Synthetic biology in the making: funding, enrolling and training a (European) community

By:

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ABSTRACT

Communities as social units have been an object of considerable theoretical interest within STS. The emergence of such communities, however, has enjoyed far less attention. Likewise, the importance of shifts in funding practices has been well established (in science policy scholarship), but the ways in which funding arrangements and epistemic communities are entangled remain understudied. In this thesis I contribute to closing those gaps in the context of the study of synthetic biology. Synthetic biology is a recent field that encompasses multiple approaches to epistemic practice. It can be described as a field that brings engineering closer to biology – although to different extents in different approaches. Despite its immaturity, synthetic biology has enjoyed considerable attention and support from a constellation of social actors.

In this thesis, I draw on an empirical study of the emergence of (an) epistemic community in synthetic biology. I do so with an emphasis on the European scene. I trace the emergence and trajectory of the (European) community in the context of the EU funding programmes, and zoom in on a (string of) project(s) dedicated to the synthetic biology of cyanobacteria. I temper this European focus with a study of iGEM (the competition and beyond). In particular, I trace the community as emerging propelled by community-making devices, which drove the enrolment / training of researchers; and explore the repertoire on which it was grounded.

I note the ways in which iGEM was a driver of epistemic purity, which was coopted by and, yet, contrasts with the messy process of making a European community. In the latter context, I contend that funding played a key role in opening up/

closing down the trajectories of the community, in a process of co-production of synthetic biology and a particular European Union; and that funding drove the foregrounding of transient assemblages in the trajectory of the epistemic community which do not neatly fit along epistemic divides, conceptualising them as *communities of need*.

ACKNOWLEDGEMENTS

You may have already noticed this thesis is one concerned with the building of community. As I look back over the process which culminates with this large stack of (virtual) paper, it always amuses me to think about how meta it is that a thesis about community was only made possible because of the communities—old and new—where I (came to) belong.

First and foremost, I have a debt of gratitude towards my research participants. You were gracious and welcoming as I stepped into your world and tried to see through your eyes. I am thankful to the members of the CyanoBioFoundry project (a pseudonym, as is the case for the individuals named) for their insight into what a large synthetic biology project looks like; and I am thankful to the members of the 2014 Sheffield iGEM team for illuminating how novices come to be part of communities (and the bottle of wine).

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LIST OF ABBREVIATIONS

CA	Coordination Actions
CWG	Collaboration Working Group
EAV	European Added Value
EC	European Commission
EFTA	European Free Trade Association
ELSI	Ethical, Legal and Social Implications
ERA	European Research Area
ERC	European Research Council
ERA-NET	European Research Area-Network
ESF	European Science Foundation
ESRC	Economic and Social Research Council
FBI	Federal Bureau of Investigation
FET	Future and Emerging Technologies
FP	Framework Programme
HLEG	High Level Expert Group
iGEM	International Genetically Engineered Machine
KBBE	Knowledge Based Bio Economy
KBBE-NET	Knowledge Based Bio Economy- Network
KE	Knowledge Economy
MS	Member State
NEST	New Emerging Science and Technology
NRC	National Research Council
NSF	National Science Foundation
OPP	Obligatory Passage Point

PBR	PhotobBioReactors
PBSB	Parts-Based Synthetic Biology
RRI	Responsible Research and Innovation
SB	Synthetic Biology
SME	Small and Medium Enterprises
WP	Work Package

PART I

SETTING THE SCENE

1 SITUATING (THE EMERGENCE OF) SYNTHETIC BIOLOGY

> “The transformative potential of this simple principle is extraordinary, perhaps only comparable to the development of the steam engine in the 18th century. If this invention marked the start of domesticating physical energy for humanity’s benefit that began our modern era, synthetic biology will enable a new type of industry – and ultimately a society where biological agents and materials (from fuels and environmental catalysts to intelligent fabrics and smart therapeutic agents) will take over many of the roles that are currently assigned to far more primitive and inefficient counterparts.” (ERASynBio, 2014, p. 2)

If there is a critique to be made of synthetic biology, it would certainly not be on the basis of a lack of ambition. Indeed, from its very beginnings, synthetic biology has largely been imagined in that transformative frame. As (techno)science which would have a profound impact on society. This is also not an imaginary which circulates solely among research circles. Synthetic biology has been very successful in capturing the attention of governance actors across the world. It was, for example, referenced by the (then) UK Minister for Universities and Science as one of “The ‘eight great technologies’ which will propel the UK” (Willetts, 2013a), which he accompanied with the publication of a pamphlet (Willetts, 2013b) and the set up of a venture capital fund with the same name, for the promotion of those technologies (8GT, n.d.). In the European context, synthetic biology emerges as a “key enabling technology” (ERASynBio, 2014, p. 4) of the (industrial) biotechnology which is to herald the EU’s transition to a Bioeconomy.

