetic biology] hasn't yet gone through its kind of *Daily Mail* moment where it achieves sufficient prominence that people start being worried about it. I think that will be the test and I hope, and part of what I was trying to do as a layman, was understand it, and prepare people for that moment. You know, Craig Venter will at some point say something so outrageous or claim to have done something so extraordinary that will be a reaction against it and that's when synthetic biology will be most vulnerable… it hasn't yet gone through that moment of challenge.
>
> (David Willetts interview, 2nd September 2014)

The minister uses '*The Daily Mail* moment' as a synecdoche for a time in which the media reports negatively on a topic, which may contribute to a public rejection. There are risks to realising the benefits of synthetic biology.

The conception of a single problematic public does get challenged. At the seventh SBLC meeting one proponent of synthetic biology said that it was important to educate the public so they respond to facts, rather than their own emotions (field notes, SBLC 27th November 2014). This view was questioned during the following discussion and Professor Joyce Tait, director of the Innogen Centre, argued that the GM controversy was a complex phenomenon. She said that the debate and its outcome depended, not on a single public, but on a coalition of NGOs with diverse interests including groups with consumer, conservation and development interests complemented by sensationalist media reportage. The reason GM crops 'failed' was not because of a single public, but because of multiple concerns about food additives, genetic modifications finding their way into the environment and the global practices of large agri-tech businesses. As synthetic biology has attracted various types of scholars, there are signs of complexifying the institutional understanding of the public.

Despite these conversations, however, GM is still an important entity which actors use to argue that synthetic biology is technologically more advanced.

> What synthetic biology is, it's an extension of all the other technological (inaudible 4.04), but the tools are just now more precise… some people, who are let's say not advocates of synthetic biology, have been calling it extreme genetic engineering… well actually it's extremely precise genetic engineering.
>
> (Industry rep interview, 1st September 2014)

Precision here implies control and safety: the capability to produce a specific effect. The participant suggests that synthetic biology is not dangerous or irresponsible because it is a defined and moderate technology.

The dominant discourse configures the public as a single unit, and one that is a threat to realising synthetic biology's potential (Welsh & Wynne 2013; Marris 2014). The idea of public acceptance of synthetic biology often includes references to a forerunner technology – genetic modification. Proponents tend to understand the possible connection to GM as problematic. They attempt to separate synthetic biology from GM in order, in their view, to create a more publicly acceptable science by presenting synthetic biology as more controlled and precise than GM.

Regulation and Release

There are other ways that a synthetic biology industry is being shaped with respect to releasable organisms.

> I think we recently alluded to the terms of commercialisation. I think you can make a broad division between things that you release into the environment and things that you don't… the things that you release into the environment… there's a huuugge number of regulatory issues that need to be addressed…
>
> (Academic researcher 14 Interview, 19th August 2014)

This participant suggests that some regulatory structures can push new technologies down different trajectories. In this case, the quotation implies a move away from releasing organisms.

The perceived regulatory issues associated with developing a new technology can, according to some actors, inhibit technological innovation because of knock-on effects in other industries.

> Regulation as well is potentially a killer in that over-regulated environments destroy platform technologies and synthetic biology's a platform technology. And with all platform technologies it's possible to a spread them too thin or encapsulate them within regulation frameworks that prevents you from being able to manufacture. A case in point would be nanotechnology. We've been producing nanoparts for donkey's years… they're in your toothpaste, they're all over, they're in paint, they're you know, we've got big industry [that] has produced them for a long time. Lloyds… will happily insure big industry that's been producing these particles because they're never called nanoparticules before. And then nanoworld was brought out.
>
> (John Collins, commercial director SynbiCITE, interview 3rd July 2014)

The main concern here is that anxiety about a new technology can result in restrictive regulations, and that this can happen even to more established industries that rely on similar technology and that appear to have enjoyed a more relaxed regulatory structure. Following this line of argument, this means it may be difficult to insure a company against future claims and therefore it becomes challenging to develop technologies. The worry for some proponents is that a regulatory structure can inhibit innovation.

Although synthetic biology relies on a range of technologies that are already widely used, such as cell culture and polymerase chain reactions (PCR), new rules could be brought in to regulate synthetic biology. One proposition is to describe a model for how synthetic biology might self-regulate.

> So, the question I ask everybody is… what's novel and new about what you're doing? Oh, yeah, I know that. Well, what potential hazards and risks may encourage? Oh yeah yeah. I do that. And then the question that always gets most people is, what does an early

> warning look like? A-right? Because that presupposes that you've not answered the first two questions sufficiently well. Right. Something's come in and you've missed. What does an early warning look like? The airline industry makes a big deal about early warnings… No whistleblowing, or anything. Everybody anywhere can say, look, you know, look at
>
> that. Because when a plane falls out the sky. Two hundred and fifty people die. And, I think it's that kind of idea that we've got to get into people's minds.
>
> (Industry rep 1 interview, 1st September 2014)

The airline industry is highly regulated but, according to this participant, because it has the right approach to risk it can be made safe by the people working in the industry. There are already efforts to make synthetic biology an industry in which workers feel able to report concerns about risk and misuse. For instance, the iGEM Jamboree included a presentation by the FBI to encourage synthetic biologists to be 'on the look out' for wrongdoing and danger and to report incidents and suspicions (field notes, iGEM Jamboree, 2nd November 2014).

The regulatory structure for synthetic biology is being imagined and created alongside the industrial possibilities. The self-regulation of synthetic biology can be a possible solution to responsibility. It seems to address the questions arising from the UK *Dialogue* (TNS-BMRB 2010) by creating a reflexive workforce. It also implies that externally created regulations, which may prove inhibiting to the development of the technology, can be avoided. Thus, the possibility of releasing synthetic biology organisms in the UK is further reduced.

Contained bio-manufacturing

Synthetic biology has the potential to produce compounds, be they existing drugs, novel medical applications, fuels, oils, rather than crops or other forms of unconfined life. Actors

articulate synthetic biology with other technologies to create a future for synthetic biology. This industry is located within a world running short of a key natural resource for fuels, oils and materials (Freemont & Kitney 2014, p.40). One plan is to use microbes as factories. As John Collins says:

> In our case its producing materials…so materials industries. Steel industry. Just the same… you look back through the history of the production… mass production, which is a slightly different process or the manufacturing at scale process which is like [the] steel industry. Materials are all manufactured at scale… Synthetic biology is no different.
>
> (John Collins, commercial director SynbiCITE, interview 3rd July 2014)

Here, Collins makes a distinction in the way that industrialising synthetic biology is to be approached. Mass manufacturing is the production of units such as cars, machine tools and electrical goods. Manufacturing at scale is the production of homogenous materials such as chemicals and metals. Synthetic biology can fit into a manufacturing at scale paradigm by producing various chemicals at scale.

The industrial revolution brought with it important changes in manufacturing processes. Developments in other synthetic materials have produced new techniques which has enabled the production of other technologies.

> …it was actually for industrial diamond and synthetic industrial diamond… which interestingly has lots of parallels with the production the manufacturing at scale which is different from mass manufacturing um of a material. In this case it was carbonaceous. But it was by a route that was the whole synthetic diamond industry is based on a process shouldn't really be able to work… much as the same as lot of biology actually… Until diamond could be synthesised diamond tools were made from near gem diamond as it was called that was mined out of the ground which has its own ethical issues in its own right. As soon as you could start to synthesis diamond and you could make diamond grit for grinding tools or for compacting into diamond tools you could actually engineer

> materials cost efficiently sufficiently well to have the cars and the planes and the light bulbs that we have nowadays.
>
> (John Collins interview, 3rd July 2014)

John Collins aligns synthetic biology with industrial diamonds and the idea they have facilitated desirable yet mundane aspects of contemporary life. Synthetic biology, he suggests, may do the same for a future way of life. Chapter 6 explores in detail one project designed to use synthetic biology to produce novel biomolecules with the aim of moving to scaled-up production in future.

A containment ethos was evident during the iGEM competition. Based on their interviews with industry, our student team reported on the reduced likelihood of uptake if they manufactured a technology based on a releasable organism. They had to change their early design to produce proteins and use a complex system of fermenters and filters in order to release a protein, rather than have the microbes functioning in the environment. In other words, technological solutions utilising synthetic biology need to secure engineered life behind screens and filters (field notes, iGEM project 2014).

Aligning synthetic biology with commonplace manufacturing industries domesticates it in a way that appears to be aimed at reducing fears imagined to circulate in the public. The notion of "contained biomanufacture" is reminiscent of the USA's sociotechnical imaginary of "containment" towards nuclear technology where "the central move was to create a newly manageable entity, the ''atom for peace,'' which converts nuclear energy from terrifying to benign form" (Jasanoff & Kim 2013 p121). Thus, by aiming for industrial production, actors attempt to produce a beneficial yet uncontentious imaginary industry.

This imaginary iteratively cycles with human action: SynbiCITE has updated its webpage and currently displays examples of existing projects. Synthetic biology has been used to

create compounds for use in medicine, fuels and foods. However, agriculture and environmental applications are still 'potential'. They have not been realised industrially. Thus, applications of releasable organisms have not been translated to production while those based on *contained bio-manufacture* have made Artemisinin (drug), 2,3-butanediol (fuel) and Nootkatone ('natural' flavour) (SynbiCITE 2015b).

Innovating responsibly, according to the *Roadmap*, involves both attending to public concerns, albeit ones drawn from the GMO debate in the 1990s, and generating a regulatory framework. Societal benefit can be achieved because the public is thought to be more receptive to microbes that are not released while at the same time the regulatory structure is thought to be more amenable to contained microbes. By containing microbes actors may avoid public rejection based on fear and some forms of regulation. The 'scorched earth' of releasable GMOs in crops and food is to be avoided by containing any engineered organisms and using them as factories and sites for manufacturing. By imagining an industry based on *contained bio-manufacturing*, both synthetic organisms and the responsibility for regulations and safety are to be kept 'in house'.

4.4 Conclusion

Articulating alignment and *demarcation* are two tandem processes of making synthetic biology a 'doable problem' (Fujimura 1987). Section 4.1 described how the actors associated with life science and synthetic biology articulated a problem-solution that could be addressed with synthetic biology. In other words, they aligned synthetic biology with state economic deficit and suggested it could be ameliorated in part by funding synthetic biology to translate bioscience in order to create a UK industry. Section 4.2 gave details of how actors use 'an engineering approach' to materially and rhetorically demarcate synthetic biology from other

biology to preserve access to resources. However, it is not a case of translating into 'any old industry'. There are specific ways, explored in Section 4.3, of how a synthetic biology industry is being established. Successful translation depends on distancing other biology and creating a recognisable infrastructure.

The UK state is performed as an innovative state, and one that needs to be capitalised upon in the post-2008 financial crash environment. One that has a strong history of life science innovation but a place where this transition is precarious. Synthetic biology is a site where the UK can be realised as a global leader, not in terms of research output, but in terms of leading on policy and standardisation. The UK government, RCUK, industry and academia are organisationally intertwined in the SBLC, IKC. The standardised and modularised approach to life is also coupled with a desire to see a successful translation to industries. This appears to require synthetic biology to be different from GMOs in that the engineered organisms of UK synthetic biology are to be used for manufacturing chemicals and compounds that are already in widespread use. The researchers themselves distance their technology from the 'release' of GMOs. Instead, by aligning synthetic biology with industrial manufacturing and controlled, mundane technologies, the field is presented as safe, capable of self-regulation and beneficial to society in the long-term. In other words, the synthetic biology industry is being directed at manufacturing, particularly niche chemicals, rather than forms of organisms that exist outside controlled environments. The imagined industry aligns synthetic biology with perceived public concerns and state needs.

An analysis of the 'GM controversy' has been applied to suggestions about nanotechnology governance where the authors argue that awareness and openness of the purposes of technologies need to be cultivated:

> The GM experience demonstrates the degree to which contemporary scientific research is informed by tacit visions and imaginaries of the social role of technology. Often explicitly utopic these tacit, technoscientific imaginaries form the basis upon which research priorities are negotiated and planned. Importantly, however, in the GM experience such tacit visions were never openly acknowledged or subject to public discussion and debate.
>
> (Kearnes et al. 2006, p.302)

One aim of this chapter has been to address these tacit visions. In articulating promises, actors make present various absences and specify them to make translating synthetic biology into a 'doable problem' aligned with state needs, features of bioscience and perceptions of publics. In the next chapter, I shift to focus on the relationship between academics and industry and the importance of successful collaborations.

Chapter Five

Universities and Industry

Translation, commercialisation and industrialisation of research imply interactions between universities and industry. This chapter focuses on these entities, particularly on the performances of relations between them. I begin section 5.1 by showing how funders and universities identify collaborations as a key route to accessing resources and realising the impact of research. This, in part, justifies the additional resources that these actors deploy in an attempt to foster collaborations. A part of this involves circulating 'collaborative success stories'. However, a central concern of the STS scholarship on 'translation' is that research cultures are different. In section 5.2, I explore how the differences between academia and industry were enacted during my fieldwork and narrated during interviews. Then, in section 5.3, I argue that actors align synthetic biology with industrial commercialisation through two channels. Actors are in the process of embedding commercialisation in the new facilities and pedagogical practices of synthetic biology.

5.1 Collaborating to commercialise

Collaborations: impact, resources and speed

As I have already discussed, synthetic biology is a field with many hopes and promises of creating a better future. These promises are for synthetic biology research to deliver benefits in health, fuel and food, and for research to produce economic outcomes.

> There's so much pressure on synthetic biologists to think of the market think of commercialisation, collaborate [with] companies, all these calls, the SBLCs and everything, they have this huge pressure on them to orient their research towards the private sector.
>
> (Social researcher 1 interview, 1st July 2014)

Some of the funding allocation for synthetic biology is specifically attached to commercialisation and private companies (these are discussed in Section 5.3). A high profile set of RCUK investments has been to establish the multidisciplinary synthetic biology research centres (SBRCs). These were awarded over two calls. The first three SBRCs were awarded to Nottingham, Bristol and a Cambridge and John Innes joint project in 2014. The second call, which was announced in early 2015, was awarded to The Universities of Edinburgh, Manchester and Warwick. The industry involvement on these projects was not stipulated but was suggested to include "cash contributions, materials, access to equipment or facilities and staff participation in research or on a project management committee/scientific advisory board" (BBSRC 2013).

In fact, RCUK is one institution that has identified collaborations as a key area for developing their own practices.

> Partnerships and collaboration are essential to bring the benefits of our research to people, to drive economic growth and to deliver excellence with impact. Working with strategic partners we can continue to leverage additional funds to maximise the investment in UK research. We will continue to build on and enhance existing relationships with key partners both within and outside of the research sector such as HEFCE and the wider UK Funding Councils; the Technology Strategy Board (TSB); relevant charities and voluntary organisations; public sector bodies of various kinds; government departments; and businesses and industry.
>
> (Research Councils UK 2015c, p.3)

RCUK connect collaborative working with realising benefits of research investments. Collaborations, for them, can also be a route to accessing more funding. The synthetic biology *Roadmap* identified the BBSRC and EPSRC as having successfully leveraged funding from the EU, Gates Foundation and NSF (Technology Strategy Board 2012b, p.16).

Furthermore, RCUK identify collaborative working as a way to realise benefits in terms of the 'use of knowledge'. Some possible routes for realising benefits are outlined below.

> There are rich pathways by which the outcomes of our investments reach application. Pathways include direct academic collaboration with companies, public sector bodies and civil society; generation of spin out companies from universities and institutes; training of a highly skilled workforce; and input to policy development. Research Councils also work with businesses and other users of research to understand their agendas and in turn influence the research base.
>
> (Research Councils UK 2010, p.8)

The private sector is listed first in these kinds of collaborations. Various forms of stakeholder participation and multidisciplinary working are often a feature for grant proposal guidelines. In Fujimura's (1987) terms, collaborations can increase the do-ability of research by increasing resources and by altering work programmes to better align them with stakeholders' goals.

Part of the rhetoric of translation is to speed the process of innovation. The *Roadmap* identifies improving collaborations as a way to speed up the realisation of benefits in the commercial sector. This is partly through being able to determine the nature of projects and also:

> It has been shown one of the best ways to speed up [the commercialisation] process is to create 'demonstrators'… In some cases the type of demonstration needed will be demonstration of scale, and access to production capability to assist scale-up will be important. Some of the facilities needed already exist in the UK. In other cases, demonstration will require access to cutting-edge laboratory equipment, and it is important that critical equipment is located within the UK – it should be made easier for businesses to access the expertise and facilities within the university sector.
>
> (Technology Strategy Board 2012b, p.22)

According to the *Roadmap*, collaborations are needed in order to specify how projects will be orientated and the production of prototypes is a way to develop technology quickly for transfer to market. This requires innovators to have access to technological spaces to scale-up or refine technologies. Here, collaborations are connected to accessing more resources in the name of accelerating commercialisation. As one administrator answered to the purpose of 'a translational agenda':

> I think they're just trying to progress it all bit faster, aren't they? I think trying to make that link between academics and industrial partners earlier on so that research is meaningful to industry and commercialisation sectors in terms of what they want.
>
> (Research administrator 2 interview, 18th February 2014)

Collaborations are identified as routes for academic research to realise benefits and impact more quickly. For translating synthetic biology, this is particularly to establish market benefits through partnership with industries. The formation of collaborations is also important as it

seems that they result in access to more resources in terms of funding and in terms of research and innovation facilities.

In the quotations in this section, collaboration is often treated as a known concept. While a dictionary definition of collaboration "suggests the working together of individuals to achieve a common goal" the details of both "working together" and "common goal" are not generally explored (Katz & Martin 1997, p.7). So, although collaborations are presented as desirable, there does not exist a clear agreement for what constitutes collaboration. Collaboration can mean different things. The next section explores how institutions such as research councils and universities attempt to initiate collaborations and begins to suggest how collaborations in synthetic biology are being done.

Stimulating Collaboration

There are a number ways that funders and institutions encourage the formation of collaborations between researchers and industry. This section describes two mechanisms – funding and events.

There is a range of funding opportunities for projects aimed at commercialising bioscience. One category of collaborative funding mechanism is called catalysts.

> Catalysts are run jointly by Innovate UK and the Research Councils. A Catalyst is a form of research and development funding which focuses on a specific priority area and aims to help take projects from research to as close to commercial viability as possible.
>
> (Innovate UK 2015)

Innovate UK's purpose, as the UK 'innovation agency', is to support projects that, in the case of collaborations with universities, are 'business-led'. The catalysts are organised, as is detailed below, to fund the development and transfer of knowledge from research to market.

The original catalyst is called the Biomedical Catalyst. It is a collaboration between MRC and Innovate UK. Catalyst funding is awarded, through competitive calls, to researchers and SMEs wanting to develop healthcare research and move it "more quickly from discovery to commercialisation" (Medical Research Council 2015a). More catalysts have been launched both within and outside the biosciences following the Biomedical catalyst. The three newer catalysts are Agri-tech, Energy and Industrial Biotechnology (IB) catalysts.

Via a webinar, I 'virtually' (Hine 2007) attended the launch of the IB Catalyst where the structure and plans for calls were announced (field notes, 3rd February 2014; see also Section 3.3). BBSRC, EPSRC and Innovate UK co-fund the IB catalyst. There are five funding streams. Early stage awards are for development of processes and technologies, and feasibility projects concerning market opportunities of an "early-stage scientific idea". Early stage translation awards are for academic-led projects at BBSRC and EPSRC eligible institutions. Business involvement is suggested at this point, but not mandatory. These awards are £2-5M. They aim to:

> …encourage the use of new technologies such as systems and synthetic biology alongside more traditional approaches such as fermentation and process engineering, and biocatalysis; including theory and modelling.
>
> (BBSRC et al. 2014, p.4)

A separate stream for early-stage feasibility funding can be academic or business-led. It is much smaller, with projects funded for a maximum of one year and £250k. The mid-stage 'Industrial research awards' are for projects that develop recent discoveries into technologies

or processes which would be commercially viable. These are business-led and up to £5m. The business partner must give 50% of the funds. The late-stage awards are for business-led projects close to proving a process or technology to be commercially and industrially viable. Pre-experimental feasibility studies are one-year projects for companies to demonstrate scale-up of their proposition. Experimental development awards are for businesses in the final stages of testing and demonstrating consistent processes established in the pre-experimental feasibility studies. These can be up to £10m. The reason given for these awards being so large is because experimentation at industrial scale can be expensive (Field notes, IB webinar 3rd February 2014). A hope is that research projects will engage with catalysts and that projects will move along the funding stages to commercialisation (BBSRC et al. 2014, p.4).

The BBSRC offers other funding for 'working with business'. Industrial partnership awards (IPAs) and 'stand-alone' LINK schemes are for developing academic-industry partnerships in collaborative research projects. The LINK scheme is for 'pre-competitive' research and development that would not exist beforehand. IPAs are for collaborative projects between universities and UK companies and are "normally funded in preference to standard grants of equivalent scientific merit" (Biotechnology and Biological Sciences Research Council 2015). Both of these funding streams require written agreements between the parties including funding arrangements, deliverables and management of intellectual property.

The research councils have a wide range of mechanisms in their pathways to develop collaborations, some of which involve Innovate UK, the UK's innovation agency. Innovate UK co-fund many of the 'translational' funding mechanisms with RCUK. The IB catalyst is structured in a way that can encourage collaboration and leverage funding from industry. These staged awards divide the responsibility for innovation. 'Translational' projects are academic-led. Meanwhile, the industrial research awards and late stage awards are

business-led. The structure of the funding means that development risks begin with publicly funded academia in the first stages and are transferred to private companies as the project moves through the Catalyst scheme. The BBSRC funds IPAs in preference to research projects judged to be of the same scientific value. This highlights the importance of forming partnerships for academics wanting to access funding, even for 'standard' research.

A second way that collaborations are initiated is through changes in universities. In order to develop translation, universities have begun implementing strategies to ensure that knowledge production is relevant to stakeholders. One synthetic biologist, academic researcher 12, held a senior role in commercialisation and knowledge exchange at their institution. They described the initiatives that they had implemented across their university to coordinate and improve commercialisation, impact and knowledge exchange. Their university had increased the number of non-academic roles related to translation and knowledge exchange, increased the funding available for translational activities and increased researcher training, including extending courses for students, to help scholars learn about translational activities (academic researcher 12 interview, 15th July 2014). These activities were also supported with data collection to check that academics were meeting with new knowledge exchange personnel and taking up the training opportunities.

Coupled to this, UK researchers are required to demonstrate the relevance of their research by describing 'pathways to impact' in their funding applications (the process was outlined in Section 4.2). These are meant to be specific routes by which knowledge can be disseminated and can be expected to contribute to "economic and social impacts" as well as academic impacts (RCUK 2014). One research administrator in a 'grant capture team' had a role to support academics to foster collaborations. In interview, he claimed to be sensitive to different groups he interacted with and altered his vocabulary depending on their audience:

> Because knowledge exchange and impact and industry engagement they're all kind of synonyms in many regards and I do change my language accordingly, depending on who I'm talking to, it's just, part of the academic kind of psyche at the moment to think a bit more like that…
>
> (Research administrator 3 interview, 3rd March 2014)

This administrator explained that they used 'impact', 'engagement' and 'exchange' interchangeably, depending on their audience. He also commented the university had removed the word "industry" from one opportunity the university offered to make it more applicable to some sciences (research administrator 3 interview, 3rd March 2014). However, their overall remit was to increase academic-industry collaboration in a science faculty. He argued that establishing a commercial collaboration could be a way for an academic to have a clear route to impact. This, in his argument, could make it more likely for an academic to get funding by writing a compelling and industrially supported proposal.