Synthetic biology, then, emerges under the support (and scrutiny) of governance actors. It is my argument throughout this thesis that this relationship (and how it is managed, particularly through the enforcement of the *authority relations* (Gläser, 2010) through funding) is of key importance in the emergence of synthetic biology.

In this chapter, I start setting the scene for that argument, as well as the broader study of the emergence of an epistemic community. I do so in five sections: in 1.1, I outline the context against which synthetic biology is emerging, and how that context itself is in flux; in 1.2, I describe the trajectory of synthetic biology in broad strokes, and justify it as an object of study; I then move to an examination of what constitutes synthetic biology, and the pluralism which still reigns in 1.3; I provide a quick overview of the core academic literature on synthetic biology in 1.4; I outline the research questions which guided this thesis in the following section, 1.5; and I finish the chapter with an outline of the remaining chapters in this thesis, as 1.6.

1.1 GOVERNANCE AND CONTEMPORARY RESEARCH

Shortly before the point in time in which the emergence of synthetic biology began, social science scholars heaped attention on and produced a flurry of work examining changes to the relationship between science and society (e.g. Gibbons et al., 1994; Nowotny, Scott, & Gibbons, 2001; Ziman, 1994, 2000; Rip, 2004, p. 2004). (Ostensibly,) from the postwar period through much of the rest of the XX century, the social contract with science was one embodied in the “Science, the endless frontier” report (Bush, 1945) Vannevar Bush produced (at the bequest of the American president). Science was expected to benefit society, but to do so without interference. Societal benefit was, then, an emergent property of the conduct of research, in modes and directions decided by the researchers themselves. The new scholarship, however, argued that this contract had been ripped up; the purported independence of science now little more than a fiction; and the ivory tower repossessed.

A running thread between the different diagnoses (albeit in different ways and to different extent) is that the renegotiation of the social contract was concomitant with a “radical, irreversible, worldwide transformation in the way science is organised, managed and performed” (Ziman, 2000, p. 67). This transformation manifested in multiple ways. For one, science policy increasingly came to incorporate public policy goals (Lepori et al., 2007). For another, the topology of the science system changed, with the crowding of the landscape with new actors. Key among those are funding bodies / agencies. These took the role of *intermediaries*, decoupling science from the state (Musselin, 2014). A third important dimension is the change to patterns of funding. Over most of the XX century, resources for research were made available in the form of a recurring block grant. In contrast, the XXI century has witnessed the *projectification* (Vermeulen, 2010) of research, with funding being made available as part of a competitive process, and in short temporal horizons (Whitley, 2010).

Contemporary knowledge production, then, must contend with the sharing of epistemic authority between researchers and a veritable panoply of other actors. In *Mode 2* (Gibbons et al., 1994; Nowotny, Scott, & Gibbons, 2001) parlance, knowledge production becomes a *transgressive* practice, one that is *transgressively* bounded, and one which gives rise to *transgressive* institutions. In particular, as the state seeks to steer the trajectory of research and its outputs (mediated by *transgressive* funding bodies), it becomes stark that the performance of research requires a balancing act between the researchers' own epistemic interests, and those of a wider pool of actors in the (epistemic) community.

Thus, as actors in governance become increasingly adept in operationalising research, the production of knowledge is steered towards the production of "relevant knowledge" (Hessels & van Lente, 2008). What constitutes *relevant knowledge* is not a fixed notion, but a moving target. It changes in tandem with changes to science policy *fashions* (Rip, 2000). The European sphere is particularly rife with these fashions – e.g. Knowledge(-enabled) Economy, succeeded by the Knowledge-Based Bio Economy, succeeded by the Bioeconomy.