Knowledge exchange personnel in universities organise events for academics and industry representatives to meet and, hopefully, for collaborations to be started. In the course of this research, 'following the actors' entailed attending various "showcases", "bazaars" and symposia where research and technical capabilities were displayed with the hope of establishing new research and commercial relationships (see Chapter 3). Occasionally, these were 'local' in the sense that only other researchers from nearby departments or universities were invited. More often, the delegate list included representatives from beyond academia.

A research bazaar at one university involved numerous presentations from academics in the life sciences. There seemed to be a particular emphasis on molecular biology and imaging techniques. In a presentation, an academic working on a technology in which proteins could 'snare' other molecules was looking for help to translate findings (field notes, research

bazaar, 20th May 2014). A possible application for this idea was as an alternative to analgesic drugs and to capture molecules involved in the sensation of pain. Their research was at a molecular level and they were looking for collaborators that might help move the early technology from 'simple organisms to humans'. As the researcher wanted to develop their findings they wanted additional expertise. Thus, the call for collaborators partly reflects an increase in biological complexity. It also reflects increases in social complexity as more concerns, such as regulations, become pertinent.

As well as attempting to establish internal collaborations and multidisciplinary working some events are staged in order develop external (outside of academia) relationships. CSynBI had adopted this kind of approach. The centre held 'club days' where industry representatives were invited to watch research presentations about on-going work and to pose possible research questions to academics affiliated with the centre.

> Our centre's five years old and in the first three years we held industry club days where we would… spend a good few months beforehand calling up whoever we thought should be interested in synthetic biology and getting them, getting someone from each company down to, to Imperial for the day where we would present the kind of work we were doing in synthetic biology. They would present problems that they have, we would discuss potential ways either that collaborating with us… or maybe they could go elsewhere. But it kind of catalysed an interest. And we had, you know, Shell, Glaxo, big companies like that and then much smaller companies coming along as well.
>
> (Academic researcher 10 interview, 1st September 2014)

Holding the club days was a way to spread the word of synthetic biology to possible industrial collaborators. Presenting research and sharing problems with one another is a way to mix the different domains of academia and industry in a short period of time. However, as I argue in Section 5.3, synthetic biology in the UK has entered a new phase in the way that it attempts to initiate industry-orientated projects.

I also attended an open day at a university where various researchers and administrators presented capabilities to other academics and industry representatives (field notes, open day, 6th March 2014). The annual event was in its second year, and the emphasis was on medical technologies. It took place in a large auditorium, which had been divided into two equally sized sections. Near the entrance, set up like a checkers board, were several rows of exam tables, each with two chairs. This effectively formed a backstage to the other half of the auditorium. A large platform, complete with theatrical lighting, a lectern and amplified microphones, faced three stands of raked seats. The delegate list included academics, academic administrators and various representatives from commercial and industrial companies. Some of these businesses specialised in servicing academic requirements for bioscientific equipment and services. Others operated outside the university sector, in healthcare and the chemical industry.

The morning programme consisted of a range of academic speakers. They spoke of the importance of innovation and the role that could be played by various forms of collaboration in ensuring both academic and commercial ends could be met. One academic had spent time on sabbatical in the industrial sector and explained how mutually beneficial that had been. These talks also highlighted the kinds of opportunities open for collaborations – funding, sabbaticals, administrative support.

The afternoon one-to-one session was based on the notion of 'speed-dating'. This explained the layout of the examination tables. Speed-dating is a form of directed interaction where participants have time-limited conversations in order to interact with a number of other participants in a given session. Before the event, attendees had been provided with a list of delegates and had been able to meet with up to three other delegates they thought they could establish research relationships with. Each meeting was to take fifteen minutes so

attendees were able to outline their research needs, and industrial problems, and see if there was the possibility of a future collaboration.

This component of the event was structured for possible collaborators to have 'meaningful' interactions. However, it also functioned as a way to introduce a number of possible collaborators to one another in a short space of time. By providing an 'opt in', delegates were able to assess the likelihood of collaboration before a meeting. This meant that participants had interacted with the delegate list and made a positive judgment regarding the meeting. The speed-dating structure relates to the previous point about collaboration being a route to accelerate commercialisation. By encouraging representatives to have a series of short meetings they could identify possible collaborators and rule-out others in a given period of time.

Funders and universities present collaborations as of great importance to the life science sector. They connect them to leveraging of further funds, accessing resources and realising the impact of academic research outside of universities by suggesting projects be designed with non-academic stakeholders. Funders create mechanisms to foster collaboration and stage-gate the transfer of risk and knowledge from the public to the private sector. Universities employ administrative teams, tasked with increasing 'grant capture', who attempt to initiate collaborations by staging events for academics and private companies to meet and discuss their research and needs. These activities are further bolstered by the formal and informal collection and retelling of other successful collaborations.

Collaborative Successes

One of the issues with the newness of synthetic biology is that it does not have an established history of translation. Success stories can be an important feature in the emergence of a scientific communities, particularly in synthetic biology (Molyneux-Hodgson & Meyer 2009). Telling 'success stories' are a way of increasing institutional memory and making a present problem seem surmountable (Deuten & Rip 2000). One administrator commented on the importance of being able to collect and retell success stories:

> So again it's part of our responsibility as a team to capture the success stories. And we have a series of thirteen, I think, at the moment, and we use those to kind of explain both to academics within the faculty what the benefits are. So it could be you know, I got a paper out [of] this, or got a patent, or whatever. But also to industry, to say, "these are the benefits to the industry". So those materials are supposed to speak to both audiences at the same time.
>
> (Research administrator 3 interview, 3rd March 2014)

One of the ways the success stories had been 'captured' was on a website with case studies of successful projects. Although hosted by a university it was accessible via the internet and open to any member of the public. This repository of success stories therefore acts as a *boundary object* as it allows "people from different worlds can use or borrow from the 'pile' for their own purposes without having directly to negotiate differences in purpose." (Star & Griesemer 1989, p.410). Furthermore, this collection of success stories is an "organic infrastructure" that actors have created to respond to "information and work requirements" (Star 2010, p.602). The administrator also pointed to the function of collecting and presenting success stories: that they might be able to 'speak' to both academic and industrial audiences and allow both to see value in partnering with one another.

In synthetic biology, the most notable success story has been The Artemisinin Project. Artemisinin is a chemical derived from *Artemisia Annua*, sweet wormwood, and in 2006 was highlighted by the WHO as the frontline co-therapy for malaria. Since 2003, Professor Jay Keasling and his team at UC Berkeley have been working on and publishing articles regarding the creation of a microbe that had been engineered to produce comparatively large quantities of an artemisinin pre-cursor, artemisinic acid. In 2004, the project received a $42.7m investment from the Bill and Melinda Gates Foundation to develop the technology. In 2009, Pharma giant Sanofi-aventis joined the project with a "no loss no profit" agreement to licence the technology to produce artemisinin semi-synthetically. On 13th April 2013, there were global headlines that the industrial production of artemisinin was about to begin with the first year's yield, of 60 tonnes, being approximately a third of the world's demand.

At the SB 6.0 conference in 2013, The Artemisinin Project featured in two tracks: *Transcending technology, transcending industrialisation* (mentioned in the Section 4.1) and *Towards Global Health*. Dr Wolfgang Laux, a representative of drug company Sanofi, presented his talk "The semi-synthetic Artemisinin Project: Learn from Nature – Go from Lab to Industrial Scale" in the *Towards Global Health* track. Dr Laux discussed the technical details of moving from 'nature to industry'.

Professor Keasling's talk, titled "Synthetic biology for synthetic chemistry", began with a story of a young boy called George that the professor had met while touring Kenyan medical clinics. George was visiting the clinic to collect drugs for his malarial brother. The goal, explained Keasling, was to produce artemisinin to stabilise the market, make access to the drug more reliable than plant-sourced precursors, and discourage the illicit trade in monotherapies (for analyses of how these goals emerged over the course of the project, see Marris 2013; Meckin unpublished). He then moved on from talking about artemisinin to talking about fuel production, and the possibility of using the Amyris bacterial platform to

produce bio-fuels. What Prof Keasling particularly focused on was the difference between high value/low volume chemicals like drugs and fragrances and low value/high volume chemicals such as oils and fuels (field notes, 11th July 2013).

The Arteminsinin Project was presented at the conference as an example of a successful project that had enabled further research to take place. Its importance was highlighted by the fact it was the only project to feature in two talks in two tracks. The academic researcher, Prof Keasling, presented a story, which had few scientific details but focused on future commercialisation and included pictures of people at medical centres in Africa and of people-less industrial manufacturing plants in Europe. (The process involves a fermentation step outsourced to Huvepharma in Bulgaria and then a photochemical step performed by Sanofi in Garessio, Italy (field notes, 11th July, 2013)). The industrial representative, Dr Laux, concentrated on the process by which 'nature's' production levels had been scaled up to industrial production levels.

The Artemisinin Project has long been the 'poster child' for synthetic biology (Marris 2013; Molyneux-Hodgson & Meyer 2009). The Artemisinin Project has featured in various scientific articles and, perhaps more importantly, there has been a good deal of media coverage (field notes, 13th April 2013). Molyneux-Hodgson and Meyer (2009) argue that telling the 'success story' of artemisinin is one device that helps the emerging synthetic biology community cohere. The Artemisinin Project at SB 6.0 became a story about a successfully integrated collaboration of academia, charity and industry. It produced further research avenues for academics and raised the profile of industry involved in humanitarian work.

In my research, another collaborative success story circulated, but this time among research administrators. Two administrators to whom I spoke talked of grant proposals from scientists not being funded because of institutional 'space' within RCUK.

> … more and more we're finding as we try spend this accelerator money that a lot of the research is fitting in the gaps between the research council remits.
>
> (Research administrator 3 interview, 3rd March 2014)

> … an ongoing conversation that we've been having with the two research councils is the need for them to work more collaboratively themselves. Instead of, you know, saying if you send it BBSRC they'll say, no, it's MRC. If you send it [to] MRC they'll say no it's BBSRC. That's what happens.
>
> *Participant places hands palm down as if picking up oranges and then gestures to the area between them. A third, empty space.*
>
> … Where does it go then? So sometimes people can kind of lose out.
>
> (Research administrator 2 interview, 18th February 2014)

These administrators perceive a 'gap' in the way that funding is awarded. The structure of the research councils, in some cases, means that some projects are not funded because it is not clear who should fund them. Synthetic biology, spanning the domains of biology and engineering, could be such an example.

However, RCUK created a cross-council working group for synthetic biology that has reportedly developed a good reputation within the overall organisation.

> So for synthetic biology, actually, we work in a very collegiate cross-council manner. It's really good actually because um, you know when this big chunk of capital got awarded to the councils it was an RCUK award; it wasn't made to any specific council… the funds are held by BBSRC which is why we lead on the implementation of the programmes behind it, but it's RCUK. So we have a cross-council working group for synthetic biology, which has members from BBSRC, EPSRC, MRC, NERC and ESRC. It's chaired by BBSRC, but we have an additional member who kind of represents our views so that the chairing is impartial.
>
> (Research administrator 10 interview, 18th August 2014)

And:

> I think synthetic biology's a good example of [research councils working together].
>
> (Research administrator 6 interview, 19th August 2014)

According to research administrator 10 above, the problem for RCUK emerged several years after the funding for synthetic biology had started. It was not directly related to an epistemic issue but to administrative concerns of how to deal with a special governmental allocation. The 'chunk of capital' was £50 million pledged by George Osborne in the November 2012 statement. This is known as the Synthetic Biology for Growth fund (field notes, 18th August 2014).

On these accounts, administering those funds requires coordination between the councils and this is enabled by a new entity, the working group. This is not to say that the working group was established in direct response to the administrators' (2 and 3) comments earlier in the section, but it does address a more general concern that "real-world problems do not come in disciplinary shaped boxes" (Jeffrey 2003, p.539). The emergence of synthetic biology requires institutions to adapt their working practices in order to accommodate the new field of science. Synthetic biology is one of BBSRC's "new ways of working" (BBSRC 2014, p.3) not just in terms of science, but in terms of the collaborations and institutions that are emerging. Thus, collaborative success stories circulate in synthetic biology to reinforce the benefits of working together in different domains.

This section has explored how collaborations result in access to funding and resources, how they are initiated and how some collaborations can become stories, or *devices*, that circulate to bond actors in synthetic biology (Molyneux-Hodgson & Meyer 2009). In designing this project, I was also interested in how actors understood the problems translation is meant to

solve. The next section is an analysis of how participants enacted different problems of academic-industry collaborations that emerged in fieldwork and in interviews.

5.2 Enacting the Valley of Death

This section picks up the metaphorical cartography of "translation" – roadmaps and landscapes – and explores the way that gaps between universities and industries are enacted in synthetic biology. The 'valley of death' is a common metaphor not just apparent in relation to synthetic biology but in the discourse surrounding translational medicine (Kraft 2013; Butler 2008) and innovation policy (Technology Strategy Board 2014; House of Commons Science and Technology Committee 2013). Many of the participants in my research had worked 'on both sides of the fence' or worked, as administrators, in some form of intermediary role (Meyer 2010). These differences were made visible during events where industry representatives were invited to a university to take part in discussions about network 'direction' or to help allocate funding, for example. These became sites for public performances of differences between academia and industry. The valley itself is subject to various interpretations and understandings of what constitutes the problem. The following discussion covers some of the contours of the valley.

In 2013, the UK government produced a report titled *Bridging the Valley of Death: Improving the Commercialisation of Research* (House of Commons Science and Technology Committee 2013). The report stated:

> There exists the concept of a valley of death that prevents the progress of science from the laboratory bench to the point where it provides the basis of a commercially successful business or product. The future success of the UK economy has been linked to the

> success of translating a world class science base to generate new businesses with the consequent generation of UK jobs and wealth.
>
> (House of Commons Science and Technology Committee 2013, p.3)

The report was critical of its own conceptualisation of the 'valley' as a substitute for a linear model of innovation and found:

> There is no single valley of death that all businesses, or even small businesses, must cross.
>
> (House of Commons Science and Technology Committee 2013, p.54)

The report suggested a range of interventions including investment in technology companies, subsidies to increase scale-up and test facilities, tax credit support for SMEs and more people with industry backgrounds in university faculties. However, in the final conclusion the report focused primarily on financial incentives to promote innovation in terms of procurement, R&D focus and fiscal policy (House of Commons Science and Technology Committee 2013, p.60).

In interview, David Willetts developed possible notions of the valley further, suggesting that as well as funding limitations there were also issues with the way science values knowledge:

> There's a problem in public policy that we don't have enough support for innovation as it [gets] closer to market. In the science community I would say the problem is that scientists exaggerate the value of what they've done in the lab and underestimate the extra value that is added before you actually have a real product.
>
> (David Willetts interview, 2nd September 2014

The idea expressed here is that those scientists who have produced knowledge do not fully understand the additional labour it takes to turn knowledge into a commercial proposition. An administrator put this a slightly different way:

> When you sit with academics and industry there's always this kind of, you know. The academics [say] the industry want everything for nothing, the industry says the academics want, you know, value their inventions too highly.
>
> (Research administrator 12 interview, 19th August 2014)

These comments suggest that collaborations between academics and industry can be problematic because of differences of value. Value does not necessarily relate to monetary value, and can be both a noun and a verb (Kjellberg et al. 2013). Thus, the different ways that knowledge or inventions are valued may explain the sense that industry and academia argue over the worth of knowledge. This section, following some of the studies on Translational Research reviewed in Section 2.3, reimagines the contours of enacted gaps. Rather than focusing on financial matters, actors' comments and actions bring into being other differences of value between industry and academia.

Phasing

Time is a dimension that appears to shape the valley. Industry, even global corporations, were described as able to operate to tight time scales and able to respond quickly to a changing environment. For example, a large pharmaceutical company might close down a whole research programme at short notice (academic researcher 10 interview, 1st September 2014). This was in contrast to academia, where the ability to respond quickly was not so crucial, as in this comment from an administrator discussing collaborative contracts:

> It's very unusual for an industry partner to be completely flexible about timescales, for instance. So, starting a conversation where you go, "oh, it may take three or four years to

> do this" can make a lot of industry a little bit kind of uncomfortable cause they tend to work on a much tighter turnover.
>
> (Research administrator 3 interview, 3rd March 2014)

And an administrator who had spent a decade in industry before getting employed at a university:

> When I first started in academia eight years ago, they said, we need a new strategy. I said fine. Fine. You know. Oh, we need it by kind of the end of next year. I said, I thought you were gonna say the end of next week! You know. I mean. Industry would kind of [say], we want a new strategy. Oh yeah? You've got eighteen months, you know? No no no. We want a new strategy. Oh, what, what today? No no no. that's fine. You've got 'til Friday.
>
> (Research administrator 12 interview, 19th August 2014)

This administrator's example describes academia as operating with long time spans while industry revise strategies at short notice. Research administrator 12 went on to suggest that this was a difference between quangos, too. RCUK funded 'excellent science' and wanted to fund clear, long-term research projects. They explained Innovate UK had fewer reservations about changing the focus of funding. Partly because the criteria of 'excellent science' did not need to be applied, Innovate UK could turn around quickly and invest money into a new area or company (research administrator 12 interview, 19th August 2014). This extends the differences in timing to funders as well as researchers and industry.

The notion of long-term plans also emerged in the way an academic explained applying for large grants. The idea was that funders would want to see that a proposal involved a complex problem that contributed to a long-term area of research.

> As a scientific researcher you must have a vision for next five or ten years so your research is aimed at next five ten years topic. So, but industry, they want immediate

> products from your research… industry want something immediately [that] can be converted into product. But if it's that easy to do, [the] research must be very mature. So in that, that's not science, scientists they really want to do that. Because [if] it's so mature there's a very little question to do scientific research.
>
> (Academic researcher 11 interview, 29th August 2014)

The notion of 'vision' here is about a project that will lead to a development of knowledge. In this researcher's experience, industry were focused much more on a short term return on investment. So, while an academic researcher's project might be funded for three to five years and their overall problem might be anticipated to be a ten-year project, an industry project probably needed answers in months. The researcher above draws a boundary – it's not scientific research if the answer can be found quickly.

That said, the 'intensity' of the work in each field can be different. For academics moving into commercial start-ups the days were very busy, partly because the deadlines were close together and work needed to be completed in short time scales (industry rep interview, 1st September 2014). Academic working practices tend to be more 'open', with self imposed deadlines for publications and disseminations, but also more diluted, with the associated administration and teaching commitments of researchers in higher education institutions.

This results in a perceived difference as to the types of problems that are tackled and the complexity of their solutions. For instance, as mentioned in the previous section, the IKCs are funded to create an entirely new industry. They are 'at the academic end' and the hope is that they will produce radical change in commercial practices (research administrator 1 interview, 19th August 2014). 'Incremental' change in production, to this participant, would be a disappointment. However, the view of one researcher was that industry was looking for gains in efficiency.

> I worked with industry a couple of times recently and it's fine but it depends on the model that they run for their R and D. So some of them seem to want things to be very close to either products or something that can improve like a product pipeline that they already have. And that's their, that's where they are with it at the moment. I don't think they're really thinking that they can use synbio to produce the next super drug… big innovation. No, I think they see it and certainly GSK were [at the event] and they see it as a plug-on to improve, you know, the production levels of what they've got, or reduce the carbon footprint, is what they say, to make it more efficient, to cost less.
>
> (Academic researcher 5 interview, 7th May 2014)

Although synthetic biology is becoming a large programme of research with a long-term vision to standardise life, large industry already has a substantial investment in infrastructure. In this researcher's experience, industry wanted mundane advances that improve their existing systems. Furthermore, during a presentation by an industrial rep at one event, a senior academic muttered to those listening that he knew of at least three people who could solve the problem in a few months (field notes, network event, 9th September 2014). "Quick wins" (social researcher 1 interview 1st July 2014) and other terms are used pejoratively to signal that industrially-orientated work is easier and less challenging because it can be done in a shorter period of time.

The idea that industrial problems might be deemed tedious and mundane was acknowledged by a researcher with experience of spinning out companies from a university.

> Round that time that it really became clear that, in the past, people sort of viewed this sort of commercial drive to do science perhaps not the thing to do and that blue skies was the thing to do. And that perhaps commercial science was a bit dull. But what we found was that the problems posed by the outside world were actually quite a challenge and drove the research really nicely.
>
> (Academic researcher 12 interview, 15th July 2014)

In other words, it is not a given that industrial work is short-term and boring. It could, in this case, be a guide for the academics and raise questions that were deemed interesting to pursue.

Synthetic biologists on other projects did not always recognise this difference between 'quick and easy industry' and 'long and visionary academia'. They felt that, yes, academia and funding streams can appear slow and cumbersome, yet as soon as money is awarded, the project can be much more responsive and flexible (field notes, meeting, December 2014). This was coupled with the idea that some forms of industry could be conservative and innovation averse with respect to synthetic biology (Molyneux-Hodgson & Balmer 2014).

Academic flexibility was also suggested by how an academic had become involved in synthetic biology:

> I've always been fairly open minded… and wanted to just get involved in loads of stuff and was quite aware that I couldn't really make um I can't just be a one trick pony… always got you know half an eye on an whether, on an exit strategy… So they invited me along and it turns out that actually what I'd done had some applications and cos I'm just interested in stuff, I didn't say no.
>
> (academic researcher 5 interview, 7th May 2014)

This comment complicates the idea that academic funding and research has a longer view and is not 'agile'. Academics can respond in short periods of time at different points in their careers, particularly if their expertise becomes applicable to a new area of research or innovation. Both industrial and academic research is thought to be able to move into new areas and respond to change, given certain motivations.

The title of this section, the notion of phasing, is therefore meant to capture the way that timescales, work intensity, flexibility and problem complexity can be a nexus of temporal issues for collaboration. Phasing suggests different periodicities related to epistemic work.

Transforming projects: publications, proposals and profitable patents

Another way actors explain the difference between universities and industry is that the two domains are geared towards the production of different outputs. The idea of *transforming projects* is meant to express tensions between the ways that academia and industry value different outcomes of project work.

For academics, important outputs were explained to be publications, proposals and further projects. Accruing grants became a part of the scientific reward structure in the 1990s and raises the status of scientists in their field (Rip 1994). This could be a reason for academics to work with a company: a collaboration would hopefully come with money. The money, and the collaboration, could be converted into PhD projects, journal papers and further grant proposals (Academic researcher 6, 5th Feb 2014). Furthermore, 'basic scientists' in other fields articulate that they are rewarded for publications rather than patents (Morgan et al. 2011). This is borne out in research audit policy – the 2014 REF in the UK prioritised quality publications over impact (Research Excellence Framework 2011, p.2). In other words, academic knowledge production involves publicly raising more questions and following further lines of investigation.

Furthermore, administrators gave the reward structure in academia as a reason for some senior academics being difficult to enrol in translational activities. Senior academics tend to have been in the field longer and have a reputation for publications. According to the

administrators, these academics know that they will be able to publish again at some point in the future. Therefore, they did not need to engage with teams whose role was about fostering industry collaborations. This was because the administrators argued the academics could remain in post based on their history of scholarship rather than needing other forms of evidence such as income generated through industrial collaboration (research administrator 2 interview, 18th February 2014; research administrator 3 interview, 3rd March 2014).

For industry, on the other hand, the main output would be a commercial product or service that could produce a measurable profit. Research administrator 12 explained how an industrial company, "the end users", could generate a profit from a particular project:

> The end users will end up with a specification to either a product or a process and they will protect that. They will have their own organism. They won't give it away. They will keep it so that the exploitative property will be either their process or their product.
>
> (Research administrator 12 interview, 19th August 2014)

An aim for businesses is therefore to maximise their profit. Measuring profit, though it comes in different forms (Miller 2012), turns knowledge outcomes into *technical objects* (Rheinberger 1992; Rheinberger 1997). However, since *technical objects* are materially defined and *epistemic objects* are unfolding, *technical objects* cannot simultaneously exist as *epistemic objects* (McGivern & Dopson 2010). This exclusivity leads to a problem. If the two forms of object cannot coexist, a collaboration between academia and industry cannot be orientated toward the production of a single object since it could not satisfy the needs of both communities, simultaneously.

Not only this, but collaborating with industry can turn into ethical issues for synthetic biology researchers as they may need to decide on whether they would accept support from companies with a dubious history.

> I would say for a materials production, you know, obviously people like Du Pont are very well known for their chemical and material production. So the question would be do I, do I go with a company like Du Pont, huge American company, you know, with some reputation issues, ah, or do I look to found my own company and then what will happen to that? It'll probably get taken over by Du Pont without me being able to do anything about it. Who knows?
>
> (Academic researcher 10 interview, 1st September 2014)

The researcher here expresses the moral difficulties in finding funding and the uncertainty, and helplessness, of the future of companies – if one spins a company out of a university it may end up being bought by a company with a questionable reputation anyway. In other words, entering a profit-orientated, commercial environment could mean leaving one's morals at the door.

This section covered how the different domains of academia and industry are thought to transform knowledge into different outputs. For academics, a good publication record and successful proposals are ways that their status can be raised. This is related to findings that, until more recently, university reward systems are not favourable to interdisciplinary careers (Bruce et al. 2004). For companies the overall goal is thought to be profit. Collaborative work was therefore problematic from the outset as these goals are valued differently (Packer & Webster 1996) and involve the production of different kinds of objects.

Disclosing ideas

One way that value became an issue in this study was about how knowledge was protected in the different fields. The notion of *disclosure* can play out in different ways.

One outcome for a participant who had attended an event aimed at initiated collaborations had signed a confidentiality agreement with a company (academic researcher 5). The researcher saw this as a 'goodwill' gesture, despite the scepticism the academic displayed about whether the conversation would lead to any further collaborative work. This was an idea the researcher took to the meeting, and suggested it to the company, but they did not have any intention of following it up with a grant proposal without company support (field notes, open day, 6th March 2014). Industrial knowledge is protected by three main intellectual property (IP) mechanisms: patents, trade secrets and regulatory data protection (Nuffield Council on Bioethics 2012). Patents, for instance, allow the holders to use knowledge themselves or licence knowledge to others at their discretion. On the other hand, academic publishing protects academic knowledge by publicly attaching findings to names. The findings can theoretically be used by anyone without incurring costs. These two practices therefore appear to be exclusive since patenting involves the power of exclusion, while publishing does not. The stakes, because the academic in this case was not intending to publish, were low.

At other times, *disclosure* was more problematic. This became an issue at a launch event for a network in biotechnology (field notes, 9th September 2014). The day involved presentations from industry representatives who were suggesting problems that the academic audience might be interested in solving. Over the course of the event there was some frustration about the level of details because academics could not be told which exact microbial strains, or their properties, were being used – industrial strains are trade secrets. This meant some of the academic researchers felt like they could not fully engage with the problems since they did not have full knowledge of the experimental or industrial system (field notes, 9th September 2014).

At the same event, there was a feedback session at the end of the second day. The aim was to share progress and kinds of projects that academics and collaborators might take forwards. A group at one table said they could not share their conversation because of uncertainties about disclosure and protection. They were not sure that they could not share, but thought it prudent to not share with the rest of the network meeting. The exchange of glances between people at my table suggested surprise (field notes 10th September 2014). This was a way that performed the differences between academia and industry – the academics were not able to engage in an 'open' conversation in the way they expected.

However, whereas academic practice appears to suggest openness and a drive to sharing, pre-publication data can be extremely sensitive (field notes, pre-conference meeting, May 2013). PhD students were instructed to not 'pre-disclose' results while preparing posters for a synthetic biology conference. This was because others may be inspired by early results and may look to repeat and publish duplicate experiments quickly. Academic work can be closely guarded up until the point of publication.

Dealing with IP issues was more common for those with commercial experience. Well-financed companies can purchase patents as they need them (interviews researcher administrator 12; industry representative) or can licence them (field notes, SBLC open meeting, 27th November 2014). However, some universities are proactive in securing patents for academic research. Yet, they may not be able to find partners to sell to or to whom they can license the IP. This can result in a university having potentially valuable IP 'sitting on a shelf'. While these patents would not be problematic if they were known it could inhibit innovation if start-up synthetic biology companies were trying to second-guess what was 'on the shelf' (field notes, SBLC open meeting, 27th November 2014). The tension, with respect to collaborations, is that the practice of academic institutions patenting research

could restrict innovation because start-ups and SMEs would have to spend additional time and money checking to ensure they did not infringe a patent.

In this way, different systems of protecting knowledge play out at collaborative events and in interviews. The processes of valuing knowledge, in terms of patenting, trade secrets and publishing, can become a problem where the stakes of disclosure seem high or uncertain.

Competencies

The last area in this analysis is the idea of 'finding the right people to do a job'. In this section, the issue appears to be identifying collaborators who have the will and skill to develop projects into successful businesses.

Knowledge and expertise is a central part of an academic's career (academic researcher 10 interview, 1st September 2014). This participant argued academics need to have specific and unique expertise on a given topic, and this defined their careers. However, their knowledge about a part of nature did not extend to the concerns and ways that commercialisation happens.

On the other hand, an academic might successfully spin out a company yet become frustrated with the work.

> A lot of the time the frustration is that they've set up a company that's become quite successful but they're not making any money out of it. Everybody else is… they've moved away from what they really love. You know, I've come across and worked with a number of companies over the years where you've had to say to the CEO, look, time for you to be chairman. Take the money and, you know, pay off your mortgage; buy a speedboat. Do

> whatever you want. Maybe invest in that other project you wanted to do… because they simply aren't the right people to take it forwards.
>
> (John Collins interview, 3rd July 2014)

The idea here is that academics can create successful companies but that their motivation and abilities can only take them so far. They may become disillusioned or others may see them as being no longer effective. Academic researcher 15, a senior synthetic biologist, agreed saying that, in order to move their project forward, they would need to recruit a CEO who had the skillset and enthusiasm.

> It's about finding the right people, and finding the people with the same ambition as you and then finding them the money to do it… I don't just mean the right scientists. I mean somebody that's gonna help you run with your idea beyond what you can do. You know. For somebody that wants to be a CEO of a company rather than a chief scientific officer. And got out and get money for you and do all the paperwork, all that kinda stuff. And then you also need a sprinkling of cash to get it started. I'm biding my time and looking for the the right CEO person. That wants to come and work with me and what we're doing. Do all that stuff for us. Because, I can't do it. I not I'm not good enough. At doing it. You know, it's not my style. Er, I've got too many other things to do. So we need somebody whose equipped, been there done that. Sees the potential of our technology and then goes and does it for us.
>
> (Academic researcher 15 interview, 28th August 2014)

Other actors suggested the problem was in academics and inventors not understanding how markets work and that innovators would not be able to work within the bureaucratic confines of academia (research administrator 12 interview, 19th August 2014).

These ideas suggest that there is an issue with recruiting people with the right skills to innovate in synthetic biology. The comments in this section chime with the idea that "SMEs, particularly those that arise from academic spin-offs, need better management and marketing skills and better financial planning" (Tait & Williams 1999, p.105). In section 5.3, I

follow up these points and describe how development of synthetic biology's infrastructure is addressing this problem.

Performing differences

This section has explored how participants understand and enact 'the valley of death' with respect to synthetic biology. I described the enactment of four 'contours' that contribute to the idea of gaps between academia and industry. In *Phasing* I sought to explore a number of issues connected with the timings of academic and industrial work. The section on *Transformations* covered ways that academia and industry are orientated towards different outputs of publishing and profit, respectively. *Disclosures* was an exploration of how different knowledge-value regimes of revealing operate in the two domains and appear to make collaborations problematic. Finally, *Competencies* was an exploration of how a gap towards commercialisation may occur because there are not the right people who have the right skills to ensure a successful project.

These findings share some commonalties with other studies. There can be tensions in academic-industry projects if academic research is pressurised into premature dissemination or delays compromise timely commercialisation (Bruce et al. 2004, p.466). In Morgan et al.'s (2011) study, basic scientists were reluctant to engage with translational work because it counted for less in the academic domain than publishing:

> Symbolic capital in most fields of basic science is mainly achieved by publishing in key disciplinary journals, being Principal investigator on a grant and establishing a long-term programme of research. Several participants therefore described translational research as 'high risk', in terms of not being sufficiently valued by their peers to form 'authentic' knowledge that would bestow symbolic capital in their field.
>
> (Morgan et al. 2011, p.949)

Thus, laboratory scientists in biomedicine tend to resist a market-orientated approach on the grounds that it is not valued by their communities' practices. While the term 'high risk' does not fit with my interpretation, the idea that academia values certain forms of epistemic output is comparable with my findings.

However, the findings I presented above suggest that there are other issues as well as acquiring forms of capital. The practices of the two domains produce different forms of objects. In academia, by encouraging publications and long, complex problems, the production of *epistemic objects* becomes of greater importance (McGivern & Dopson 2010). In industry, packaging specifications into patents and measuring profits means that *technical objects* are valued. Since these are mutually exclusive forms of entities this poses a problem for collaborations orientated to producing objects for each domain.

Any gaps between academia and industry are multiple and variable and enacted at specific sites. These differences concern professional working practices and knowledge value systems. In conclusion, the Science and Technology Committee report *Bridging the Valley of Death* focuses on financial remedies and therefore ignores a large of part of the translational landscape when it comes to synthetic biology. However, as the next section explores, synthetic biology proponents have implemented strategies that may address 'the valley of death' – by remaking biological research and researchers.

5.3 Embedding Industry

There is a section of the roadmap called 'creating the industrial translation process' (Technology Strategy Board 2012b, p.22), which describes the way that translation may be

constructed in synthetic biology. This follows Figure 10 of synthetic biology translation, displayed in Section 4.2 (p. 163), and Figure 11, the linear graph below.

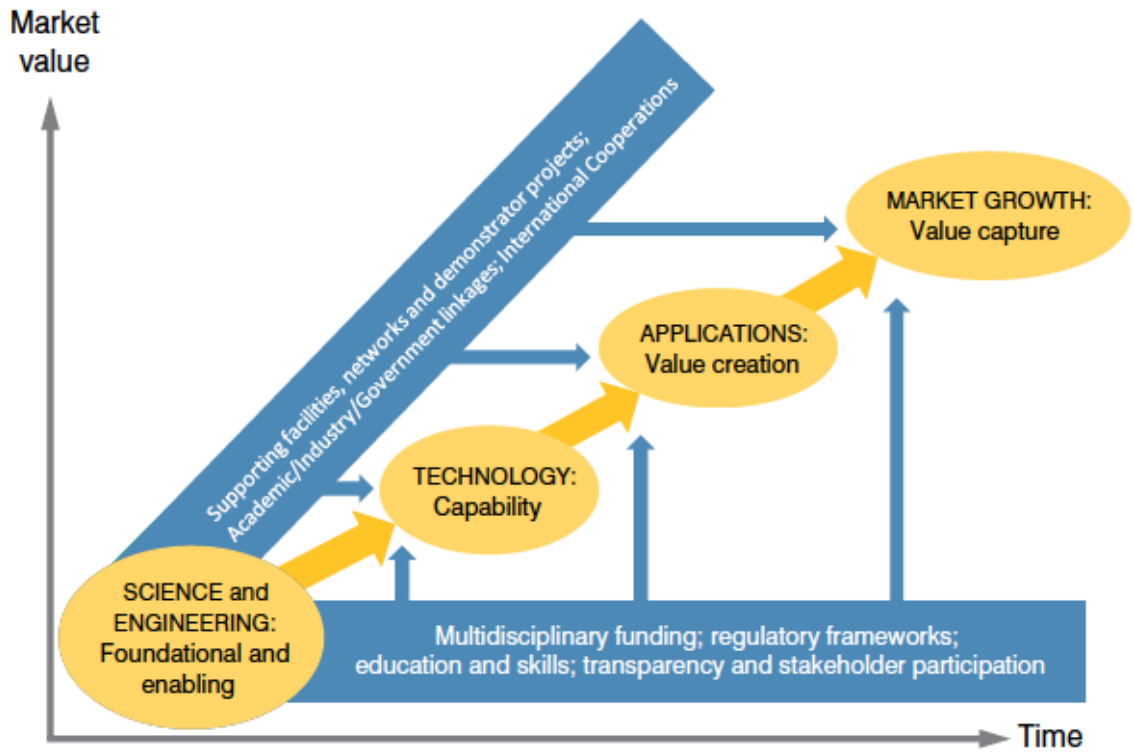

Figure 11. Graph of increasing the value of synthetic biology

(Technology Strategy Board 2012b, p.16)

The outline of the plan continues: first, synthetic biology uses knowledge of fundamental bioscience to create new parts, host organism chasses, or new ways of assembling parts. Next, is to create "industrial engineering methods appropriate for the applications being developed and ultimately the development of biofactories" (Technology Strategy Board 2012b, p.22). An effect of the diagrams and description is to make it seem that all stages in the process lead to products and markets.

A Landscape for the future of high value manufacturing in the UK (Technology Strategy Board 2012a) was published at approximately the same time as the *Roadmap*. The

document listed five “national competencies” which are “that attribute of the national manufacturing industry that enables businesses to respond to the changing global trends and drivers in a way that captures value for the UK in the future” (Technology Strategy Board 2012a, p.4). These themes were: resource efficiency, manufacturing systems, materials integration, manufacturing processes and business models. The *Landscape* highlighted synthetic biology as a component of “securing UK manufacturing technologies against scarcity of energy and other resources” (Technology Strategy Board 2012a, p.12), which suggests a role for a future synthetic biology industry.

The *Roadmap* also calls for more interaction, not only between academics and industrialists, but also public funding. The document argues that risk needs to be spread out and resources for new developments should come from a tripartite arrangement in which:

> Public funding contribution would normally be in terms of cash or the de-risking of the investment to make it more attractive to potential funders (such as venture capitalists). The main university contribution is in terms of research facilities and highly skilled research personnel. Industry may contribute cash or know-how. The public and university components of the model act as a catalyst to counteract the common causes of failure of application projects as seen from industry, for example through provision of training, mentoring and expansion of partnership opportunities.
>
> (Technology Strategy Board 2012b, p.23)

This quote from the plan establishes the roles for the parties in collaborative projects (Deuten & Rip 2000, p.79; Callon 1986). Overall, the role of public and university resources is to ‘de-risk’ the involvement of companies and investors by insuring them against financial loss. It is the role of universities to provide training and partnership opportunities to industry, taking into account issues that industry has identified. In this model, industry guides the research and other provision by identifying its needs.

An argument in the synthetic biology roadmap is to increase collaborations between academia, government and industry to produce scalable demonstrators that can be developed and sold for profit. However, as described below, this model can be problematic.

> Where it starts to go fall flat is when you start taking out of the laboratory and into an industrial situation. Currently there's not the metrology, there's not the standards, there's not the interoperability. There's not the culture, there's not a culture in biology at the moment of [an] industrial approach. That's why in my mind industrial biotechnology [hasn't] become an industry in the UK.
>
> (John Collins interview, 3rd July 2014)

Collins connects the failure of innovation to a combined issue of infrastructural and cultural absence when it comes to industry in bioscience. The infrastructural changes are being particularly addressed by the funding of The Flowers Consortium – a group of five universities tasked with developing standardisation which "will provide the critical mass and synergy necessary to make synthetic biology a well-characterised and usable tool for developing applications and products" (The Flowers Consortium 2015). Scholars at the University of Edinburgh and King's College London, who are partners in the consortium, are currently conducting social studies of these infrastructural developments.

The next section, following John Collins' point, focuses on ways that synthetic biology may be changing bioscience research culture. I focus on two aspects: aligning synthetic biology facilities and the institutionalisation of collaboration and commercialisation training.

Aligning facilities

There are many new organisations emerging in synthetic biology. At the start of Section 5.1, I argued that the SBRCs, the fundamental research centres for synthetic biology, are

orientated towards industry and the commercial sector. This section details the way that other organisations in synthetic biology are set up with a commercial orientation. Gaymon Bennett writes:

> …it seems worth posing the question of what facilities have actually been put into play as part of the making of the synthetic biologist… The defining feature [of synthetic biology] has been the proposition that the near future of biotechnology depends on inventing of a new style of facility for research, design, pedagogy, and production.
>
> (Bennett 2015, p.128)

Bennett uses "facilities" in the double sense of "organisations" and "capabilities". He argues that in synthetic biology "the facility becomes the primary artefact of collective biotechnical practice (Bennett 2015, p.130). I aim to show that the deployment of institutional funding, language and computer-assisted automation are bound together in the making of commercially orientated facilities in the UK.

SynbiCITE is dedicated to identifying projects that may generate market profits. The name 'engine' is an overt reference to the notion of 'driving innovation', and also to industrialised processes. The aims of SynbiCITE are:

1. To act as an industrial translation engine which translates university and industry based research in synthetic biology into industrial processes and products
2. To be an effective vehicle for the support of small to medium sized UK companies including Start-ups in synthetic biology
3. To actively engage in open dialogue with the public and other stakeholders focusing on the risks and benefits of synthetic biology technologies

(Engineering and Physical Sciences Research Council 2015a)

SynbiCITE specifically identifies 'industrial' outcomes as its main focus, while at the same time supporting SMEs and broader societal engagement. The grant proposal lists a large

number of academic institutions and businesses, which could form research collaborations. Apparently, this was the result of a lot of work on behalf of Professor Kitney:

> Dick Kitney, who brought it all together, is quite a political animal, and he made some great political alliances and he's very inclusive. So there's about seventeen or more universities actually in that consortium. Everyone realised that if they threw their lot in with Paul [Freemont] and Dick [Kitney] at Imperial at least they'd have a slice.
>
> (Industry rep 1 interview, 1st September 2014)

Collaborators included synthetic biology startups like Green Biologics Ltd, Oxitec Ltd and Synthace Ltd, but also large multinationals such as GSK and Shell. The large amount of co-investigators and collaborators appears to have been convincing to the funders. The successful proposal was funded in 2013 for five years. This links back to the point made at the start of the chapter – that forming collaborations can be about leveraging more resources.

However, SynbiCITE did not appoint a CEO until mid 2014. In response to this point, an administrator explained:

> All the IKCs take a long time to get started. They are difficult things to set up. They're doing something different that universities don't do routinely. So both there's a capability thing and also a whole, you know, they're pushing against the university administration and… in their way they are pushing the, you know, the culture change in universities they're, you know. And aside from recruiting different sorts of people perhaps on different sorts of contracts they're also putting a pressure on the university to be more strategic.
>
> (Research administrator 1 interview, 19th August 2014)

By having a different remit the IKCs, according to this statement, are part of changing cultures within universities. SynbiCITE has recruited staff with industrial experience. Building large consortia of this kind can be time-consuming (Bruce et al. 2004, p.464). As SynbiCITE

is hosted in an academic institution, but is 'outward looking', it can be understood as a *boundary organisation* in which "technology-transfer specialists thus dwell, Janus-like" (Guston 1999, p.105). However, rather than containing a large population of 'specialists', SynbiCITE has implemented a range of strategies to develop commercially aware researchers. The most visible work by SynbiCITE is in the provision of innovation laboratories and training for researchers.

SynbiCITE has a number of ways that it supports actors to translate synthetic biology. As well as providing meeting rooms, there is also a new DNA synthesis facility.

> SynbiCITE is home to a DNA Synthesis and Construction Foundry which we hope will establish a common framework to build DNA by using an automated robotic system. With a common framework for creating DNA in place, synthetic biologists will be able to scale up the volumes of DNA produced to more easily test their new function.
>
> (SynbiCITE 2015c)

The Foundry is an automated laboratory space for synthetic biology start-ups to be able to design, build and test constructs. The foundry is one of five new DNA synthesis facilities funded as part of the Synthetic Biology for Growth capital fund. One of the aims of the foundry is develop a standard system for building DNA. The British Standards Institute (BSI) can be seen as having identified a lack of expertise and requiring a plan to construct standards in the synthetic biology community:

> In partnership with the Technology Strategy Board (TSB), we've been working with SynbiCITE to develop a strategy for standards in synthetic biology to help create a digital biomanufacturing industry and to accelerate the rate of commercial success using the technology.
>
> (British Standards Institute 2014)

The key point in these perspectives is that industrial orientation is 'embedded' in the overall project of synthetic biology. The idea is that biological innovation will happen in the future because synthetic biology will facilitate a better manufacturing, investment and research culture.

Biological research is presented in synthetic biology as being a product of design (Mackenzie 2009). This is partly achieved through using certain vocabulary. Words more readily associated with engineering, words like 'platform' and 'switch', have come to refer to microbes and their constituent parts. Calvert explains:

> In order to align itself with engineering, synthetic biology makes heavy but rather indiscriminate use of engineering analogies. For example, the word 'chassis' is borrowed from mechanical engineering to describe the cellular context into which biological parts can be put.
>
> (Calvert 2013, p.410)

The hierarchy of "parts, devices and systems" is used, for instance, when actors are explaining synthetic biology to what may be an uninitiated or inexpert audience such as students or academics from other disciplines (field notes, SBLC open meeting, 27th November 2014). In an induction session for a group of undergraduates entering iGEM, a PhD student referred to an ideal DNA construction consisting of a promoter, gene and terminator as a "cassette" (field notes, iGEM training, 15th July 2014). A digital technology metaphor of "plug and play" gets used to convey the idea that biological parts can put together in a predictable way (Isaacs & Collins 2005). This in turn has implications for what needs to be done. To enable assembly in this manner the parts need to be consistent and regulated so they do not need to be designed and made each time from scratch (Arkin 2008).

Analysing metaphorical language can reveal important aspects about how actors understand their world (Lakoff & Johnsen 1980). I argue that the repeated use of this language performs the connection to manufacturing and that this connection has extended beyond the biological. Synthetic biologists mobilise language that aligns synthetic biology facilities and institutions specifically with industrial manufacturing.

Aligning Researchers

There are many new institutions emerging in synthetic biology. These are established in line with the expectations and promises of synthetic biology and in turn reinforce particular visions for the future of the science (Schyfter & Calvert 2015). I suggest that creating a new generation of researchers is a primary goal in creating the new institutions (see section 7.2 for how this contributes to the temporal expansion of synthetic biology). I centre my discussion on SynbiCITE, the SBRCs, the new Centre for Doctoral Training (CDT) and the iGEM competition (see Section 1.2 for a general description and Section 3.2 for my experience of iGEM in the course of this research).