The steering of research, however, is problematised by the technicity of science. Researchers occupy a privileged position in relation to their research objects; a position which is beyond what is attainable to actors in governance. Thus, the steering of research has not taken place through direct intervention, but rather at arm's length, by setting thematic priorities and making access to resources contingent on meeting those priorities. In other words, governance actors steer research through its funding. This applies also to the emergence of new fields. In a model of "de facto governance" (Rip & Voß, 2013), in contemporary research funders have began to push for new areas / fields, even in the face of little interest of the extant research community, or when it is unclear whether it can be meaningfully said that such a field exists. I end this section with a question, following in the footsteps of Braun (1998), who made a compelling (albeit only theoretical) case for a role of funding in the *cognitive development of disciplines* – what does this funding (and wider governance) environment mean for the emergence of synthetic biology and its concomitant epistemic community?

1.2 TRACING THE EMERGENCE OF SYNTHETIC BIOLOGY

Synthetic biology has had a meteoric rise since its (contemporary) beginnings. It has been an area of prolific academic production, having jumped from a handful of publications to a pool of over 4500 within less than two decades (Raimbault, Cointet, & Joly, 2016). The speed at which synthetic biology appeared to be developing is in line with the assessment that "synthetic biology is *the* new technoscience" (Balmer, Bulpin, & Molyneux-Hodgson, 2016, p. 25). Figure 1 provides a rough outline of the increase in the number of publications through time and the geographic distribution of authors. As noted in the literature (Campos, 2009; National Research Council (U.S.) et al., 2013; Cameron, Bashor, & Collins, 2014), the early work stemmed largely out of the USA, which shines out when examining the geographic distribution of publications in the 1995-2004 period, shown in a). The dominance of American synthetic biology publications continued over the following four years, but that period also witnessed the emergence of a considerable volume of publications by researchers based in European countries (and, to a lesser extent, Japan), as shown in b). Moving another four years into the future, shown in c), reveals a sustained rise in the number of publications worldwide. Their geographic distribution also followed a