The synthetic biology leadership excellence accelerator programme (LEAP) is aimed towards "catalysing a next generation of leaders in synthetic biology by providing the environment to learn skills for engaging a broad range of stakeholders in the development of the field with a strong ethical foundation for the future" (SynbiCITE 2015d). The international programme is a collaboration between SynbiCITE and the Knowledge Transfer Network in the UK and the Alfred P. Sloan Foundation, BioBricks Foundation, iGEM, National Science Foundation, SynBerc and the Wilson Centre in the USA. The website includes some example strategic action plans from 2012 and insight papers from 2015. Some of the programme outcomes are explicitly 'visions' for creating engagement, partnerships and

training. “Many LEAP Fellows have already begun implementing and refining their plans” (LEAP 2015). Thus, the LEAP partly functions as a development space for ideas of how to expand synthetic biology and ensure its success.

There are a number of actions plans available on the website (LEAP 2015). For example:

- *Enhancing undergraduate education to drive responsible growth of the bioeconomy* (Facciotti 2013)
- *Opening new channels for industry-academic relations* (Lindstrom & Agilent Technologies 2013)
- *Synthetic biology for global health: a problem-driven approach to healthcare innovation* (Tyo 2012)

The 2012 plans highlight the way that proponents of synthetic biology aim to educate students for economic gains, partner various stakeholders and find problems in other societal domains for which they can propose synthetic biology solutions.

One insight paper is titled *Technology is not the Problem* (Ravi et al. 2015). The paper explains that “public engagement is important in the future success of synthetic biology applications” (Ravi et al. 2015, p.3) and that “examining existing technologies and their relative acceptance by the public (e.g. nuclear power, nanotechnology, GM, space exploration), could safeguard against unconscious bias, and reveal proven ideas as to how to communicate success stories” (Ravi et al. 2015, p.4). The authors also imagine:

> …that the synbio community, as it stands today, will create an organisation that tracks how quickly companies using synthetic biology can get, for example, drugs, industrial biomaterials or even consumer products to market compared to competing companies that do not apply systematic, engineering principles to biology.
>
> (Ravi et al. 2015, p.2)

This insight paper describes how synthetic biology needs to be able to prove its efficacy by tracking innovation times, and to effectively communicate successes to 'the public'. The uncertainty of making "consumer products" is signified by the preceding word, "even". This relates to the imaginary of *contained bio-manufacturing* in the previous chapter as synthetic biologists are shaping their field towards making existing compounds. The predominant areas for production include manufacturing chemicals and materials.

The researchers do not question synthetic biology. While they acknowledge that synthetic biology can occasionally answer 'no' to specific applications, overall, they appear to be spreading the message that synthetic biology is good. They argue this can be achieved by proving synthetic biology does commercialisation faster.

Secondly, SynbiCITE offers 'The Lean Launchpad'. This is a twelve-week training programme in which synthetic biology entrepreneurs can enrol and work out a business model for their idea.

> This course will allow participants to gain real world, hands-on experience of what it is like to start a business. It is not a theory based, classroom activity – rather, it is a practical exercise in talking to customers and using these discussions to inform the development of a useful, coherent, relevant business model and product.
>
> (SynbiCITE 2015e)

Both the LEAP and Lean programmes originated in US biotech entrepreneurship training. The LEAP began in 2012 and in 2016 will be brought to Europe for the first time. To underscore the ethical dimension to the training the 2015 course will be held at Asilomar, CA, site of the conference on recombinant DNA held in 1975. The international scope of the training, and its focus interacting with 'real life' customers, further emphasises the particular commercial focus of this arm of synthetic biology.

As part of establishing synthetic biology, the CDT was awarded for a collaborative proposal submitted by the universities of Bristol, Oxford and Warwick. The CDT is funded for five cohorts of overlapping PhD courses and so has a seven-year funding timeline. The aim is that new researchers will be trained in synthetic biology and take that forward into their future working practices.

> The SBCDT will provide five annual 15-student strong cohorts with high-quality and highly practical training in Synthetic Biology that will fill this skills gap and deliver the next generation of internationally excellent researchers and industrial leaders.
>
> (Engineering and Physical Sciences Research Council 2015b)

This addresses the tensions of creating the right *competences* in the previous section. The seven years of the SBCDT is orientated to producing candidates who can drive both the underpinning science and commercial profitability of synthetic biology.

Finally, the structure and implementation of the iGEM competition is partly aimed at producing researchers that focus on applications. iGEM teams must enter their project into a specific competition 'track'. The 'traditional' tracks for iGEM are energy, environment, food and nutrition, foundational advance, health and medicine, information processing, manufacturing and new application (iGEM 2014). In 2014, the competition also listed seven new tracks, including entrepreneurship, policy and practice, and software. Of the 246 teams, 27 entered 'foundational advance', suggesting that most of the work in iGEM is orientated towards application. One administrator commented:

> … to a certain extent, I feel that translation is something which is kind of innately embedded in synthetic biology. So if you look at competitions like the iGEM… you're training people with a very different paradigm to those who are running the show now. There's always kind of a difficulty in trying to allow those people to filter up into the kind of

> upper echelons of, you know, being the stars, star researchers of tomorrow. So, I think, I think… there's two worlds of thought to be honest… So, I think, what they're doing now is great and I think translation is embedded in the younger generation coming up.
>
> (Research administrator 15 Interview, 19th August 2014)

The quotation presents translation as an integral part of the 'design' of synthetic biology. Training researchers disciplines a future generation into considering the uses of their work. The comment also suggests a concern that, as the first generation of synthetic biologists get superseded by researchers who have been schooled in application and market-orientated science, there may be a paradigm shift (Kuhn 2012).

The iGEM competition is particularly important in synthetic biology as it has provided a model on which synthetic biology has been established:

> The idea that whatever the students built went into the registry [and] the registry was provided to everybody the next year, so it's a level playing field [and] in that sense. [Synthetic biology] could bootstrap itself. That I thought was a really good [idea]. The idea that everything was pre precompetitive and open source was a good one… Now that ten years has passed and several thousand, maybe even ten thousand, students have gone through most of them have dropped out of synthetic biology but a minority have now done PhDs and some are even starting their own labs. And of course that means that the profile of the field has been bootstrapped from this competition. To the point that now, the BBSRC in the UK, synthetic biology is actually a research priority and you can get grant funding for it.
>
> (Academic researcher 14 interview, 19th July 2014)

The iGEM competition was based on an ideal for what synthetic biology could be. Undergraduate and postgraduate students from the UK and around the world then orientate their research towards specific problems and many describe their market orientation. The success of the competition, judged by its rapid increase in size and participation, has raised the profile of synthetic biology. In the quotation above, the academic researcher connects

this success to the funding of synthetic biology. By modelling a scientific community with students, by training them and structuring their interactions (Cockerton 2011; Balmer & Bulpin 2013), the field has provided a 'compelling demonstrator' of itself (Frow & Calvert 2013a). This is despite the problems, such as a lack of flexibility in the modular connections, which are inherent in the BioBrick™ standardisation system (Frow 2013).

In conclusion, manufacturing industry is embedded in synthetic biology in various ways. The synthetic biology language choices perform connections to industry. I supplement Mackenzie's point that their vocabulary connects design with life with the notion that it also connects life to industrial manufacturing. The words derived from industry and change life into an entity which can be treated as an industry. "Foundries" and "factories" are some of the key ways manufacturing is embedded in synthetic biology. The future translation of synthetic biology is performed in the way SynbiCITE structures the courses and support it offers. SynbiCITE is "unfolding" (Knorr-Cetina 1997; Knorr-Cetina 2005a) synthetic biology in a specific way. There is an overall push towards automation in order to speed up testing and scaling of research and a push towards encouraging entrepreneurship by training scientists.

5.4 Conclusion

Synthetic biology has emerged at a time of increased pressure on academics to create research 'impact'. Pressure to turn research into economic value in synthetic biology is not within a vacuum. There is a trend, at least in Europe and the US, that academia is being held accountable through various means, particularly auditing (Rajan & Leonelli 2013; Shore & Wright 2004). As academic work is increasingly required to anticipate the future use or application of knowledge and to generate a possible line of revenue, universities and research councils have developed a range of mechanisms to foster commercialisation.

The first section described how collaborations are argued to be an important route to making knowledge relevant. Synthetic biology is under pressure to deliver on synthetic biology's promise to 'impact' in areas of health, fuel and food. Administrators use events and funding schemes to encourage academics to reach out and form partnerships for contract and collaborative research. Section 5.2 explored how, in particular, discussing collaborations (in observations and interviews) turn out to be sites where the differences between academia and industry are enacted. These differences are articulated with respect to the protection and disclosure of knowledge, different research outputs, differences in work vision and timing, and the competencies of researchers. Section 5.3 described how synthetic biology in the UK and beyond has implemented a set of strategies that 'embed' industrial manufacturing into the research culture. This occurs through various training schemes, funding requirements and by aligning synthetic biology with manufacturing through language. By orientating researchers and research to manufacturing, synthetic biology may hope to bypass some of the 'causes of failure' of innovation as identified by industry.

In response to synthetic biology, new formations are required because synthetic biology challenges established boundaries between UK research councils and between research fields. People come together from different fields of expertise in order to realise the goals of synthetic biology. This produces collaborations and also produces other practices and organisational structures. The absence of biological standards can create new entities such as research consortia and the production of a plan to formulate standards.

One of the key elements of this chapter is the way that collaborations themselves are a route to accessing resources. The act of gathering people and institutions, and co-signing proposals, is a way to gain confidence for investment. This means that, in the name of building collaborations to accelerate innovation, proponents of synthetic biology have been

able to secure a large amount of public funds. These have been used to fund research centres, innovation centres and a training centre. Furthermore, these centres are orientated to industry to different extents.

What is also clear is the diversity of actors involved in translating synthetic biology. These include staff in research councils, universities, industry and government. Calvert has noted:

> By making biology into an engineering discipline, synthetic biologists are simultaneously broadening the range of voices that can enter into the discussion of their field. The boundaries surrounding biotechnology are becoming more permeable, and this is opening up synthetic biology to a diverse range of global groups.
>
> (Calvert 2013, p.417)

This is true for commercialisation, too. By making synthetic biology 'translational' and prioritising collaborations the field is 'opened up' to actors seeking to commercialise technology. The way that different groups are enrolled into projects depends on who is attempting to define the problem. Thus, research administrator 3 was attempting to encourage more academics to 'reach out' to industry. This puts the problem of translation as a social one. One apparent solution to this is to increase the chances of collaborations by a range of techniques, which goes some way to explain the proliferation of showcases, bazaars and sandpits across the academic and commercial sector. On the other hand, difficulties in collaborations mean those with industrial experience have instituted training programmes so that researchers are more aware and knowledgeable when it comes to industrial manufacturing and marketing needs. These training practices and institutions shape the form that synthetic biology takes as it grows.

However, before tackling this point in more detail, the next chapter turns to examine how synthetic biology is made translational at the level of the laboratory.

Chapter Six

Cells, Molecules and Engineers

This chapter focuses on the 'lab level' of translation. The two previous chapters focused on the way issues of do-ability, such as aligning with sponsors' needs and fostering academic-industry interaction, have become embedded in the organisation of people and institutions. Here, my focus turns to the material interactions of scientists (Pickering 1995).

I followed a small group of researchers, in what I will collectively refer to as "the skin graft project", as they attempted to produce a synthetic biology solution to a problem in clinical practice. In the skin graft project, actors were involved in organising experiments and components of biological parts to satisfy criteria in the domains of industrial manufacturing and medicine. The skin graft project involved realising these issues in the way the experiments and life were designed. Previous writers have argued that technology can embody power relations (Winner 1989) and that technologies make social arrangements 'durable' (Latour 1991). Latour calls the process of embedding values in technology "delegation" (Johnson 1988; Latour 1993b) (see Section 2.3). This chapter explores the processes of enrolment and delegation in the course of scientific work. I examine how the creation of a particular solution requires the binding together of a heterogeneous community of entities. Some of the themes I discussed in the previous chapters also play out materially in this account.

In section 6.1, I describe the origins of the bioglue project – how the researchers secured funding, what they acquired it for and how, conceptually, they intended to solve the problem using synthetic biology. In section 6.2, I detail how the research progressed and how researchers and microbes collaborated to produce a chimeric protein, which might be able to solve the problem. Section 6.3 explores the difficulties in materially and semiotically aligning viral DNA, bacterial biology and researchers' competencies and theorises these issues as the synthetic biologists attempted to translate technology.

In order to maintain the focus on biological work, I have supplemented quotes with 'rich' technical description (see Section 3.7) to emphasise the material practices involved in translating synthetic biology from a laboratory to, in this case, another laboratory. As an aid, there is a glossary of relevant biological terms at the end of the thesis. Lastly, a brief warning: this chapter contains Figure 14, a graphic depiction of human injury at the start of Section 6.2, on p.248.

6.1 Patients to Projects

Network origins of a synthetic biology project

The Networks in Synthetic Biology (NSBs) were awarded in 2007 to seven collaborations or institutions. As described by Molyneux-Hodgson and Meyer (2009), the initial formulation of one NSB began when two academic engineers decided to create a proposal for the network. This resulted in a collaborative proposal from three primary investigators – a tissue engineer, a chemical engineer and a microbiologist.

An outcome of the discussions, conducted partly during a workshop in the Peak District, was to orientate the network towards solving a clinical problem in hospital surgery. The problem was that the surgical grafting of autologous human cells and tissues to wounds or diseased sites often failed because the cells or tissues failed to bond to the new site's tissue surface. The network proposed to address this issue.

> Using forward engineering tools to generate biological materials via a synthetic biology framework that mimic the basement membrane. This will have major benefits for providing materials for tissue engineering, stem cell therapies and regenerative medicine. We propose to mimic the complexity of the human extracellular matrix (ECM) using microorganism-based synthetic biology chassis as factories to produce and/or modify adhesive or embedding macromolecules and matrices for eventual use in tissue engineering.
>
> (Biotechnology and Biological Sciences Research Council 2011)

The NSB's overarching direction of research was towards producing biomolecules that could be applied to a range of surgical and therapeutic procedures. However, the NSBs were aimed, not at research, but "to develop and establish communication and networking between researchers in the biosciences, engineering and the physical sciences in the area of synthetic biology" (Biotechnology and Biological Sciences Research Council 2007). The NSB ended in 2011 and the RCUK Gateway to Research website lists a single academic publication arising from the NSB. The article discusses the connection of systems biology to synthetic biology (Noirel et al. 2009). The website also lists six projects as outcomes from the NSB. These are:

- Mass Spectrometry Underpinning Synthetic Biology, Industrial Biotechnology and World Class Bioscience
- Utilising Steel Mill 'Off-Gas' for Chemical Commodity Production using Synthetic Biology

- C1net: Chemicals from C1 Gas (A network in Industrial biotechnology and bioenergy)
- ROADBLOCK: Towards Programmable Defensive Bacterial Coatings & Skins
- SynbiCITE - an Imperial College led Innovation and Knowledge Centre (IKC) in Synthetic Biology
- Use of Synthetic Biology in the Development of Bacterial Adhesins for Skin Grafting applications

(Research Councils UK 2015b)

The scale of the various outcomes varies considerably: the grants for these projects range from £25k to £5m. Some of outcomes listed are very large and include either multiple collaborators, both at the institution and between multiple institutions. For example, by far the largest outcome in terms of funding and co-investigators is SynbiCITE, discussed in the previous chapter. The emphasis on community construction (Molyneux-Hodgson & Meyer 2009) is evident in these project outcomes compared to the single research publication.

The "synthetic biology adhesins" (henceforth "the bioglue project") is the only project related to the technical problem addressed by the NSB. According my study participants, the NSB was developed into two further research projects developing ideas for the same problem. (In section 5.2, I discussed how value is realised in academia through the *transformation* of research into further projects.) A researcher described generating the follow-up investigations:

> The two projects that came out were the collagen and the bioglue thing, you know, we did get a grant on the bioglue which it finished and we're trying to do some bits and bobs and see what decide where we go next with it. The collagen idea that came out was included as one of the projects when we applied to the university for this crosscutting PhD

> network… so I guess it's just morphed into that PhD network rather than dissipated, but the[re are] people who were originally in [the NSB] that are still involved.
>
> (Academic researcher 5 interview, 7th May 2014)

The bioglue project aimed to engineer molecules that will "help natural skin cells stick to surfaces and also improve adherence of these cells in a laboratory based skin grafting assay" (Biotechnology and Biological Sciences Research Council 2014).

'The collagen thing' is not listed on the RCUK site. The project was also aimed at creating skin-grafting applications by using "a synthetic biology approach to generate designer collagen molecules using engineered Escherichia coli strains that secrete collagen chains", which "will have major benefits in the areas of tissue engineering, stem cell therapies, regenerative medicine and burns wound treatment" (FindAPhD 2015). It was not funded by RCUK. The collagen project was funded by a university as part of a PhD network focusing on synthetic biology for human health.

In this chapter, I focus on the projects directly related to the NSB. These are the bioglue project funded via a responsive mode grant listed on the RCUK site and the collagen PhD project investigating the microbial production of collagen. What follows is a brief description of the projects and the decisions about which directions to take the work in.

Introducing Flagella

The two skin graft projects emerging from the NSB sought to use existing knowledge about *E. coli*, in particular, the way they make flagella. Flagella are bacteria's 'tails' that move the cells through their environment. This section is a short account of the way the flagella system was described to me, supplemented with additional material.

E. coli tend to produce eight to twelve flagella per cell. Flagella are composed of individual subunits of “flagellin”, a protein monomer. These are synthesised inside the cell and transported to the membrane. At the membrane they pass through the ‘hook’ in ‘type-3 secretion’. The first flagellin monomers pass across the cell membrane and, instead of floating off into the extracellular environment, attach to the outside lip of the channel through which they passed. As each successive monomer passes through the channel and attaches to the lip, the channel increases in length to become a hollow filament, still attached to the external cell surface (see diagram below).

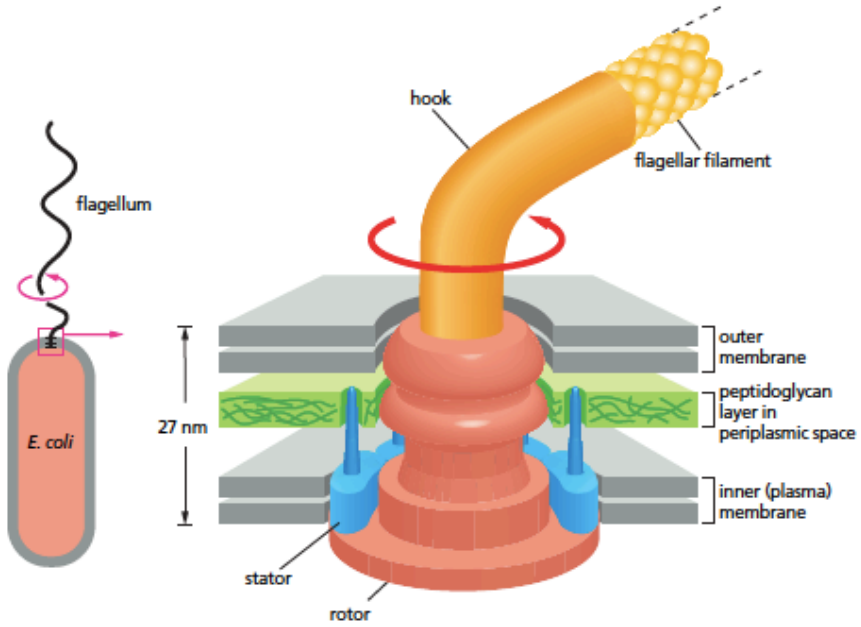

Figure 12. Diagram of a bacterial flagellar motor (Alberts et al. 2008, p.943)

The base of the channel is also able to rotate, powered by the hydrolysis of ATP, and this energy-releasing reaction allows the flagellum to turn like a long stringy propeller. The spinning movement of the filament moves a bacterium through its environment.

Overall, the two reasons given for selecting the flagella pathway were that there was research expertise in the biology and that it would make the next stage of purification simpler. First, one of the researchers in the NSB had spent a number of years working on 'the interesting problem' of flagella assembly. This meant they knew the literature base and were familiar with the kinds of techniques that would be needed by the project. Second, flagella are assembled outside the cell. If the desired chemical was produced inside the microbe then the purification steps would involve breaking open or 'lysing' the cells. Releasing all the other cellular contents would make purification difficult since the resulting 'soup' would contain many different substances that would be tricky to separate. Instead, the filaments self-assemble to make a large macromolecule that can be mechanically sheared off the cell. These can be centrifuged to 'spin down' the cells and leave the sheared-off filaments in solution. To the researchers, the flagella pathway seemed like a good site to reengineer because protein monomers could be synthesised internally and the cell did the job of exporting the monomers and assembling the proteins externally.

Efficient Porcupines

The collagen project sought to reengineer the flagella system in two main ways. One of these ways was to make cells that secrete a non-native protein, collagen. The other line of engineering was to increase the number of secretion points on each cell so more proteins could be manufactured. The aim was to use the bacteria to produce a human protein that could then be purified and perhaps, in the future, be used in skin grafting and stem cell procedures.

The first element of the project was to engineer *E. coli* to produce human collagen. To researchers, collagen and flagella had similarities. Human collagen, much like the native

flagella, is constructed from subunits which self-assemble into fibres. The researchers reasoned that if it was possible to express a human gene in bacteria, it would be possible to export the subunits through the flagella type 3 secretion pathway and have the units self-assemble externally, thus having the benefits of more simple purification procedures. The process of engineering therefore required both expressing the subunits and having them 'tagged' in such a way that the bacteria would be able to move them the internal membrane surface where they would be transported across the membrane, through the 'hook'.

In engineering cells to produce human collagen the researchers encountered several problems. One of these was whether the researchers could know whether subunits were being expressed without them being exported. In other words, if they were being expressed but not transported, then it was a problem with the 'tagging' for transport – less of a concern than total non-expression. The researchers undertook many Western Blots (protein assays) to try to determine whether the collagen subunits were being expressed. Another problem involved the production of the subunits. Collagen is made up partly of a proline derivative and the cells were thought to be using proline for their own proteins. The researchers devised an experiment to 'shock' the cells into using proline to make collagen by using a high concentration of proline in the growth medium. This did not appear to have the desired effect.

The second investigative strand involved trying to make the bacteria have the ability to make more flagella. In laboratory conditions *E. coli* produce eight to twelve flagella. The researchers felt that, in order for the microbe to be a product that could interest industry by being an effective 'factory', the *E. coli* would need to be able to produce many more flagella and so be able to make and export a far higher volume of collagen subunits. This was jokingly referred to as 'making porcupines'. The expression of more channels in the membranes was problematic. There seemed to be difficulty in expressing enough channels

to make the project worthwhile, yet not making so many that the bacteria were unable to survive. The researchers found they had to balance resources for what the bacteria needed to live and what they hoped the bacteria would be able to do. In line with an overall aim of synthetic biology, this element of the project was geared to create a 'modular platform' that could be used to display and export other proteins and so be useful in a wide range of other applications.

Sticky Chimeras

The bioglue project focused on adhesins and was aimed at reengineering the flagella pathway so that instead of being composed of flagellin monomers cells the cells would create a filament that would have 'sticky' elements along its length (see Figure 13 on the next page). The project was "a pilot/proof of principle type project" (Biotechnology and Biological Sciences Research Council 2014) which aimed at improving the adherence of cells in tissue models.

> We aim to produce a 'bioglue' targeted at attaching split thickness skin grafts or cultured cells to collagen I. This bioglue must increase adhesion in these situations and persist in the body long enough (5-10 days) for adhered skin cells to begin remodelling wound beds, promote vasculature and ultimately restore barrier function. Our approach is to use a synthetic biology pathway to redesign the bacterial flagellum to produce adhesive protein fibres.
>
> (BBSRC 2015)

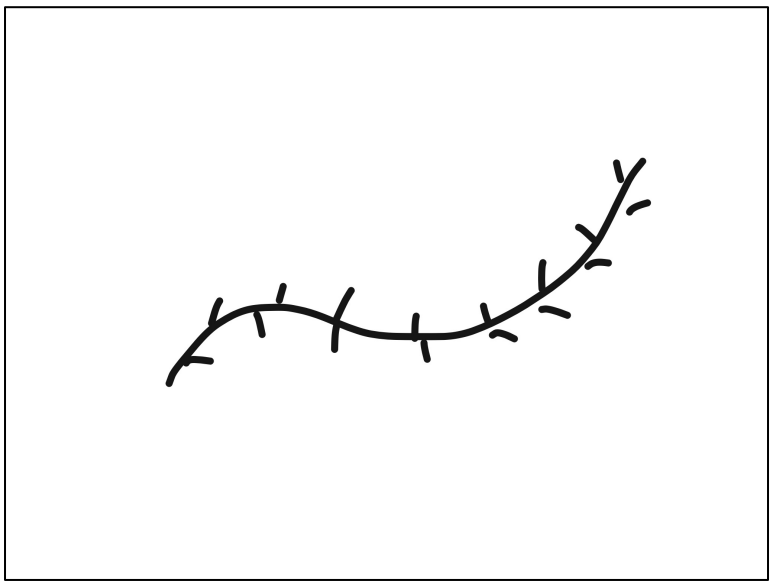

Figure 13. Sketch of a bioglue molecule
(Redrawn by the author after meeting, 10th January 2014)

The sticky filaments could then be removed from the microbes, purified and used to help temporarily 'glue' human cells into place and allow them time to create their own bonds in order anchor themselves to the experimental site. The researchers imagined a protein that would contain some native flagellin subunits and also the 'sticky' sections, which would be copied from another organism, perhaps mammalian or viral. This is known as a chimeric protein. A chimera, to molecular biologists, is a protein that is formed from splicing together genes coding for different protein subunits from different organisms.

The researchers also claimed a range of possible future impacts in terms of biomedical research, policy regulations and career advancement for the postdoctoral research assistants. One further impact was that the researchers intended the bioglue would be translated to industry through a specific collaboration.

Overall, the researchers constructed a modular approach: the two projects could, in theory, be put back together. The 'porcupine' bacterial strain might be able to efficiently produce 'sticky chimeras' in large volumes that could glue cells in place.

6.2 Molecules to Tissue (Engineers)

Performing a therapeutic need

The researchers designed the projects following discussions with tissue engineers. More specifically, the problem they were attempting to solve was that in certain types of wounds, such as burns, skin cell adhesion is problematic because the 'wound bed' lacks many key macromolecules.

> … cultured cells usually fail to attach well to challenging wound beds, as are often present in burns or chronic non-healing ulcer patients. These wound beds are characterised by poor vasculature and a dearth of extracellular matrix proteins that ensure attachment of the epidermis to dermis (i.e. Collagen IV, VII and laminin). They contain predominantly Collagen I, are rich in degradative enzymes, sometimes infected and usually poorly vascularised. Even conventional split-thickness skin grafts can fail to attach well on such wound beds.
>
> (BBSRC 2015)

The above description moves quickly from patients to skin to molecules. Despite the technical, molecular focus of their daily work, the researchers contextualised their work as a possible solution to problems with skin grafts. At the opening of talks and presentations, and in the introductory text to conference posters, they introduced themselves and the title of their project. Then, they led the audience to The Problem. This took the form of displaying

photographs of seriously burned legs (see Figure 14). Mottled red limbs pictured on green surgical fabric.

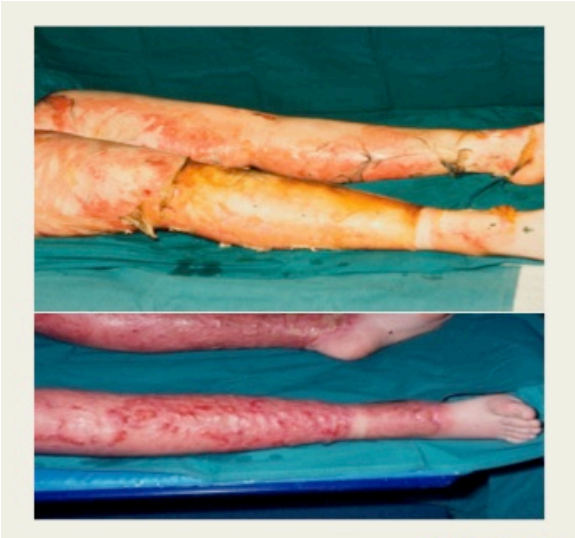

Figure 14. Photographs of burned legs
(Part of slide from presentation, 10th January 2014)

Two things were particularly notable. First, the title slides of their presentations were often textual, or images of microbes or molecules. The researchers did not warn the audience that graphic slides were coming up. As the burn images were important to the way the researchers framed their investigations, the pictures usually featured on the second or third slide of a presentation. Each occasion they were displayed in a matter-of-fact style, which I found striking. Although I saw the pictures repeatedly, I was nevertheless surprised each time by the sudden appearance of disembodied, wounded legs. The second thing, which I asked about, was where the pictures had originated. How did microbiologists have access to these images? They had been copied from a presentation used by some of the collaborating tissue engineers. The presentation concerned a tissue engineering intervention in the process of skin grafting.

The researchers' iterative use of the pictures re-asserted the medical goal of the project during each presentation. The surgical details about patients, as happens in my account, quickly gave way to molecular and microbial concerns. The presence of the pictures also recalled the collaboration. The tissue engineers had experience of collaborating with surgeons and with setting up biomedical companies and were therefore important to the imagined futures of the porcupines and chimeras. The researchers 'performed alignment' with the original skin graft problem by repeatedly showing how their research, creating a bioglue and human collagen, was relevant to the adhesion of skin cells in surgery.

Gene Candidates

The bioglue project used a modified bacterial strain that researchers had created during the NSB (BBSRC 2015). The flagellin monomer is normally composed of four subunits. The bacterial 'device' expressed only two subunits meaning the researchers could display other peptides in the middle of the flagellin protein. By searching existing literature the researchers had found four possible genes that they could express within their redeveloped *E. coli* flagella to create the chimera. The four candidate genes coded for:

- Human laminin binding protein
- Hydroxyapatite binding protein
- Sialoprotein binding protein
- *Streptococcus aureus* collagen binding protein

The first three proteins are all derived from the human genome. The last is derived from a bacterium, which has become notorious for its methicillin-resistant form – MRSA. This

collagen binding protein is key to the microbes' mode of infection and binds with high affinity to collagen 1 (there are many types of collagen).

The researchers intended to capitalise on the existing knowledge of infection and appropriate it for the purposes of human health. The bioglue project, and synthetic biology more broadly, are aligned with a larger observation about biotechnology.

> Biotechnology seeks to instrumentalise the already instrumental capacities of living entities along particular lines… This surplus value is produced through setting up certain kinds of hierarchies in which marginal forms of vitality—the foetal, the cadaverous and extracted tissue, as well as the bodies and body parts of the socially marginal—are transformed into technologies to aid in the intensification of vitality for other living beings.
>
> (Waldby 2002, p.19)

The researchers took sequences of bacterial DNA and, by re-contextualising the DNA through the processes of the bioglue project, repurposed it for human health rather than human pathology. Yet, it was the existing flagella components of the chimera that proved most problematic in terms of aligning the bioglue with medical applications.

Preparing An Adhesive

The potential adhesive needed to satisfy two main criteria. Primarily, the researchers needed make a bioglue that would work in a tissue model. However, the bioglue needed to be made in such a way that it could be of interest to industry. In other words, the preparation steps should be scalable and industrially viable. This process is explored in this section.

The researchers needed to express the candidate genes in the modular system they had designed. The genes were spliced into plasmids. Microbes were then transformed by

inclusion of these novel plasmids into the cells, which were then grown in cultures. Making mutants of this kind takes a long time and so finding out whether one can construct what one hopes is often a slow process. The first point was to establish whether the chimera was exported by the microbes. This was a key step in the process given the researchers' original identification of the flagella system as a production-export mechanism.

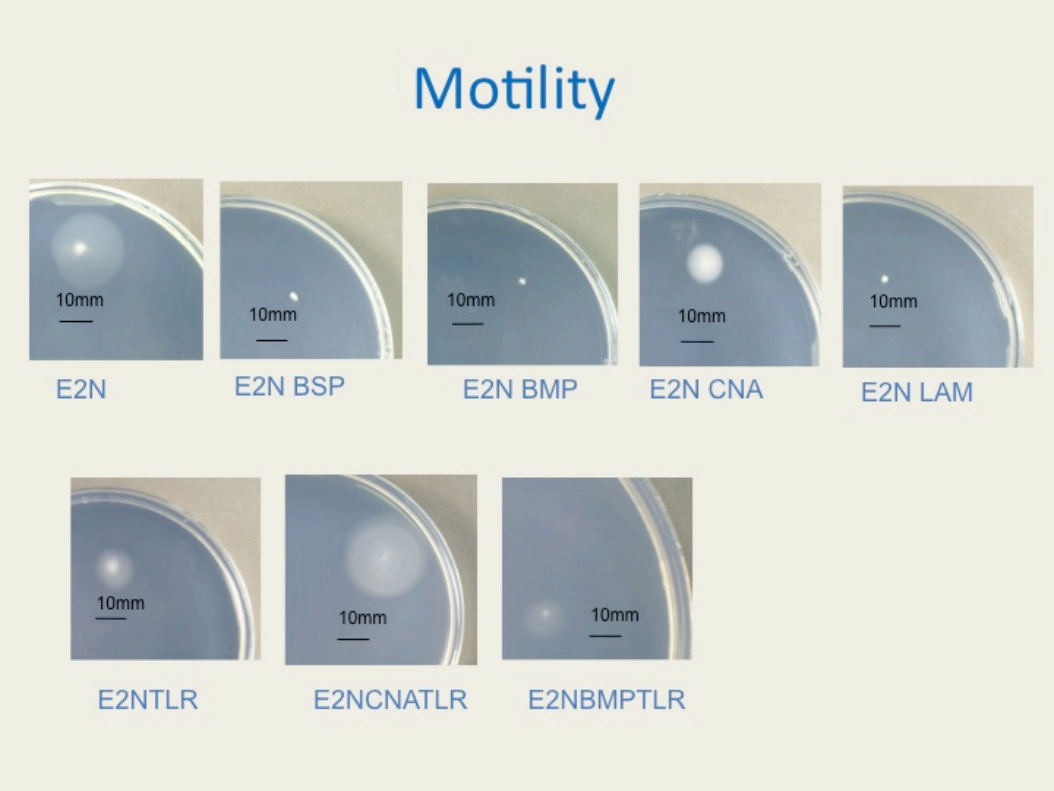

Figure 15. Slide showing bacterial motility in a growth medium of two controls and six mutants (part of slide from presentation, 10th January 2014)

The researchers devised an assay they could use to select which genes they would investigate further which I called 'the swimming test'. First of all, this involved growing a culture of mutant bacteria. A small culture of bacteria was then added to a petri dish with agar and left for 24 hours. If the bacteria were mobile they would be able to move through the growth medium and would disperse more quickly than bacteria that did not have functioning flagella. The selection took place by measuring the halo around the initial colony.

A small corona would mean the cells were unlikely to be able to move while a larger one meant that cells could move and probably had functional flagella. Using this method, the researchers selected colonies with a larger halo for further investigation (see Figure 15 on the previous page).

The researchers recognised this assay was flawed in the resolution of answers it gave. Swimming bacteria would have flagella that facilitated movement. In other words, the subunits were made in the cell, exported, assembled and the filament was able to rotate. Instead, there were several possible reasons why bacteria might not be able to swim. The subunits may not be made, may not be exported, may not self-assemble or may not rotate. The assay, however, only selected between assembled, spinning filaments and everything else. The 'not-made', 'not-exported' and 'not-assembled' results would not be taken forwards because of the anticipated difficulties in purification. However, the swimming assay would give a negative result for a situation where the filaments self-assembled but were unable to rotate. This was not thought to be a problem because the turning mechanism would be attached to the filament and so the filament would have to mechanically prevent rotation, a situation the researchers thought unlikely. At any rate, the project had only a short funding timescale and so the quicker and easier the assays could be developed to identify 'goers', the more quickly the project could be advanced to purifying the molecules. Following repeated testing and applications of the assay the researchers selected two of the four mutants for investigating further. These mutants contained DNA of the *S. aureus* collagen binding domain and the human hydroxyapatite binding domains.

The collagen binding was hoped to act like a double-sided sticky tape and bind both to collagen 1 produced by the cells and to collagen 1 that would be in the tissue model assay. The other route, with the hydroxyapatite binding domain, was hoped to help with bone grafting though this became less important because the project was nearing the end of the

fourteen-month funding as the researchers felt that it was best to concentrate on demonstrating the function of the *S. aureus* chimera in cell and tissue models.

Producing the bioglue also required researchers to overcome mechanical problems. One of these was that the flagella did not shear away from the cells as easily as expected. One suggestion was to use an old stainless steel "french press" which, with its vertical plunger, looked like a giant cafetière with a small tap at the bottom. The researchers were able to press the plunger and, as the cells were pressurised through the narrow outlet, the acceleration sheared the flagella off the cells. Perfecting this required practice and subsequent centrifugation – which also needed to be refined because 'of difficulties with pelleting' – but in the end the researchers were able to generate a suspension to form the bioglue. The articulation of existing equipment through action and forming new plans has been understood as *tuning* (Pickering 1995) and *tinkering* (Knorr Cetina 1981).

The researchers had thus far been able to develop the project in their own lab. This had involved one researcher learning a new technique of mammalian cell culture in order to use the cell line to test the adhesion of mammalian cells to petri dish plastic. The researcher felt the time they spent learning was a minor accommodation – the technique was similar to bacterial cell culture and the growth media came ready-mixed (academic researcher 4 interview, 4th December 2013). The researcher did this by giving the cells time to adhere to the plastic in a control and comparing with a petri dish smeared with a thin layer of the adhesive.

The articulation work of learning new skills meant the cellular work could continue within the synthetic biology laboratory space. However,

> … the next stage, is we have models for wounds in tissue engineering and so the next stage would be that we show it works in tissue in a culture dish. Once it works in tissue in a culture dish that's the time at which we start looking at getting home office approval for animal experiments to see if it'll improve healing at an organism level. Also, we've gone [through] like a funnel of levels to show how it works. We've shown it works at a molecular level, we've shown it works at a cellular level, and we've shown that it works at a tissue level, so we've got a really good chance that it will work at an animal level.
>
> (Academic researcher 4 interview, 4th December 2013)

The researcher conceptualised the project as succeeding stages of increasing complexity. This imaged future sequence functions as an alignment with developing medical technologies. Overall, the regulatory process involves demonstrating safety and efficacy of interventions in various models, from molecular to tissue to animal. Once the evidence has been collected at these levels, the research can then be developed to human trials. However, the current drive for medical innovation is within medical devices rather than drugs because of the less onerous regulatory structures. Structural proteins, like the bioglue chimera, could well fit within the device market regulations (academic researcher 6 interview, 5th February 2014). However, because of the complexity, moving testing into mammalian tissues would require the expertise of the tissue engineers. The tissue engineers marked both a key step in imagining the development of the technology and, simultaneously, they were the end point of the bioglue project's scope.

Immunogenicity

The bioglue solution had an inbuilt problem. Overall, the researchers felt they were moving toward success by showing that the engineered flagella would bind with a thousand times greater affinity to collagen on cells (academic researcher 4 interview, 4th December 2013).

However, the choice of engineering bacterial flagella meant that, in order to preserve alignment to skin grafting and human medicine, more material work would need to be done.

> Whenever I talk about this project to a qualified scientific individual they say "but it'll never work because flagella are immunogenic…" Flagella are well known throughout medicine as being a protein that stimulates the innate immune response. Now this could be a bad thing in wound healing. It could cause rejection of skin grafts and so forth so we've got some… assays to find out a) how much the immune response is stimulated using isolated mammalian cells and also b) whether a novel version of flagella that's been genetically engineered to be less immunogenic is indeed less immunogenic, having shown already that it still works.
>
> (Academic researcher 4 interview, 4th December 2013)

The researchers were concerned that their choice of system contained a mechanism for causing an immune response in patients who were already ill. Immunogenicity is an undesirable quality for any medicine and can justify terminating product development. This feature was recognised at the outset since some aims of the project were to "improve both yield, purity and efficacy while also reducing any potential immunogenicity" (BBSRC 2015).

The tissue engineers were involved for a number of reasons. Initially, they had identified the cell adherence problem, which offered a way to organise the project. They had expertise in creating tissue models and so could build a model in which to test the bioglue. They also had important experience working with surgeons and forming biomedical companies. One of the collaborating tissue engineers described their experience of generating a product that had to be reformulated from polyvinyl chloride (PVC) to use medical grade silicon because of late-stage testing (I include the whole quote because it begins humorously yet makes a serious point about developing devices).

> Once you've made something that then has to be tested in say, animals or people that's when you've got to start thinking, "should we really be making out of neat poison. You

> know. Should we take the spike? Should we remove the spike? Should we stop making out of the material that's horrifically toxic," and that kind of thing because you will eventually run into the prob[lem]… the MHRA will look at it and say, "well we'd like it not to be made of poison" … It seems flippant but we made [X] using PVC and it was PVC that was clinical grade. It was clinical grade, useful for packaging and making simple devices that could be in contact with people. But when we sent it for sensitivity testing – we had to have it tested to see if it would cause any immune response or inflammation or in any way make the people sensitised to it. And we thought we're on a winner here. Of course it's not going to, it's already been tested, but we have to do it again. And we found that the PVC we were using, it did, it failed the sensitivity testing, you know? The animals and the cells it was tested on showed a response and it was because it was leaching phthalates which are chemicals, they're plasticisers that are used in the formation of the poly, the PVC, there's hardly any of it there but enough of it was coming out of the plastic the way we were using it to have an effect so suddenly we have to reformulate the product and use really expensive medical grade silicone.
>
> (Academic researcher 6 interview, 5th February 2014)

The discovery that PVC turned out to be unsuitable for the product highlights the contingent nature of innovation and 'getting it to work' in a medical setting. The story works to show the important concerns about sensitivity testing and the diligence that needs to be employed to meet regulations in order to make a successful medical application. If the synthetic biologists wanted to produce a bioglue then it would have to pass immune response tests, and these could be a 'stopper', or involve expensive redevelopment. Since the flagella *were* the bioglue, this could mean starting again from scratch.

A strand of the research, which proved time-consuming, was to find a way to make flagella less immunogenic. The researchers found a DNA sequence in the literature. This also proved to generate a positive swimming assay for the *S. aureus* domain but, unfortunately, not the bone morphogenic protein (see the bottom row of photographs in Figure 15).

By attending to the safety aspect of the bioglue earlier in the project the researchers sought to maintain the problem's do-ability. At this stage, with a month of funding left, time was running short. The researchers focused on developing the bioglue in tissues and decided that demonstrating the lower immunogenicity in a model would be done only if there was sufficient time. However, the imagined future application was in medicine. Without addressing the immunogenicity it may also have been be more difficult to recruit the tissue engineers and access facilities to test the bioglue in a wound model. The bioglue researchers needed to work on the immunogenic feature of the flagella because doing so maintained alignment with the tissue engineers, with skin-grafting applications and with a future for the bioglue in medical surgery.

"On the cusp" of translation

In the final few weeks of the project, and in collaboration with the tissue engineers, the researchers began testing their adhesive in tissue models. One assay, devised in the final week, was designed to show that cells in a homogeneous solution would clump together with addition of the adhesive. Back in their own laboratory, with a day left on the staff contract, the researchers used a keratinocyte cell culture line (HaCaT) and tried binding these to a bioglue coated plate. 3% of these cells were found to have bound to the bioglue plate after 60 minutes compared to 0.5% in the non-bioglue plate (field notes 10th January 2014).

These results were significant but had two problems. The first problem was the binding percentage was based on only one repeat. Biological work is conventionally carried out in triplicate so variability and precision of an experiment can be assessed. In the final project meeting, several of the researchers discussed whether it was problematic having only one

repeat. They decided it was valid for their purposes. The second problem was that HaCaT cells are an immortal cell line and have survived in laboratories in certain conditions. One of their properties is that they adhere to plastic. Again, this was deemed not to be problematic due to the controlled experimental procedure. From the point of view of gluing cells to wound sites, these results were positive indications.

> … And I think what we've found is that there's a small increase in the percentage of attachment. I think, the percentage, I mean often the percentage of attachment is about one percent so, a little [bit] of an increase in that, like about 2 or 3 per cent would be great. And it looks like that's roughly the order of the magnitude of increase that we're getting. So, I mean, it doesn't seem like it's a barn stormer but, that's, if you can get two or three times the number of cells attaching they can start modifying a wound environment.
>
> (Academic researcher 6 inteview, 5th February 2014)

In the end, due to the time constraints, the researchers had only one biological repeat that they were comfortable sharing the results of, but were concerned that the results, without repeats, were not robust enough to convince others. In the final meeting the project was "frustrating" because it was "on the cusp" (field notes, 10th January 2014). In Fujimura's words:

> While conducting the tests, however, the researchers ran into 'glitches'. Nature is recalcitrant; it does not always do what it is 'supposed' to do. Experiments often fail, and presidents of companies get impatient when a product is not ready by established deadlines. Colleagues may disagree with interpretations of results. In sum, a project - that is, the development of a problem from inception to solution - rarely runs smoothly.
>
> (Fujimura 1987, p.171)

By the end of the project the main goals had been at least partially met. The researchers had been able to produce a bioglue by purifying modified flagella produced by bacteria. They had improved the efficacy of the NSB attempts. Theoretically, they had been able to reduce

the immunogenicity of the flagella but had not tested this satisfactorily. They had also been able to test the bioglue in a solution of cells that was somewhere in between cell and tissue scale. The project has been the focus of a number of talks and posters but no publications to date.

In this section I have explored how the researchers articulated and maintained alignment in their rhetorical and material practices. In one way, the research projects were aimed at producing biomaterials efficiently, and in a way that could function in industrial manufacturing. This was achieved by working towards an easier purification step. On the other hand, the researchers maintained alignment with a surgical application. They worked towards this by repeatedly referring to the clinical problem, improving the binding of the bioglue and attempting to reduce its immunogenic properties. The difficulties of articulating and maintaining alignment through these different channels are explored in the next section.