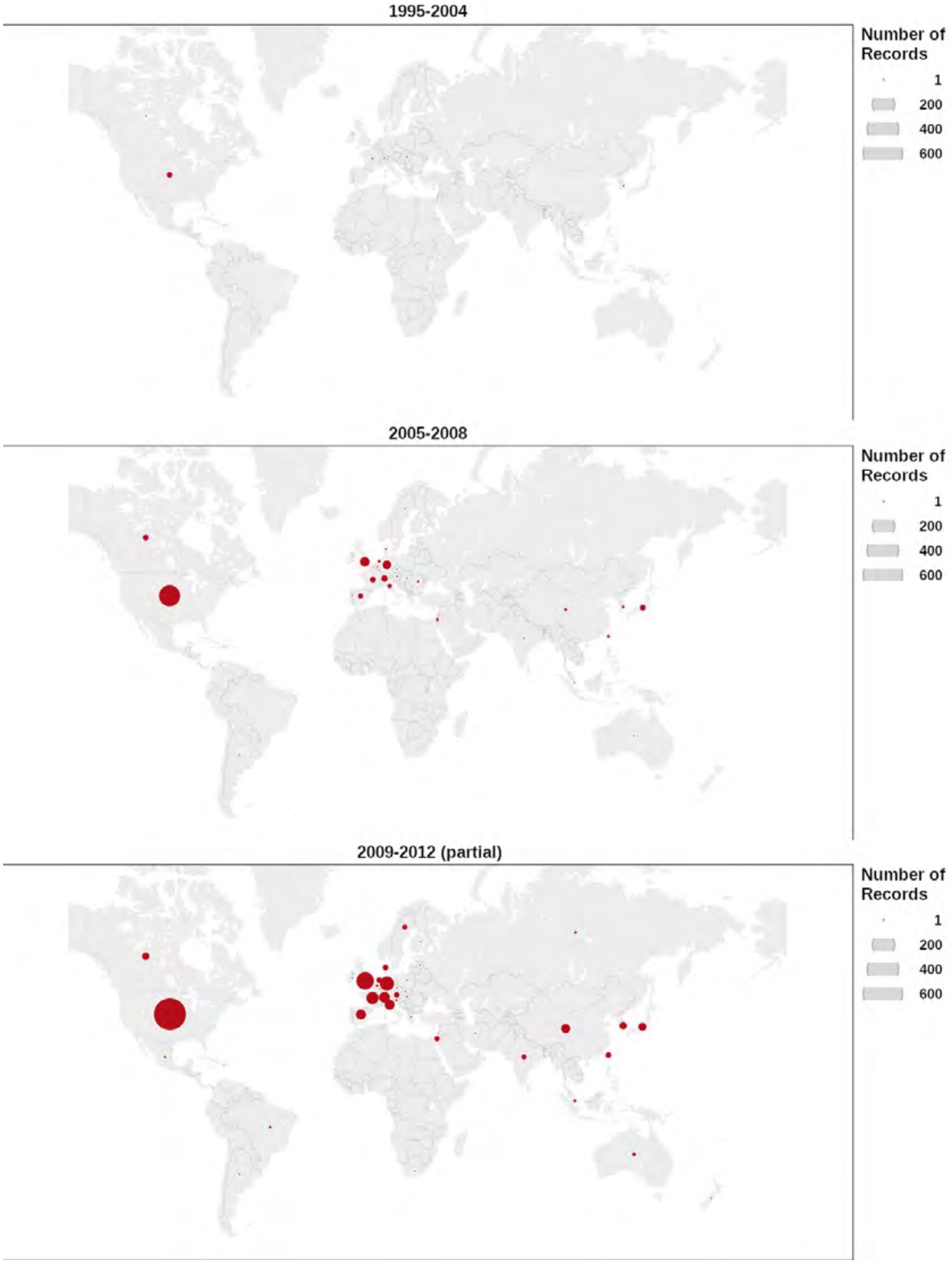

Figure 1: Number of synthetic biology publications per country of affiliation, between (a) 1995 and 2004; (b) 2005 and 2008; (c) 2009 up to mid-2012. Dataset from Oldham, Hall, & Burton (2012).

similar pattern, with publications by USA-based researchers continuing to greatly outnumber those of any other nation; research from European countries trailing the USA; and a number of new players, mostly to the East, ramping up the volume of publications.

The field was heating up, which was in no small part enabled by the wide availability of (public and private) funding, the sheer volume of which is impressive. Roughly 1 billion USD were invested in synthetic biology in the USA up to 2014. European funding took a (distant) second place, with a volume in the neighbourhood of 450 million EUR up to 2013. Patronage for synthetic biology in other regions was more timid in this period and/or had only recently started being offered – as was the case of China, where investment was in the vicinity of 200 million RMB (circa 30 million USD) in 2010 (OECD, 2014)[1]. Such patterns of funding are consistent with the geographies of publication outlined in Figure 1.

Figure 2 provides a more detailed snapshot of the how funding and publications were linked in the period of 2007-2011. The mapping of this complex ecology of public funding sources, as acknowledged in published synthetic biology research articles, makes explicit the existence of three institutions which were key funders of (published) research in synthetic biology: NIH, NSF and the European Union. NIH and NSF, the two American funding bodies which provided the majority of grants in the country, appear as the key funders of research published by USA-based researchers (and globally). In Europe, however, that role fell to the European Union. National funding bodies are mapped as smaller nodes, centred around the former. This suggests that, for the first decade of the century, funding synthetic biology in Europe fell largely on the shoulders of the EU – which is a remarkable departure from the role previously afforded to EU research, and is relevant in the context of the study of the epistemic community which became established.

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[1] However, investment in synthetic biology in several of these nations on a yearly basis was large – e.g. China was earmarking 260 million RMB (circa 40 million USD) to synthetic biology research per year in the years that followed (National Research Council (U.S.) et al., 2013). The contemporary funding and publication landscapes are likely to differ from those of the period analysed in this thesis.