6.3 Containing Bioglue

In this section I argue that, as part of their enrolment strategy (Callon 1986), the researchers inscribed values into the DNA of the bacteria using different modes (Latour 1991). The enrolment of the bacteria proved successful over the project. However, the enrolment of the other actors was problematic. Their collaborators seemed unaware of the complexity of the problem and so, in the view of the researchers, did not seem to devote enough resources to the project.

Skills, time and materiality: "You've gotta bring all that together"

I will now discuss some of the processes and tensions that arose in the project and the problems of engineering heterogeneous stuff (Law 1993). In the following quotation a synthetic biologist, who was at another institution, described their experience of problems in trying to move from molecules to patients in a different project:

> I wanted to go and do something more translational… the problem is you start hitting brick walls. This is what you'll find all the time. So, first of all, we need to be able to produce this these proteins in large enough quantities that cell biologists can basically just throw them, well not down the sink, but that sink via doing a whole load cell biology science. So the, as a protein engineer or protein designer I'd be quite happy with a few micrograms of material to work with. These guys need grams. So all of a sudden we've gotta scale up by a million-fold. To get enough material to do some cell biology work. That's the first bottleneck. The second one is working with people that have er, not only cell biologists, cos you're trying [to] translate cell biology into the clinic, but also that are clinically minded. And the second bottleneck we've found is that lots of cell biologists are just like us, basic scientists. They wanna know about how cells respond on these gels we've created. This fibrous materials we've created… so we're still a step away from the clinic and it's only now that we're starting to talk to the clinicians and say well what do you need?… And they'll say, oh, I need autologous cells from the patients, and need your gels, and I need a sprinkling of cell biology to make it work. So you've gotta bring all that together. So there are many roadblocks in the way of actually doing that piece of work.
>
> (Academic researcher 15 interview, 28th August 2014)

In order to work with other groups the synthetic biologists need to be able to meet their requirements. It is fine doing things at a given scale and with certain values. But 'translating' in this context means aligning scaling up work in terms of volume and mass. The actor identified scaling, medical use and unanticipated requirements as points where alignment needs articulating. As the 'failure story' of the electric vehicle *Aramis* shows, bringing together different things in order is difficult (Latour 1996), which is important to bear in mind

as the work of translation involves creating complex alignments that can be difficult to manage and fulfil.

Returning to the "skin-graft project", the synthetic biologists worked to align their problem with a varied set of entities, including:

- The work of the earlier NSB
- RCUK and universities by addressing both a 'real world application' and trying to continue to build a 'critical mass' of researchers
- Industrial manufacturing
- Bacterial and viral DNA
- Tissue engineers
- Surgical practice

As I have detailed in the previous sections, the researchers maintained alignment to different domains by reorganising their experiments, tinkering with life and learning new skills.

Unfortunately, from the perspective of the synthetic biologists, the tissue engineers were not fully committed in terms of time and resources to the project.

> The link up with you know with the tissue engineers hadn't worked as well as we'd hoped because I don't think they really realised quite the scale of what we wanted to do and so when we came to actually do those experiments at the end they were like, "oh, we've only got enough time and people to just do it once..."
>
> (Academic researcher 5 interview, 7th May 2014)

This highlights a difference in the division of the complexity of knowledge work. Instead, from the perspective of one of the collaborators, they would have preferred the bioglue to be in a more advanced state of development:

> Once they've [the synthetic biologists] worked out exactly what to make the problem will then be working out how to scale it up and trying to get it into some in vitro testing and then some in vivo testing to show that it does what you say it's going to do. I can make something in the laboratory that will do a job but it may not have a clinical application because you know, it's also made of solid poison.
>
> (Academic researcher 6 interview, 5th February 2014)

The collaborators thus wanted a defined object that could be scaled up in terms of volume and tested for safety. The synthetic biology technology was not yet 'packaged' sufficiently to turn it into a 'technical object' from the perspective of the tissue engineers (McGivern & Dopson 2010).

Similar to the notion of *phasing* I described in Section 5.2, academic researcher 5 explained that the tissue engineers did not understand the researchers' ambitions. The researchers were tackling a complex problem, but the tissue engineers' commitment in terms of resources was low. Thus, academics were thought to engage with long, complex problems whereas their industrial collaborators wanted solutions quickly. Despite the efforts to materially maintain alignment during the project, it was likely that follow-up funding depended on the continued enrolment of the tissue engineers. This is an additional problematic on top of the issues with engineering the viral DNA into the bacterial plasmid, successfully culturing the cells and shearing off the flagella for purification. The product was still in the process of being 'materially defined' (Rheinberger 1997) and so was not in a state for the tissue engineers to be able to use it.

A connected issue, which also relates to Section 5.2, is about the right *competencies* being available:

> It's all new and you're in a new area there's almost having somebody with the skill set say to be able to do the molecular biology know everything about collagen which even I don't know and the tissue engineering testing. There probably isn't a person like that and so we tried to do it you know with a person that had some of that skill set and who did their best but, with the best will in the world, they probably couldn't make… we should have had some better insight into that but it's easy to look back. Obviously. You know you just wanna get stuff going and have a go but you know. Maybe it was always gonna be really difficult to expect one person to be able to do all those things and that's the truth probably.
>
> (Academic researcher 5 interview, 7th May 2014)

In retrospect, the bioglue project was more ambitious than the researchers had initially realised. This is despite one researcher developing new skills including using the French Press and mammalian cell culture. Furthermore, the tissue engineers were required for their competencies in making tissue models. It seems these capabilities did not become available soon enough. The project ended without convincing results in models at tissue scale.

Alignment also had a material component whereby futures are coded into technologies (Akrich 1992). Here I focus on the alignment of synthetic biology through the manipulation of *E. coli* with both manufacturing and medicine.

One of the project aims was to use synthetic biology to address a clinical problem. This supports the existing medical technologies that are used in treating burns. It says, 'the current interventions are on the right path and require refining, rather than rethinking'. By generating a bioglue the project cements the existing arrangements of medical and patient practices when it comes to burns treatment. It prescribes an existing order within its structure of the future. Furthermore, the researchers attempted to maintain this alignment by

inscribing medical needs in the project. They addressed efficacy by selecting the chimera that promoted the most molecular binding. However, the bioglue seemed incompatible with a medical future. They addressed safety by reengineering the flagella with the aim of reducing the immune response. In this way, they materially aligned their project with a future of medical regulations.

At the same time the project was designed to manufacture as pure a product as possible, and to do that as efficiently as possible. This meant that the flagella system had been selected as a viable site of modification. The researchers interpreted the existing biology as being able to deliver on these manufacturing needs. They inscribed the manufacturing possibility on the bacteria from the outset and attempted to 'optimise' this inscription in the course of their work. The bacteria materially incorporated the alignment for both industrial manufacturing and medicine.

Finally, the researchers collaborated with the tissue engineers and co-designed the assays meant to test the efficacy of the bioglue. They broadly agreed on the meanings of the test results: the additional 'stickiness' was not a "barn stormer", but it was efficacious and could be worth pursuing. Both researchers and collaborators were concerned about the effects of flagella on an immune system. The immunogenic properties, even if they could still be reduced, could still be problematic as soon as the product entered sensitivity testing. At the time I ceased collecting data, the skills, materials and meanings of the project were not aligned in such a way as to facilitate a transformation of the project. Innovation had reached a hiatus.

Secure synthetic biology

The researchers designed and manufactured a bioglue that, in their eyes, worked at the molecular level. As Mackenzie (2010) notes:

> Rather than separating out ethical–social issues from the doing of the science, intensification of design generates concrete entanglements and partial connections (Haraway, 1999) between sciences, business, state-power, popular and media cultures.
>
> (Mackenzie 2010, pp.195–6)

Entanglements and connections were materialised in the design of the bioglue project. The bioglue partially entangled bits of DNA, humans, bacteria, laboratory equipment, tissue engineering knowledge, medical device regulation and industrial production. Researchers inscribed the manufacturing and medical goals into the bacterial DNA. On the one hand, these were already there in the sense the bacteria provided the starting mechanism of flagella export and assembly that could be easy to purify. The selection of the flagella was made in order to produce a protein that was easy to purify. This was hoped to be a modular platform that could be used to display other proteins. In so doing, they aligned the project with the overall synthetic biology project of standardised systems. Flagella were also selected because the researchers could imagine a way to optimise production by increasing the number of hooks to create ‘porcupines’. On the other hand, the researchers materially inscribed ‘efficient production’ and ‘medical efficacy’ through their practices and so the bioglue project incorporated values for both industrial production and medical intervention.

The trouble with flagella was they stimulated an immune response in mammals. This causes a problem if they are to act as the backbone of a sticky molecule to be used in surgery. In these terms, the ambitious nature of the bioglue project is a function of academic funding requirements and the likely avenues for dissemination – novelty is a priority for making

science fundable and marketable (Fujimura 1987, p.171). The projects required a broad range of skills from the researchers. The resource constraints, including project time and the competencies of other people, proved difficult to manage.

The researchers used further synthetic biology techniques to attempt to solve the problem and maintain alignment with medicine. This involved rewriting the flagella DNA with what was hoped to be a sequence that would reduce an immune response. Regardless of the lack of experimental proof in the project, this activity was an attempt to preserve the alignment of synthetic biology with medicine within the bacterial plasmid DNA. Furthermore, a central connecting point between the researchers and bacteria, the modified flagella, was not viable in a future medical scenario. In this way, the imaginary industry of *contained bio-manufacture* in Section 4.3 played out materially.

The bioglue molecule, with its immunogenic properties, still needed to be contained. It was an innovation too disruptive to be released. This is a material realisation of the imagined industry of “contained bio-manufacturing” I explored in Section 4.3. Synthetic biology can produce synthetic versions of existing compounds if the fabrication process is secured and any novelty kept under control. In this project, the synthetic biology novelties in terms of molecules and cells, are not releasable. Synthetic biology remained materially contained in the petri dish and conical flask.

6.4 Conclusion

In this chapter I have focused on the work of alignment at the level of a laboratory. Researchers maintain and articulate alignment with rhetorical, pictorial and material work. The very sequence of DNA in this project had been delegated duties of alignment. At the

same time, nature resisted or facilitated only certain kinds of formulations, and so had to be accommodated (Pickering 1995).

Translation appears to be dependent on actors aligning different strands of the world. Materially, if cells do not sick or if bacteria do not survive, there can be no translation of a synthetic biology bioglue. Skills and abilities need to be available at the right times for translation to happen: for assays to be done, data made convincing and for meanings to be aligned. Thus, *phasing, competencies* and *imaginaries* interacted and were salient to this particular academic-academic collaboration. The bioglue cohered mammalian cells in the laboratory. But, it failed to create adherents among the wider community. Synthetic biology's bioglue remained contained.

Chapter Seven

Doable Research, Multiples and Vulnerabilities

This final chapter summarises the answers to my research questions and then details two theoretical contributions to the STS field. The chapter is also an experiment in "academic minimalism" described in Section 3.7. The style is deliberately sparse, yet additive. In so doing, I aim to 'layer' the arguments laid out earlier in the thesis to contribute to overall themes of multiplicity and coherence. It is thus a performance of a fractal reality (Law 2002) and, where my *Introductions* was a series of connections, this concluding chapter might be considered as multiple extensions.

Throughout this thesis I have explored many different versions of translation. Starting with a dictionary definition, translation can entail transferring meaning between languages such as French to German, or information between mediums like DNA and RNA. Translation can also be the movement of bodies in mathematics and, in theology, formally moving objects and people between sites. In academia and innovation, translation can mean the reshaping of research (Edge 1995) and alterations to sociotechnical systems (Williams & Edge 1996) to suit other contexts. In biomedicine, the term "translational research" suggests moving knowledge between laboratory and clinic (Woolf 2008; van der Laan & Boenink 2012; Cooksey 2006). In STS theories, the translation metaphor comes in many guises, such as in *co-ordination work*, when actors use correlation studies to move between ultrasound readings of pumping blood and angiographs of blood vessels (Mol 2002, pp.72–85). Or, in ANT, where actors translate the interests of others into their own projects (Callon & Law

1982; Callon 1986), or when they delegate/inscribe actions and morals to technology (Akrich 1992; Bijker & Law 1992; Johnson 1988; Latour 1991; Latour 1992), or when innovation practices transform objects (Law & Callon 1992), or the process of perceiving a world of connected hybrids as separate, individual objects (Latour 1993b). All these forms of translation involve versions of movement and change.

A limitation of an ANT type approach is knowing when one is at the edges of a network and so deciding what is 'in' and what is 'out' (McLean & Hassard 2004). While I made every effort to follow translation in synthetic biology, there were points when the research trail appeared to peter out. Furthermore, the final work thesis was also shaped by what was pragmatic and possible – it had to fit various institutional timings and requirements. These two points necessitated various omissions and exclusions. For instance, the thesis would likely have been different if the methodology had prioritised comparison of 'cases' of translation, or if I had been able to extend the fieldwork to visit SynbiCITE as it began its substantive work. The conclusions I present rely on data generated in a particular time and place and perhaps offer inspiration for future explorations of these avenues of research.

At the start of the thesis I set out with the overarching aim to find out how synthetic biology is made translatable. This involved exploring how multiple actors understood translation, the kinds of activities that counted as translation and how these activities shaped synthetic biology in the UK. In this study, I explored translation as the way actors align the field of synthetic biology and sponsoring state's goals (Section 4.1, Section 4.3), the alignment of technical solutions with possible futures (Section 6.1, Section 6.2), the ways actors collect new collaborators (Section 5.1) and other entities (Section 6.2), and the differences between research cultures (Section 5.2, Section 6.3). The sensitivity to multiplicities is a particular strength of the approach I have taken. As was the methodology of connecting a specific project to a range of practices in the wider world. In sum, I encountered multiple translations

realised in specific arguments and specific practices. I tackle these research concerns in Section 7.1.

Addressing the issue of translatability meant, for me, exploring the kind of object synthetic biology might be – the question being, what is translated to what? In Chapter 2 I reviewed two strands of theories of objects in STS. ANT and post-ANT researchers conceptualise objects as networks of actors and, later, as composites of practices that produce multiple objects. Post-social theory conceptualises epistemic objects as partial and unfolding objects, composed of more partial objects, through which actors loop their desire for completion. In Section 7.2, I identify features of synthetic biology in order to generate a conceptual framework that combines post-ANT and post-social theories. My aim is that this could be applied to other contemporary objects with fuzzy boundaries e.g. other emerging fields of research, open source computer programs, governmental policies, as well as existing research programmes that STS researchers analyse.

Finally, throughout the research, as actors made connections to make synthetic biology translatable, they pointed out issues in wider society that synthetic biology could address. Actors also identified elements of society that posed a threat to synthetic biology. In Section 7.3, I present an analysis of the way these issues and threats were mobilised and offer a theory for how the multiple object discussed in the previous section may cohere. I suggest that reframing the way actors argue for resources and for protection of their research programme may have important implications for the current research agenda to create "science for society, with society" (Owen et al. 2012).

7.1 Answering the Research Questions

***Research Question 1**: In what activities do researchers, administrators and policymakers in synthetic biology engage to address "translation" in synthetic biology?*

In formulating this question I aimed to be able to comment on how actors understand translation in synthetic biology and what they do as translation. There were three main types of translational activities – initiating collaborations with events and funding, doing collaborative projects and training researchers.

In Chapter 5 I detailed how translation is rendered as collaborative working. Forming collaborations can be a way to combine the expertise of different actors in projects. This can be within academia, such as with interdisciplinary work, but also with actors outside of academia. In synthetic biology, this especially involves connecting researchers with industry. In the course of the research I followed actors to a range of events that universities and research councils set up to stimulate collaborations, especially with businesses. These included 'showcases' and 'open days' and funding launches. The events were structured to bring academics and industry closer together, at least for short periods of time. An aim appeared to be to better align the needs of the two communities at an early stage of research in the hope of expediting translation.

RCUK and research administrators also identified collaborations as routes to leverage further funding. Actors who can demonstrate they have formed a collaboration stand a better chance of accessing funds. The BBSRC say that, of two projects of equal scientific merit, they will fund the one that has industrial partners contributing at least 10% of the full cost of the project in preference (Biotechnology and Biological Sciences Research Council 2015).

Collaborations can therefore have a particular effect of facilitating actors' access to resources.

Research administrators in quangos (RCUK and Innovate UK) and in universities have created staged funding mechanisms aimed at transferring knowledge. Academics and business partners can enter into research collaborations with the initial funding available to academics. Over the various stages of the mechanisms, risk is transferred from RCUK and academics to Innovate UK and businesses.

Collaborative projects were a significant aspect of doing translational activities. SynbiCITE, funded for five years at Imperial College, was the UK's seventh Innovation and Knowledge Centre. This £10m organisational response involved a grant proposal, which listed 52 partnering organisations, including many UK universities. The proposal also stated involvement of multiple businesses, from large international companies such as Shell and GlaxoSmithKline, to new start-ups like Synthace and Oxitec. A part of SynbiCITE's role involves bringing together academic researchers with potential collaborators in industry.

At a smaller scale, the skin-graft project was a collaboration between academics in biosciences and engineering. The researchers repeatedly spoke of their engagement with the future medical application. However, the final part of their project, which involved designing and conducting adhesion experiments in tissue models, was difficult to manage.

Finally, various actors have instituted translational training, particularly to academics. These can be short courses at universities, international fellow opportunities offered by SynbiCITE, and the iGEM competition where students produce projects that can benefit society. Translating synthetic biology therefore involves changing the professional expectations of researchers.

In this research, translational activities were about creating collaborations, funding projects which transfer the risk of innovation and educating academics to increase their awareness and sensitivity to commercial needs. Initially, this puts the responsibility of translation onto academics. Both funding and training begin with academics. The onus of translation is on the university sector. Translation is shaping academic bioscience to produce people and networks in order to create translatable knowledge.

One prevalent metaphor in the discourse of translation is "the valley of death" (House of Commons Science and Technology Committee 2013; Kraft 2013). This suggests there is a 'gap' between academia and industry. In some reports, this can be framed as problems with funding and financing innovation. Industry rep 1 spoke of 'doing the funding rounds' to get investment. On the whole, however, funding for translation did not seem to be a major issue for academics or administrators with respect to synthetic biology. In my analysis I generated four other 'gaps' in the valley of death – *phasing, disclosure, transformations* and *competencies*. These were four axes along which tensions emerged in interviews and in field sites.

Phasing. There are ways in which temporal issues come to fore when people talk about or actively begin collaborations. Knowledge-work in industry is imagined to work on tight time scales, be responsive to market changes, and to generate solutions to problems quickly. For academics, knowledge-work was imagined to take a long time, involve problems that were complex and time-consuming, and to operate to self-imposed deadlines. I conceptualised this as a problem of phasing or meshing, where the domains were running to different periodicities.

Transformations. Academia and industry are orientated towards producing different outputs from knowledge work, or converting research into other things. Thus, the way credibility can achieved in the academic sector is different to the industrial and commercial sectors (Packer & Webster 1996). Academics were imagined to want project outcomes that included publications, proposals and further projects. Industry was imagined to focus on patents or, more importantly, profit. This appeared to be a potential problem for actors initiating collaborations.

Disclosure. A third contour appeared to be around the different ways that knowledge is protected in academic and commercial settings. For academics, publishing their discoveries and findings is a way to ensure their work is attached to their name. For industry, copyrights, patents and trade secrets are the main ways that knowledge is protected (Nuffield Council on Bioethics 2012). These differences played out in surprising ways. At one event attempting to foster collaborations, a table of academics claimed they had an idea but did not want to share it because they were uncertain of divulging information in case it jeopardised a future patent claim. At the same event, some academics expressed frustration with the lack of details from industry because they could not apply their expertise in the absence of knowledge of industrial secrets, such as bacterial strains and experimental conditions. At another event, an academic happily signed a confidentiality agreement with a company because they were unlikely to develop a project without industry support. The agreement was a ‘gesture of goodwill’ for the academic. Differences in disclosing knowledge can make conversations during initial interactions between academics, industry and universities less specific.

Competencies. The final contour concerned the different skillsets and abilities of workers in each domain. Academic work is highly specialised and academics have ‘niche’ knowledge. Furthermore, academic experts are likely to have specific expertise, even within their own

discipline. For industry, knowledge skills were more general. Industrial scientists may need to be able to adapt to changes quickly, perhaps by moving to do work in an area they had not previously experienced. Furthermore, academics related their expertise to their 'interests'. Some academics claimed they were not interested in knowing about markets and running a company. They said they would need somebody else to do that work. This implies that making synthetic biology translatable involves assembling a network of abilities and interests.

In Chapter 6, I argued that the themes of *competencies* in terms of researcher skills, and *phasing* in terms of timing and problem complexity, interacted and made interdisciplinary work difficult. The researchers wanted skills from their collaborators, but the project was running out of time. The collaborators wanted the solution to be closer to application before they dedicated resources and time. Thus, the skills of the collaborators were not available at the right times for the researchers. This suggests that some of these findings may be applicable to other forms of collaboration beyond academia and industry in research and innovation.

What these findings imply is that collaborative practices play a key role in acting out translation. The 'gaps' between research cultures can be enacted as different ways to achieve credibility. A more profound interpretation might be that academic and industrial practices produce epistemic objects with different characteristics. So, where policy focuses on financial remedies to encourage translation they may miss some of the other differences between academic and industrial knowledge-work. Furthermore, actors intending to embark on collaborations may profit from being aware of the kinds of differences between the domains of academics and industry.

Research Question 2: *What connections do researchers, administrators and policymakers make and unmake as synthetic biology emerges as a 'translational science'?*

As I worked through my analysis I noted a number of other entities: science, state, industry, medicine, human bodies, experiments and bacteria. These seemed to broadly fit with Fujimura's analysis of *constructing doable problems*. Fujimura notes that scientists select problems in part for their 'technological do-ability'. She goes on to argue that "do-ability is better conceptualised as the alignment of several levels of work organisation" (Fujimura 1987, p.258). I employed a framework of *articulating alignment* (Fujimura 1987; van Lente & van Til 2008) to study the emerging field of synbio. As such, I expanded the use of Fujimura's framework from making a "doable problem" to making a doable field of research.

Furthermore, Fujimura (1987) argues actors construct problems by aligning them with social worlds. Implicit in her formulation is the notion that social worlds are stable and antecedent to the research problem. I did not make this assumption – through selections of characteristics of other entities, actors perform and bring into being entities along with the field of research.

Alignments

In Chapter 4, I argued that synthetic biology was emerging alongside and in dialogue with another entity: the UK state. Throughout my data were enactments of the UK as an entity with a history of great bioscience and the potential for making important discoveries, which could have dramatic impacts on medicine and energy. Actors connected advances in biological understanding to returns for the UK in terms of economic and social impacts. In

this project, different actors connected investment in the life sciences, industry, human health and the national economy.

The state, I argue, is presented as an ambivalent character. It is the plucky underdog in biology on a global scale. The UK 'punches above its weight'. Research output is repeatedly claimed to be world class, both in terms of quality and quantity. The state is supportive of bioscience and aims to be "a scientific state" (Sismondo 2010, p.191). The state is also a state with a history of global leadership. However, the state has a deficit of knowledge translation and is failing to convert knowledge and discoveries into 'health and wealth'. This legitimises funding for converting bioscience to industry and commercial markets.

Actors then connect synthetic biology to features of this state. The connections are performed at conferences, during interviews and in ministerial speeches. Actors claim that the state is in economic recovery and, by standardising DNA and cellular systems, synthetic biology has the potential to create a new industrial revolution. They say this could impact health, food production and lead to economic recovery. Synthetic biology can also help the UK realise its identity as a global leader in bioscience. This appears to be an aspect of a 'compelling start-out story' in which actors create an impetus for innovation (Deuten & Rip 2000). These rhetorical alignments are realised in organisational structures. The formation of the SBLC connects government, quangos, universities, industry and regulators. Establishing SynbiCITE, the innovation and knowledge centre, connects synthetic biology with industrial manufacturing. The names actors give to biological parts (Calvert 2013) and facilities perform these connections.

Actors connect synthetic biology to a range of other industries and technologies. Synthetic biology is aligned with technologies that are seen as desirable and beneficial to the contemporary state. They are *infrastructural* technologies. These include microchips, air

travel and fermentation. These connections perform work. They make synthetic biology seem innocuous in the sense that it is nonthreatening and good, and that, as an infrastructural technology, it could dramatically improve life.

In Chaper 6, I was concerned with the laboratory and experimental levels of alignment. I showed how actors perform connections between synthetic biology, medicine and industry in their material practices. The actors selected to engineer the bacterial system for producing flagella. This was partly because of expertise of biological knowledge in the area. It was also because bacteria produce flagella outside of the cell. The actors felt that this would be a good mechanism to adapt because it would be easier to separate products rather than have to digest the whole cell. There were also ways that production could be 'optimised'. This included increasing the number of secretion points. These reasons align the project with industrial manufacturing because actors felt that producing molecules efficiently, and creating easy purification steps, could be of interest to an industry. The actors also aligned their work with the modularisation aspect of synthetic biology. They argued that they were creating mutant bacteria that could theoretically produce other materials, not just collagen and sticky chimeras. Thus, they actively aligned their work with an industrial manufacturing vision for synthetic biology.

The actors also aligned the project with medicine. Their overall goal was to create solutions to clinical practice. Surgical interventions for burns and ulcers can fail. Skin grafts and stem cell grafts can fail because wound beds are hostile places. The researchers invoked images of human injuries to perform the alignment of their work with health. They collaborated with other health scientists who had experience of setting up companies and working with surgeons and publicly mentioned this medical goal at the start of research presentations. One key aspect of the work was to try to reduce the immunogenic character of flagella. Re-engineering the flagella in an attempt make it less toxic was also an attempt to preserve the

project's connection to medicine. Without attending to this issue, there could be no clinical future for the bioglue element of the project. The connections to medicine and industry were written into the DNA of the bacteria.

In this thesis, actors connected synthetic biology to the UK state, to industrial technologies, and to clinical practice. These connections were realised in organisational, rhetorical and material practices.

Demarcations

At the same time as making connections, actors struggled over dismantling other connections. In section 4.2 I explored the messy processes of attempting to demarcate synthetic biology from other biology. I employed the notions of rhetorical boundary work (Gieryn 1983) and material boundary-work (Meyer 2006), which occurred in interviews, at events and during the assessment of grant applications.

Proponents of synthetic biology identify problems with the reproducibility of biology, and with the 'culture' in terms of understanding what it takes to scale up to commercial propositions. This can be understood as actors trying to maintain that synthetic biology has the potential to make a new contribution to innovation which justifies support. The idea that publics can disrupt technological innovation plays out in the distancing of synthetic biology from GM. Actors, keen to emphasise the differences of synthetic biology, argued that it offers greater control, both over the production processes and over the genetically modified organisms themselves.

On the other hand, microbiologists argue that synthetic biology is not novel. At the most cynical, synthetic biology is simply rebranding of existing bioscience. It relies on the same techniques and processes and does not offer a new contribution. These performances reduce the status of synthetic biology. The various connections enact a struggle for credibility (Gieryn 1999; Rip 1994).

The practices of connecting and unconnecting can be seen as ways for proponents of synthetic biology to preserve both the epistemic commitments of synthetic biology and the access to resources. For micro and molecular biologists, maintaining their connection to synthetic biology reduces its novelty and preserved their access to funding and an identity of cutting-edge research.

Research Question 3: *How does attending to translation shape the emergence of UK synthetic biology?*

Imagining industry

Making synthetic biology a doable field of research partly means, in the current academic climate of impact, making sure it is connected to realising benefits for the UK. One effect of this is to align synthetic biology with the UK's desire to be a global leader of bioscience (see research question 1). At the same time, actors distance their research from GM, claiming that the forerunner science ran into difficulties for various reasons. Actors appeared to create an imaginary industry, which circulated as a plausible version of an 'industrial revolution'. Certain forms of materials and manufacturing, and public fears, shaped the imaginary.

This imaginary can be understood as based on the notion of *contained bio-manufacturing*. In terms of containment, this meant that the products of synthetic biology, engineered organisms in particular, were not allowed out. Synthetic biology novelties such as engineered bacteria must remain trapped in bioreactors or laboratories. This means that synthetic biology can be used to make things. Biomaterials, drugs, fragrant chemicals can all be manufactured provided the novel aspect remains under control in specific sites.

A *contained bio-manufacturing* imaginary is performed in various instances. In Chapter 6, the researchers imagined they could reengineer the flagella of bacteria to use as a surgical adhesive. However, because flagella stimulate immune responses, even reengineering the flagella was not enough to convince collaborators that the novelty was safe. Thus, the biological novelty remained contained. The imaginary also plays out in The Artmisinin Project described in Section 5.1. The artemisinin precursor is not a novel compound. Any novel organisms remain in the Huvepharma bioreactors in Bulgaria. Finally, the synthetic biology special interest group circulated a new research paper: *'Deadman' and 'Passcode' microbial kill switches for bacterial containment* (Chan et al. 2015). This paper was about engineering bacteria in such ways that they cannot survive outside of contained conditions. Thus, an imaginary of *contained bio-manufacturing* has material consequences for synthetic biology realities.

There is a caveat to this narrative. In Section 4.2 I told the story of Ecover claiming it used oils from synthetic biology and how this resulted in a public backlash and public relations campaign. This suggests that imaginary may not be enough to facilitate the translation of synthetic biology.

However, the imaginary does work in the present a plausible, attainable industry, as opposed to ‘in the next fifty years, being able to grow houses’ (Industry rep 1, 1st September

2014). Thus, actors tell narratives that make connections which constrain and enable future actions (Deuten & Rip 2000). *Contained bio-manufacturing* seems to work in a similar way. It facilitates some forms of future industrial contributions and inhibits others. Certain forms of research and collaboration become more fundable, and doable, and others become less so.

Embedding translation

One way to enhance the do-ability of synthetic biology is to attempt to embed translation, as commercial manufacturing, in various institutions, practices and materials. In Chapter 4, I argued that the SBLC is an organisational realisation of relations between government, industry and academia. Embedding translation is also realised in SynbiCITE and its activities, which includes training new researchers. Much of the training in synthetic biology, whether in iGEM, through SynbiCITE or through the CDT, has a specific component to create industrially aware researchers, who may become future industry leaders. This means the future identities of researchers may include orientation to forming collaborations with industry and commercialising research.

Synthetic biology is aligned with industry through the naming of various facilitates and biological parts. These include automated laboratories called “foundries” and SynbiCITE as the “Industrial Translation Engine”. This chimes with the idea that specific expectations are tied to the creation of specific institutions (Schyfter & Calvert 2015). In terms of biological parts, the proponents of synthetic biology have begun using industrial terms such as “chassis”, “switch” and “oscillator”. These align the work of synthetic biology with controllable industrial mechanics. Furthermore, actors work on these symbolic findings which can then alter their statuses: they can become key infrastructural parts of the research field as different promises of controlling biology are realised at different times (Mackenzie 2013b).

Finally, in Chapter 6, the futures of industrial manufacturing and surgical application are inscribed in the DNA of microbes. The researchers change the genomes to produce more materials or change them. They delegate to the bacteria.

The overall aim was to find out how synthetic biology is made translatable. In answer to that aim, attending to translation appears to be shaping the emergence of synthetic biology towards industrial manufacturing in organisational, epistemic, pedagogic, and material ways.

7.2 Synthetic Biology: An *Unfolding Multiple*

The first theoretical contribution I wish to discuss draws together post-ANT and post-social theory to generate a framework for further STS research. I reviewed these starting perspectives in detail in Section 2.4. Here, I argue that elements from the two theories can help conceptualise synthetic biology as an object. I discuss three features of synthetic biology – its generative, expanding and multiple qualities – and suggest that the concept of an *unfolding multiple* can help to research objects such as fields of scientific research in STS.

Generative

Actors, in their practices associated with synthetic biology, produce new formations. They make new definitions and categories of life (Section 5.3), new publications and policies (Section 4.1), and new biological standards. There are new institutions in the sense of facilities: new computer programs and automated foundries, training centres, research

centres and innovation centres (Section 4.1, Section 5.1). There are new strains of bacteria, new strands of DNA and novel biomolecules (Section 6.2). Actors also produce new arguments claiming synthetic biology can make an impact and meet the goals of other actors (Section 4.3, Section 5.3, Section 6.1). All of these new things are produced by different actors doing their work in, and on, synthetic biology. So how to think of this in theory?

Both post-ANT and post-social theory understand objects as generative (see Section 2.4). In post-social theory, objects of knowledge are a series of lacks, a chain of absences, about which researchers ask questions and act to produce knowledge, and this facilitates the identification of further lacks (Knorr-Cetina 2005a; Knorr-Cetina 1997; Knorr Cetina & Bruegger 2000). The post-ANT formulation is similar and theorises how lacks are identified and produce new specific presences – concatenations of void and existence. So, in the process of designing of an aircraft:

> …presence, once created, in turn generated novel (perhaps deferred) forms of absence. That is, it shaped other new but absent realities: a wing, for instance, of a particular shape; a series of wind-tunnel tests of possible wings; and, in due course, an aircraft designed in a particular way with particular aerodynamic properties. The argument, then, is that we cannot understand objects unless we also think of them as sets of present dynamics generated in, and generative of, realities that are necessarily absent.
>
> (Law & Singleton 2005, pp.346–347)

The quotation articulates the idea that patterns of absence generate new things in the world. In the idiom of both strands of STS object theories: absence produces presence, which points to further absences.

Actors identify *absences of translation* in synthetic biology and this produces new meanings of biology, new institutions and new professional expectations. More specifically, actors

often do translation in synthetic biology as an absence of collaborations. Thus, forming collaborations draws in new actors and loops new sets of practices through synthetic biology. One effect of this, looking at a short history of UK synthetic biology, is that it appears to be rapidly getting larger.

Dilation

As synthetic biology is emerging its timescapes (Adam 1998) are changing. The original NSBs were funded for comparatively shorter periods of time – three years. Some of these networks developed into other projects. In Chapter 6, once the funding had finished for one NSB, the primary investigators acquired new funding from their institution. This became a new network of three PhD students in 2012, each with a thesis deadline four years hence, and a shorter BBSRC-funded project lasting fourteen months (Section 6.1). Furthermore, the RCUK website stated that further 'funding outcomes' included a one year mass spectrometry project, a four year international partnering award, a five year Network in Industrial Biotechnology and Bioenergy, a three and a half year collaborative science project and the five year multi-partner SynbiCITE (Research Councils UK 2015b). Thus, the NSB projects through spacetime in multiple ways.

The subsequent larger awards have been made for longer periods. From 2009 to 2014 the Centre for Synthetic Biology and Innovation (CSynBI) was funded at Imperial. In 2012, the "Flowers consortium" of Imperial, Cambridge, Edinburgh, LSE and King's College, and Newcastle universities was funded for five years to develop infrastructure for the "platform technology" synthetic biology. In 2014, three SBRCs and SynbiCITE were funded, each for five years. Three more SBRCs were awarded in early 2015. The five-year SBRCs have been awarded to Bristol, Cambridge-Norwich, Edinburgh, Manchester, Nottingham and

Warwick. The Centre for Doctoral Training, funded for seven years, is instructing, not just researchers, but 90 future leaders of the field (Section 5.3). This means that synthetic biology, in an imagined sense, is projecting further and further into the future. Future professionals emerging from the organisation may well enact that projection.

Synthetic biology has also dilated across geographic and social space. The NSBs were funded at a total of nine institutions and, since then, more and more universities have become involved in synthetic biology, either through large grants, responsive mode grants or by involvement with the iGEM competition. Thus, synthetic biology is enmeshed in universities, people, resources, meanings, practices and microbes (Part II). In its current state synthetic biology is expanding.

From the outset of the NSBs, interest and involvement in synthetic biology was not confined to biologists and engineers. Social researchers became involved on epistemic and ethical grounds. They wanted to ask questions about what life meant to different groups since it appeared to be contested in early meetings (social researcher 2, 2nd July 2014). Another, interested in academic bioscience, got 'sucked in' by accident (social researcher, 1st July 2014). Some were commissioned to write reports on the social implications of synthetic biology (Balmer & Martin 2008) and conduct the 'dialogue' to research public opinion (TNS-BMRB 2010). People beyond academics and funding administrators have also become enrolled in synthetic biology including government ministers like David Willetts and various companies and businesses registered as collaborators on proposals (see Chapter 5). By 2015, there were 33 industrial partners and 19 academic organisations listed online as part of SynbiCITE.

Dilation of an object (Engestrom et al. 2003) may have discernible effects. Two participants (academic researcher 5 and social researcher 2) remarked on a difference between hopes

and excitement of synthetic biology at the international synthetic biology conference SB5.0 held in Stanford, 2011 and the SB6.0 conference held at Imperial in 2013. There was a sense here of a difference between the promise of designing biology and reality of engineering the materials of life which appear to interact in a probabilistic way. This 'slowing of the pace' was also touched on by an administrator referencing the innovation 'hype curve' where, after an initial flurry of engagement with the an exciting novelty, the more mundane work of realising what will be feasible takes hold (research administrator 4, 16th July 2014). Thus, the dilation of synthetic biology also connotes a reduction of hype. As the field diffuses it becomes a more mundane science. So, the dilation of an object occurs across multiple domains and there may be a relationship between the expansion in some spaces and the perception of a slowing pace in others as discussed as 'rates of realisation' (Mackenzie 2013b). This notion of expansion, then, may account for the perceptions that developments in synthetic biology are, in some areas, decelerating.

The outcome of this section is that post-social theory can deal with dynamic objects in a more satisfying way that post-ANT. Post-ANT has been worked out with complex medical diseases such as atherosclerosis and alcoholic liver disease that, in terms of practices, are comparatively stable in comparison to synthetic biology.

Multiplicity

Synthetic biology is partly constituted of collaborations between different academic disciplines. Thus, the idea of an *object multiple* (Mol 2002) that is composed of several practices was an attractive conceptual option in the first instance. However, it turned out that I found trying to 'operationalise' the concept for analysis was problematic. For one, Mol's argument is based on convincing the reader that a shift to focusing on material practice

alters one's ontology. Thus, an object that is single in theory is multiple in practice. But, synthetic biology is not a single object, even 'in theory'. It is "many things to many people" (academic researcher 15, 28th August 2014). Most proponents and other researchers regard it as an approach. And one that is not theoretically unified. So, a key argument of *The Body Multiple* is undermined.

In addition, post-ANT and post-social theories have different interpretations of multiplicity. In post-ANT, multiplicity arises in large, messy objects that are done differently by groups, even though they may be in the same site, referring to the same body, as with an atherosclerotic patient and a doctor (Mol 2002). In different sites the different constitutive practices may be contradictory, as in both atherosclerosis and alcoholic liver disease (Law & Singleton 2005). This is an effect of understanding objects as enacted or performed (Law 2009). In contrast, multiplicity for post-social objects arises primarily from an assemblage of partial representations. As Knorr Cetina says:

> Take the case of detector in a high-energy physics experiment. 'It' continually circulates through a collaborating community of physicists in the form of partial simulations and calculations, technical design drawings, artistic renderings, photographs, test materials, prototypes, transparencies, written and verbal reports, and more. These instantiations are always partial in the sense of not fully comprising 'the detector'.
>
> (Knorr Cetina 2005, p.191)

This idea of 'circulating representations' is very similar to the early ANT concept of *immutable mobiles* (and therefore boundary objects) that stabilise networks because they are resistant to deformation (Star & Griesemer 1989; Latour 1986). The object of synthetic biology does circulate in diagrammatic form (see Section 1.2). However, despite my earlier caveats, I suggest it is more compelling and more complete to conceptualise synthetic biology as a post-ANT multiple consisting of overlapping bundles of practices involving academics, administrators, businesses and government.

An unfolding multiple

To think about synthetic biology, I propose drawing together the concepts of heterogeneity and generativity of post-ANT and the dynamic, unfolding qualities of post-social objects. But, if an object is unfolding in multiple ways is there a theoretical mechanism for this? Knorr Cetina's (Knorr-Cetina 2005a; Knorr-Cetina 1997) thesis on post-sociality employs Lacan's work on desire and, in this psychoanalytic vein, she argues that in epistemic practice researchers loop their own desire through the incompleteness of their epistemic or partial objects. For her, it is the ability of objects to unfold and give off signs that facilitate a relationship where researchers 'follow' a chain of lacks. Some knowledge is missing; the object 'signals' the way. In the case of a financial market:

> The articulation of the object, the market, is looped through the subject: as a structure of lacks, of the questions it poses and the things that "it" needs, the market receives the kind of extension that the subject determines.
>
> (Knorr Cetina & Bruegger 2000, p.157)

This 'binds' the researcher to the object and, as such, an object like a financial market can become a space in which the self can be embedded (Knorr Cetina & Bruegger 2000).

It may be possible to extend this idea to groups. If the self can be embedded in unfolding objects, so groups can be integral to unfolding multiples. At the end of Chapter 5 I noted how synthetic biology is 'opening up' as many different actors identify translational absences in synthetic biology. Whether scientific, commercial, pedagogical or social. A standards agency, for example, finds a lack of standards key to translation (British Standards Institute 2014). They loop their practices through synthetic biology, and unfold it. Another example of the way groups identify lacks is in the way the proposal for the CDT referred to a 'skills gap' (Engineering and Physical Sciences Research Council 2015b). It could have been, for

instance, that all the skills for synthetic biology were already 'out there' and needed bringing together. This would have created a different absence and a different solution. An absence of training, once funded, altered the way that synthetic biology emerged. These groups unfold synthetic biology in ways that are relevant to the questions they ask (see table in Figure 16 below).

Figure 16. Table of different groups' extensions of synthetic biology

Group	Lines of Extension
Engineers	Systematic design, abstraction, modularisation, standards in biology
Microbiologists	Knowledge about manipulating and maintaining (laboratory) life
Computer scientists	Programs that can predict and simulate biological environments and reactions
RCUK	UK capacity for synthetic biology expertise
Government	Strategic leadership, specific funding
Innovation leaders	IP, business collaborations, markets, profit
Social studies academics	Ethical, legal, social changes
Standardisers	Experience in creating and managing standards

This chapter has shown how different groups engage with synthetic biology and unfold it in different ways. A multiple object such as synthetic biology contains a vast array of actors/subjects who work to unfold the object in their own ways.

A question then becomes, how do these practices and different actors stay together? An implication of unfolding multiple is how it configures the approach to sociality. Knorr Cetina

suggests that, while unfolding and sign-giving are the two important characteristics for researcher-object relations, it is their representational multiplicity that may allow integration:

> In expert contexts, the binding role of knowledge objects may rest on their multiple instantiations; for example on their ability to circulate as test materials, visual displays, maps, prototypes, substances, etc. This form of objectual integration may create communities 'in thought' (compare Hutchins, 1995), collective obligations towards the lacks displayed by partial objects, and emotional affiliation through the concentration of feelings, images and metaphors on central objects. I assume that objectual integration plays a crucial role in the formation of research groups (Geison, 1993) and experimental systems (Rheinberger, 1992), across generations of participants.
>
> (Knorr Cetina 1997, pp.24–25)

Knorr Cetina's proposition is that it might be the multiple instantiations of objects that facilitates integration.

My account means objects are able to be at the centre of a different mode of objectual integration because an *unfolding multiple* concept facilitates a range of practices operating along the lines of 'a structure of wanting'. There may well be a concentration of metaphors that create collective obligations but, for synthetic biology, the lacks and absences are different for various groups. A task, which I begin to address in the following section, is to identify potential integrating metaphors and images. However, it may be as much about how objects have the capability to unfold in multiple directions, and so loosely weave together diverse bundles of practice, that might account a 'binding' quality. In Section 7.3, I explore a mode of coherence for synthetic biology.

Implications

An *unfolding multiple* is a theoretical entity that can be used to conceptualise objects of research in STS. Thus, whether in terms of epistemic objects or partial, multiple objects more generally, this notion allows researchers a way to understand an object that is spread out, that contains materials, representations and practices. It also offers a way to understand the way objects change over time – dilation may simply be a phase of an object lifecycle (Engestrom & Blackler 2005; McGivern & Dopson 2010). There are, I suggest, three domains for an analyst to chart:

1. The multiple practices constituting an object
2. The unfolding of meanings, materials, facilities and skills, and the effects of expansion and contraction
3. Modes of coherence

Reflexivity is built into this theory. Researchers can play a part in shaping the technologies they study (Williams & Edge 1996, p.892). I, as a social researcher, contributed to the expansion or extension of synthetic biology in specific ways. I performed the importance of translation to a small selection of people, and also performed the idea that social researchers could create social knowledge from synthetic biology (see Section 3.5). The unfolding multiple concept therefore links the personal and the communal (Wright Mills 2000) and sensitises the researcher to their role in creating an object, how their own desires for knowledge and action extend an object.

It is also, then, weakly predictive. If specific types of actors, say scientific researchers, policy makers, government ministers, specific industries, involve themselves in synthetic biology, if they loop through their desire, then synthetic biology expands in specific directions.

Making synthetic biology translatable might mean actors creating an object with a permeable ontology that allows for interweaving of multiple practices. This leads to the final section of this thesis, in which I suggest a mode of coherence that may function to loosely bind various practices.

7.3 Mobilising Vulnerabilities: Society, Surgery and Synthetic Biology

Synthetic biology can be understood as an *unfolding multiple* that is generative and expanding. The mechanism for expansion is that various groups loop their interests through the object and unfold it in multiple dimensions – epistemic, political, medical and so on. However, there is a problem of understanding coherence. How does such a composite object 'hang together'?

In this section, I argue that *mobilising vulnerabilities* can effect coherence of a complex object. Many stories cast synthetic biology as an object with an heroic character, or as a panacea, with the ability to solve many problems. It turns out that synthetic biology is a solution to many vulnerabilities in the world. These include issues for the UK state, the public, industry, and surgical processes.

I use the term vulnerability in a dual sense. It means 1) exposure to the possibility of harm 2) the incapability of a (socio-technical) system to withstand change. This second meaning is extensively explored in literatures in climate studies, geography, development studies, engineering, health, disaster management and security studies. These literatures tend to focus on defining vulnerability, and reducing it. An edited STS collection sought to explore "what vulnerability can mean and how it affects cultures and societies" (Bijker et al. 2014,

p.3). Thus, the meanings have implications for the conceptual frameworks that people use and for the governance of vulnerabilities. Instead, my focus is on how actors deploy vulnerabilities in the pursuit of resources.

A Panacea

This section explores how synthetic biology is performed (on verbal and textual 'stages') as the solution to many problems. In the course of asking for investment and justifying requests for resources, actors liberally deploy vulnerabilities. It is a key part of making synthetic biology translatable as actors translate the interests of others into the (claimed) abilities of the field (Callon & Law 1982; Callon 1986).