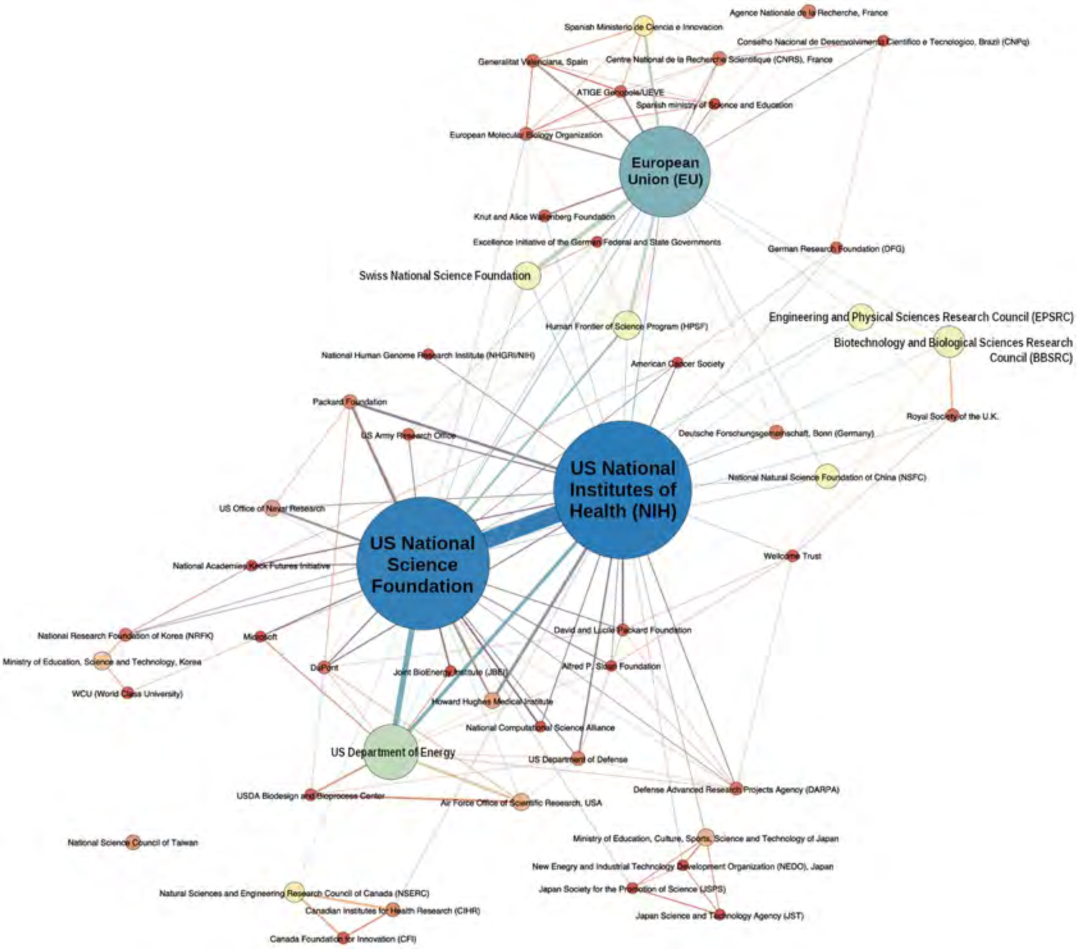

Figure 2: Top Funding Organizations referenced in research articles on synthetic biology catalogued in Web of Science database between 2007 and 2011. Adapted with permission from Oldham, Hall, & Burton (2012).

In national (European) contexts, the sole country which supported the development of synthetic biology since the early 2000s is Switzerland[2], with a string of programmes which maintained a close link between systems biology and synthetic biology (Pei, Gaisser, & Schmidt, 2012)[3]. Several other countries created funding pro-

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[2] In the interest of simplicity, in context of this thesis I do not make a distinction between the EFTA and EU nations. As all nations contribute to the Framework Programme and take part in it equally, I believe it is a justified decision.

[3] While no detailed exploration of the development in synthetic biology from many national (European) perspectives exists, readers are suggested to consult Pei, Gaisser, & Schmidt (2012), for a brief overview of a handful of countries and the integration of social scientists in the development of synthetic biology; Meyer (2013) for the placing of synthetic biology in France, and

grammes dedicated to the development of synthetic biology, and others yet took a "response mode" (ibid.) stance to the budding field. However, where dedicated support to the field was made available, it was so either towards the end of the decade or to the start of the current one. Even in the UK, where synthetic biology has been most strongly and consistently supported, dedicated funding was made available for networking activities only in 2007 and to the support of technical work two years later (Technology Strategy Board, 2012). In the intervening year, Denmark, another nation which has invested considerably in synthetic biology, gave the green light to the funding of the first large-scale centre for research in synthetic biology in Europe (OECD, 2014). High-profile initiatives followed in subsequent years in the Netherlands and France, as well as a number of more modest ones in Germany (ERASynBio, 2014).