In the skin graft project, actors presented wounds that did not heal and remained open to the environment. Bodies were materially exposed. Pathogens could enter the body through these sites. Wound beds were inhospitable places for cells because of their lack of an ECM. Skins cells died because they did not adhere well enough. Furthermore, collagen is a key component of the ECM to which cells adhere. Collagen could be used in surgical techniques. However, partly because of regulations emerging from the BSE crisis, collagen could not be easily sourced (academic researcher 6, 5th February 2014). Therefore, synthetic biology is proposed as a solution to risks to sourcing and using mammalian collagen. Thus, the human body is cast as a vulnerable site.

In Jay Keasling's SB 6.0 conference talk George's brother was struggling with malaria. He was also a vulnerable body that synthetic biology can save. Furthermore, in Keasling's account, George's mother contributed to the wider community's vulnerability by not completing the course of antimalarials. This is an issue that synthetic biology can solve by

making cheaper drugs that are more accessible (Hale et al. 2007). So, actors mobilise vulnerabilities of human bodies and communities to make synthetic biology into a solution. The mobilisation of bodily peril legitimises the intervention of synthetic biology. It connects the science with protection and recovery.

But, innovation itself is precarious. As I showed, several actors claim biology is not reproducible (Section 5.2). Innovation in biology is vulnerable and knowledge cannot be easily translated because the science is not robust enough. Thus, by making life easier to engineer, the proponents argue that an industry is more likely because it will improve reproducibility. Synthetic biology is a hero that can ensure and speed the transfer of knowledge into application.

Standardising biology will have further effects. Actors present the UK nation as a vulnerable state. There is international competition for status, science and profit. Synthetic biology can realise the state's desire for international status. By setting standards and regulations in the UK, the nation can exert some power in the administration of the (global) field. Finally, synthetic biology can support economic recovery because it encourages investment. Synthetic biology, with the proper support, can save the UK state. So, mobilising vulnerabilities creates a hero (Deuten & Rip 2000) capable of great feats, from repairing human bodies to bolstering a state's economy.

This creates a potential object which cannot be ignored. It binds different groups to the future of synthetic biology by creating a *passage point* (Callon 1986), which leads to many benefits. Potentially, this establishes a coherent moral obligation to supporting synthetic biology, as not supporting the field could prevent benefits to society.

Maintaining Beneficial Qualities

Throughout Part II, I argued that synthetic biology novelties currently remain contained in both imaginaries and realities, partly because of the safety testing in medical technology development. However, even when the skin graft project appeared flawed synthetic biology 'was not the problem'.

The researchers acknowledged that the use of flagella was problematic. The immanent feature of mammalian immunogenicity threatened the overall conceit of using flagella as a scaffold for their bioglue. Instead of abandoning the project, or choosing a different scaffold, the researchers sought to use synthetic biology to remedy the problem. By reengineering the parts of the flagella to be less immunogenic, the researchers preserve the panacea – synthetic biology can solve many problems.

This kind of activity has another precedent. The early promises of the Arteminisin Project were to produce an antimalarial drug "inexpensively for the people of the developing world and potentially save one or two million lives every year" (Keasling 2004). However, over time, different promises emerged. The semi-synthetic production of artemisinin became a way to 'stabilise' the market prices and make a more reliable source for artemisinin (Hale et al. 2007). But, instead of understanding the changing promises of the Artemisinin Project as problematic for synthetic biology (Marris 2013), I want to reframe them as being integral to maintaining synthetic biology as an object of great potential.

Synthetic biology is also maintained by how it does allow groups to realise their goals. At RCUK actors talked of how synthetic biology was a good example of cross-council funding. Academic researcher 18 said, "synthetic biology has a lot to be thanked for". These help

keep synthetic biology together, to protect it in its emergence by acknowledging interim successes.

But, synthetic biology is in peril

Synthetic biology, actors argue, can have major industrial, health and economic benefits. Above, I described how synthetic biology is expanding. A persistent metaphor in the context of UK synthetic biology is that it is 'emerging' or 'growing'.

> As a discipline, I'm going to say immaturity here. And I think you know the polite interpretation is that, you know, it's technological development. But actually it does describe how some of the community behave as well. It's an area that does seem to attract a certain amount of in fighting. I don't know if that's something that. It's not. It needs to mature on several fronts.
>
> (Research administrator 1 interview, 19th August 2014)

The idea of maturation suggests that synthetic biology needs nurturing. Some parenting. It is juvenile. It seems to be at risk if the community does not agree and work together.

The environment surrounding synthetic biology can also be hostile. In Section 4.3 David Willetts connected the public, the media and an outspoken US scientist. Some synthetic biologists try to distance themselves from Craig Venter. He is cast as a liability that threatens synthetic biology. The media and public may also cause synthetic biology problems. Willetts also said some of his actions were about trying to prepare people for a turbulent time. Thus, the immaturity of synthetic biology is problematic and justifies support. These comments externalise synthetic biology and make it an object separate from the community. Yet the environment still poses a threat.

Synthetic biology is at risk to people not legitimately engaged in the project. They can ruin it by 'diluting' it (Academic researcher 24). If they do work, but do not contribute to standards and modules and contribute to the community, synthetic biology could fail. Also, if people are too focused on applications, synthetic biology may fail because not enough resources are allocated to the underpinning development (Schyfter & Calvert 2015). There is a tension between underpinning infrastructure and impact. This is further exemplified in the extended quote from CSynBI at the start of Chapter 4. There, the UK infrastructure can threaten an innovation. The statement argues that proponents of microchips did not do enough, that they did not support their innovations loudly enough.

Finally, regulations in synthetic biology. The examples of nanotechnology and medical technologies were highlighted as possible threats to realising potential (John Collins, industry rep 1 & academic researcher 6). Saying regulations threaten synthetic biology appears to be attempts to inhibit them: synthetic biology researchers should be allowed to regulate themselves since external regulation could prevent innovation. Thus, *mobilising vulnerabilities* shapes the future industry of synthetic biology.

7.4 Conclusion

I have shown how vulnerabilities are mobilised in two ways. They are used to construct a panacea. A single character capable of great contributions to society. In this way, actors mobilise vulnerabilities to gather resources for their projects. Vulnerabilities are also deployed, almost in reverse, to construct a hostile environment, and justify protective support for synthetic biology. Thus, the mobilisation of vulnerabilities creates an ethic of support and protection towards synthetic biology.

Object relations and resources

I suggest that mobilising vulnerabilities helps establish a single object of synthetic biology. They contribute to coherence by performing emotional and ethical affiliations (Knorr-Cetina 2005a) towards the immature object of synthetic biology and towards its potential to benefit society.

In their work on markets, Knorr Cetina and Bruegger suggest that coherence is an achievement of "the articulation and management of lacks" (Knorr Cetina & Bruegger 2000, p.155). Knorr Cetina posits that there must be shared 'emotional affiliation' with central objects – feelings, images and metaphors. For Mol (2002), cohering the various practices is accomplished via translations. 'Emerging coherence' in innovation and product creation can be accounted for by understanding *narrative infrastructure* (Deuten & Rip 2000). Although the latter authors focus on 'product creation', I suggest that a similar approach may be fruitful in understanding the formation of a scientific field. I drew on these ideas, which I covered in more detail in Chapter 2, to suggest a mode of coherence for synthetic biology. Thus, the stories of synthetic biology as capable of solving many problems, yet also vulnerable to its environment, may establish emotional affiliation and create an apparently singular object.

Secondly, engineers and scientists look for problems. What are they doing when they identify problems? Synthetic biologists publish ideas such as *a problem-driven approach to healthcare innovation* (Tyo 2012). Or they proclaim "malaria is a global health problem" (Ro et al. 2006, p.940). Indeed, scientists do more than identify doable problems. They actively construct them (Fujimura 1987). In this process, they instrumentalise vulnerabilities. They turn them into ways of securing resources for their projects. So what of vulnerabilities?

As a provocation to policy and practice (Russell & Williams 2002a, p.149) *mobilising vulnerabilities* implies a conceptual shift. For instance, it is one thing to say, "scientists need resources to fix a problem". Here, resources are allocated because the solution is imminent. It is quite another thing to say, "scientists identify vulnerabilities to get resources". This suggests a more indefinite connection between 'the problem' and resources. Scientists are capable of saying where problems lie in order to create convincing proposals. Perhaps this practice is the product of a risk society (Beck 1992). Talking of vulnerabilities shifts the focus from the future promise of benefits onto the present practice of acquiring resources.

This has implications for funding and resource allocation for science. Responsible research and innovation (RRI) has become a buzzword in science administration (Owen 2014; Owen et al. 2012). I suggest that vulnerabilities are a way to sensitise actors to the potential benefits they propound, the way promises change, and why they mobilise specific attributes. New questions can be foregrounded: "how is an actor mobilising a vulnerability? What is vulnerable? What are they asking for?" This highlights the relationships between problems and solutions. So, reframing the construction of problems as mobilising vulnerabilities also raises the question of reflexivity for scientists, and asks them to critically assess their reasons for making claims. Are the resources they are asking for going to contribute to ameliorating vulnerability? Is the mobilisation of vulnerability 'fair' in terms of the emotional connections they make?

In this last chapter I summarised my main findings as responses to the research questions I posed at the end of Chapter Two. I went on to outline two academic contributions. The first of these, an *unfolding multiple*, is a contribution aimed at the STS research community. It is a reflexive framework for understanding and researching complex, multiple and dynamic objects. The second, the notion of *mobilising vulnerabilities*, offers a mode of coherence for

complex objects. Furthermore, I suggest, it offers a provocative reframing of 'constructing problems' to emphasise double-sided deployment of vulnerability – both to highlight the potential for beneficial contributions and to gain resources for one's endeavours. This may be of use for researchers, funders and public bodies in assessing the contribution of different programmes of research.

Throughout this thesis I have tried to show the complex processes that make an emerging field of research into a relevant and fundable science. Making synthetic biology translatable involves aligning science with other stakeholders in rhetorical, organisational and material ways. Thus, synthetic biology is made into an object that needs to be supported to realise its potential benefits to the UK state, academic science, commercial industry and society.

Glossary

AHRC	Arts and Humanities Research Council
ALD	Alcoholic liver disease
ANT	Actor-network theory
Atherosclerosis	Disease characterised by fatty deposits causing a smaller lumen and a thickening and hardening of arterial walls
BBSRC	Biotechnology and Biological Sciences Research Council
BIS	Department for Business, Innovation and Skills (UK government)
Catalyst	RCUK & Innovate UK collaborative funding mechanism
CDT	Centre for Doctoral Training (e.g. SBCDT)
Chimera	A protein coded by DNA from genetically different sources
CSynBI	Centre for Synthetic Biology and Innovation (Imperial College)
Culture (cell)	Growth of cells (e.g. bacterial, mammalian etc), usually in a laboratory, in a medium containing nutrients
DNA	Deoxyribonucleic acid
E. coli	*Escheria coli*, 'gut' bacteria commonly used in biotechnology
ECM	Extracellular matrix. The mesh of macromolecules that helps binds cells to one another.
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
ETC Group	Erosion, Technology and Concentration Group. A campaign organisation which raises awareness of the impact of

	technology on poor and vulnerable communities.
Express	Act of bacteria showing signs that a particular gene is having an effect. i.e. making a protein or demonstrating antibiotic resistance.
Gene	Unit of DNA that determines amino acid sequence in a protein.
Genome	Full (haploid) set of chromosomes in an organism
GM	Genetic modification
HaCaT cells	Immortal cell line derived from human skins cells, used in biomedical science
HEFCE	Higher Education Funding Council for England
HGP	Human Genome Project
IKC	Innovation and Knowledge Centre
Innovate UK	Innovation agency (new name for the Technology Strategy Board)
MHRA	Medicines and Healthcare Products Regulatory Agency in the UK
Microbe	Micro-organisms e.g. bacteria, fungi, viruses
MRC	Medical Research Council
MRSA	Methycillin resistant *staphylococcus aureus*
Mutant	A non-wild version of an organism; has usually been 'transformed'
NERC	Nature and Environment Research Council
NSB	Network in Synthetic Biology
Plasmid	Nonchromosomal DNA that can independently replicate, typically a small circle of DNA in bacterial cytoplasm. Used extensively in bioscience to manipulate genes.

RCUK	Research Councils UK (collective of seven councils)
RCT	Randomised controlled trial
REF	Research Excellence Framework – quality assurance exercise for UK research conducted by quangos.
SB	Synthetic biology
SBRC	Synthetic biology research centre. Six centres funded by RCUK.
SCR	Stem cell research
Sequence	Specific strand of DNA
Splice	Insert one sequence of DNA into another
STS	Science and Technology Studies, sometimes Science, Technology and Society
SynbiCITE	Synthetic Biology Commercial and Industrial Translation Engine (the synthetic biology IKC at Imperial)
Synbio	Synthetic biology
Transformation	Act of inserting an experimental plasmid into a bacteria, usually duaeying antibiotic resistance among other genes. Bacteria that failed to take up the plasmid die when the culture is grown on a medium with a specific antibiotic.
TSB	Technology Strategy Board (now called Innovate UK)

Appendix I

Lists of Participants & Interviews

Participants:

Participant Code	*Role and/or affiliation*
Academic Researcher 1	PhD candidate. Microbiology.
Academic Researcher 2	Professor. Bioinformatics
Academic Researcher 3	PhD candidate. Microbiology.
Academic Researcher 4	Postdoctoral Research Assistant. Microbiology.
Academic Researcher 5	Senior Lecturer. Microbiology.
Academic Researcher 6	Research Associate. Engineering.
Academic Researcher 7	Masters student. Microbiology.
Academic Researcher 8	Professor. Engineering.
Academic Researcher 9	Masters student. Microbiology.
Academic Researcher 10	Senior Lecturer. Synthetic biology.
Academic Researcher 11	Professor. Synthetic biology.
Academic Researcher 12	Professor. Biotechnology. Head of translation.
Academic Researcher 13	PhD candidate. Synthetic biology.
Academic Researcher 14	Group Leader. Bioinformatics.
Academic Researcher 15	Professor. Biochemistry.
Academic Researcher 16	PhD candidate. Synthetic biology.
Academic Researcher 17	PhD candidate. Synthetic biology.
Academic Researcher 18	Professor. Molecular micribiology.
Academic Researcher 19	Lecturer. Computing Science.
Social Researcher 1	Reader. Sociology.
Social Researcher 2	Senior Lecturer. Sociology.

Research Administrator 1	RCUK
Research Administrator 2	University. Grant capture.
Research Administrator 3	University. Science-industry relations.
Research Administrator 4	RCUK
Research Administrator 6	RCUK.
Research Administrator 7	Dr John Collins, Commercial Director, SyniCITE
Research Administrator 10	RCUK
Research Administrator 12	RCUK
Research Administrator 15	RCUK
Research Administrator 16	Rt Hon David Willetts
Industry representative 1	Synthetic biology startup
Industry representative 2	Synthetic biology SME

Interviews:

Participant Code	*Interview date*	*Mode of interaction*
Academic Researcher 2	28th July 2014	In person; unrecorded
Academic Researcher 4	4th December 2013	In person
Academic Researcher 5	7th May 2014	In person
Academic Researcher 6	5th February 2014	In person
Academic Researcher 7	28th July 2014	In person
Academic Researcher 9	28th July 2014	In person
Academic Researcher 10	1st September 2014	In person
Academic Researcher 11	29th August 2014	In person
Academic Researcher 12	15th July 2014	Telephone
Academic Researcher 14	19th August 2014	Video internet call
Academic Researcher 15	28th August 2014	Video internet call

Academic Researcher 18	28th July 2014	In person
Academic Researcher 19	28th July 2014	In person; unrecorded
Social Researcher 1	1st July 2014	Video internet call
Social Researcher 2	2nd July 2014	In person
Research Administrator 1	19th August 2014	In person
Research Administrator 2	18th February 2014	In person
Research Administrator 3	3rd March 2014	In person
Research Administrator 4	16th July 2014	Voice internet call
Research Administrator 6	19th August 2014	In person
Research Administrator 7	3rd July 2014	Video internet call
Research Administrator 10	18th August 2014	In person
Research Administrator 12	19th August 2014	In person
Research Administrator 15	19th August 2014	In person
Research Administrator 16	2nd September 2014	In person
Industry representative 1	1st September 2014	In person
Industry representative 2	10th September 2014	In person; unrecorded

Appendix II

Research Ethics Documentation

The University Of Sheffield.

Department Of Sociological Studies.

Rob Meckin
Department of Sociological Studies

10 January 2014

Department Ethics Co-ordinator
Dr Harriet Churchill

The University of Sheffield
Department of Sociological Studies
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Dear Rob

PROJECT TITLE: ***The meaning and practice of translational research in Biomedicine***

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 10 January 2014 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documents that you submitted for ethics review:

- Ethics application form dated 7 January 2014
- Participant information sheet dated 23 September 2013
- Participant consent form dated 23 September 2013

If during the course of the project you need to deviate from the above-approved documents please inform me. Written approval will be required for significant deviations from or significant changes to the above-approved documents. Please also inform me should you decide to terminate the project prematurely.

Yours sincerely

H Churchill

Dr Harriet Churchill
Department Ethics Co-ordinator

Participant Consent Form

Title of Research Project: **The practice of translational research in synthetic biology: a sociological study**

Name of Lead Researcher: Robert Meckin

Participant Identification Number for this project: **Please initial box**

1. I confirm that I have read and understand the information sheet and I have had the opportunity to ask questions about the project. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐

3. I understand that my responses will be kept confidential.
I give permission for other members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research unless I give my consent. ☐

4. I agree for the data collected from me to be used in future research ☐

5. I agree to take part in the above research project. ☐

_____	_____	_____
Name of Participant	Date	Signature
_____	_____	_____
Name of person taking consent (*if different from lead researcher*)	Date	Signature
_____	_____	_____
Lead Researcher	Date	Signature

Copies:

Once this has been signed by relevant parties the participant will receive a copy, to keep with the information sheet and any other written information provided. A copy of the signed and dated consent form will be placed in the project's secure storage.

INFORMATION SHEET for RESEARCH PARTICIPANTS

PROJECT TITLE

The practice of translational research in synthetic biology: a sociological study

INVITATION

You have been contacted because you are a member of a synthetic biology group or are working in a related area (another scientific field, policy arena, industry etc).

You are being invited to take part in a research project that is studying the development of the field of synthetic biology in the UK and beyond. In particular, this study focuses on the translational research aspect of synthetic biology.

Before you decide whether to take part in the research, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me (Rob Meckin) if there is anything that is not clear or if you would like more information.

Thank you for reading this.

PURPOSE of the RESEARCH

To investigate and understand how a new scientific field is created, defined and practiced.

COMMITMENT

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep has it contains my contact details. You will be able to withdraw from taking part in the research at any time by contacting me. If you decide not take part or wish to withdraw please, please ensure I have been informed.

WHAT TO EXPECT

I may visit your place of work and record (often written notes) some of the activities that take place there. I may also ask you to take part in recorded conversations or individual / group discussions about your research. My visits are intended to be informal occasions and I may ask to simply follow you around for a while as you do your everyday work. There will hopefully be little disturbance to you and your on-going activities. Although I will spend time with you as an individual, the research is not studying you as a person, rather just the kinds of things that go on in your work and what you feel about those and your area of work more generally. I do have a background in biomedical science, but have not practised in recent years so sometimes I may ask seemingly simple or odd questions in order to understand what is going on.

BENEFITS

While there are no immediate benefits to people taking part in the project, it is hoped that this work will contribute to understanding how translational research is undertaken in synthetic biology and may raise awareness among scientists and engineers about some of the factors impacting the way contemporary science is conducted and developed.

CONFIDENTIALITY

Any information that I collect will not be attributed to individuals without explicit consent. Any reports or papers that I write will contain anonymised information and I will aim to keep the identification of labs and institutions to a minimum when this is appropriate.

INFORMATION

Any digital recordings (audio/photo) made during this research will be used during analysis and may be used for illustration in conference presentations or lectures. No other use will be made of them without your written permission, and no one outside of myself or my supervisors will be allowed access to the original recordings. If being interviewed using digital audio, you will be asked to give verbal consent to the interview.

RESULTS

My primary aim is to write up the analysis of the data as a doctoral thesis. Some of the anonymised data will likely be used for presentations and academic publications.

ETHICAL APPROVAL

The project has received ethical approval from the University of Sheffield, Department of Sociological Studies Ethics Committee and will follow professional guidelines laid down by the British Sociological Association.

CONTACT

If you have any questions about the work or about the conduct of the researchers, then please contact me, Rob Meckin:

Email : r.meckin@sheffield.ac.uk

Or my supervisor, Dr Molyneux-Hodgson : s.hodgson@sheffield.ac.uk

If you decide to take part in the research, please sign the Consent Form attached.

MANY THANKS

Appendix III

Publications & Participation in Science and Technology Studies

Publications

Meckin R, 2015. Innovation and STS in Torun: The EASST Conference as a Generative Object. *EASST Review*, 33(4) pp. 25-28

Haywood, G., Nilsson, J., Franklin, M., Gilbert, P., Krafve, L. J., Linden, L., MacGillivray, M. and Meckin, R. 2014. Valuation Studies: A Collaborative Valuation in Practice. *Valuation Studies*, 2 (1): 71-85. DOI: 10.3384/vs.2001-5992.1421. Open Access.

Academic participation – training and presenting

Year	***Month***	***Event***	***Role***
2012	October	EASST & 4S conference (Copenhagen)	Student, observer
2013	April	Dimensions of Value (Edinburgh)	Student participant
		Med tech conference (Sheffield)	Observer
	May	Ian Hacking seminar (Leeds)	Student participant
	June	PGR conference (Sheffield)	Organiser, presenter
		STS Italia Summer School (Puglia)	Student participant
		PFGS colloquium (Leeds)	Presenter
		Sheffield study in peak district (Eyam)	Student participant
	July	SB 6.0 (Imperial)	PhD researcher
		ChELSI symposium (Sheffield)	PhD researcher
		Making Science Public (Nottingham)	Observer

	October	Bio-objects training (York)	Student participant
	December	MRI symposium (Sheffield)	Student participant
2014	February	Valuation Practices (Edinburgh)	Student participant
	March	Innovations in Healthcare (Sheffield)	PhD researcher
	May	Life Science Research Bazaar (Sheffield)	PhD researcher
	June	Nurturing Genetics Symposium (Leeds)	Student participant
	July	Challenge of Translational Research (KCL)	Student participant
		PGR Showcase (Sheffield)	Student participant
	September	Young SB conference (Wellcome, London)	PhD researcher
		Crossing membranes (Sheffield)	PhD researcher
		EASST Conference (Torun)	Presenter and panel chair
	October	Quagos workshop (Wellcome Trust)	Participant
		iGEM (Boston)	Participant, advisor, PhD researcher
	December	Bio-objects (Brussels)	Student participant
2015	February	Translational symposium (Sheffield)	Self-initiated organiser
	April	ESRC final year conference (Oxford)	Senior student participant
	May	Making sense of clinical translation (Geneva)	Awarded competitive place to present
		PGR conference	Senior student participant
	June	ESRC overseas institutional visit (Maastricht)	Awarded funding for visit

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