As the new decade progressed, these initiatives multiplied, both within and across borders. Still, while support for synthetic biology was on the rise across Europe, the new decade witnessed little reduction in the asymmetry of patronage among the nations. The UK was a clear outlier in the sheer volume of funding made available to synthetic biology, a stance which was tied to a particular domestic context, as noted in the first section. This state, along with four others – Denmark, France, the Netherlands and Switzerland – made up the bulk of European funding in national spheres. The sole other major funder of synthetic biology over this period, making up (slightly shy of) a quarter of European public funding was (trans or) supranational. It was, in its various guises, (administered by) the European Union.

The European Union thus appears as a key actor in the making of synthetic biology in Europe. From the standpoint of temporality, the EU was the sole major funder of synthetic biology in Europe across most of the first decade of the century, and continued to be a major funder into the following decade. In addition, the different trajectory synthetic biology took within the national spheres meant the funding landscape was patchy. Even as time went on, EU funding remained a (if not the) key enabler for carrying out synthetic biology research in many European countries. As

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Meyer & Molyneux-Hodgson (2016) for the synthetic biology in the UK and France.

such, the European sphere configures a productive arena where to study the emergence of an epistemic community. I now move to an examination of the many faces of synthetic biology and extant scholarly work.

1.3 A LOOK (BEHIND THE CURTAIN OF) SYNTHETIC BIOLOGY

In the early 2000s, several approaches operated under the umbrella of synthetic biology. These can be loosely categorised as approaches modelled on engineering, and approaches modelled on chemistry (Bensaude Vincent, 2013). The latter, however, quickly waned and dissolved into the ether. As such, contemporary synthetic biology is a field which draws on an engineering ethos. Among the approaches which (still) operate under this reduced umbrella, one has gained particular purchase – a parts-based, modular approach. Its definition for synthetic biology is also the most popular, reading

> "Synthetic Biology is
> A) the design and construction of new biological parts, devices, and systems, and
> B) the re-design of existing, natural biological systems for useful purposes." ('Synthetic Biology - OpenWetWare')

Synthetic biology can thus be productively characterised by a *drive to make* (Schyfter, 2013). And a drive to make following a particular ethos. One of the pioneers of synthetic biology – Drew Endy – made the engineering ethos clear from early on, positing synthetic biology was underpinned by a tripartite engineering approach: those of abstraction, decoupling and standardisation (Endy, 2005). Over the years, that triumvirate expanded to encompass a quinum...well, five points:

- "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
- Decoupling: de-linking the requirements for design from requirements for manufacture to allow non-biologists to use biological components in various applications
- Modeling: testing the projected design and its function" (National Research Council (U.S.) et al., 2013, p. 12)

In this way, synthetic biology is drawn explicitly along the core tenets of (some) engineering ethos. Indeed, a similar characterisation can be found, for example, in papers describing *process engineering* (e.g. Chatha & Weston, 2005). In this conceptualisation of the manipulation of biological material underpinned by an overriding engineering ethos, the proponents of this approach make a case for a synthetic biology driven by the rational (re)design of biological entities. This stance has come to prominence, again, underpinned by the parts-based imaginary. In this imaginary, metabolic pathways become *circuits*. Genes and ancillary DNA sequences (e.g. promoters, ribosome binding sites, terminators, etc.) become *parts*. These parts are then combined for a particular purpose, with the resulting biological mass consisting of a *device*. And, lastly, these devices can be combined for a higher level purpose, resulting in a *system*. This imaginary has its greatest proponent in iGEM, which I will address shortly.

It would be reductive, however, to frame synthetic biology as fitting wholly under this imaginary. Indeed, synthetic biology is characterised by *epistemic pluralism* (Chang, 2012). This is made clear by looking at different approaches operating under the synthetic biology umbrella, portrayed schematically in Figure 3. While the diagram does not include all (contemporary) approaches to synthetic biology, its pluralism shines through nonetheless. Epistemic commitment to one approach frames the locus of work and the epistemic practice and problems for researchers.

Having introduced synthetic biology, I will now briefly locate its study in the STS literature. Firstly, a link between systems and synthetic biology has been established, with synthetic biology being described as the sister / other side of the (epistemic) coin to systems biology (Calvert, 2008; Kastenhofer, 2013). Yet, while systems biology is driven by an attempt to understand biology, synthetic biology strives

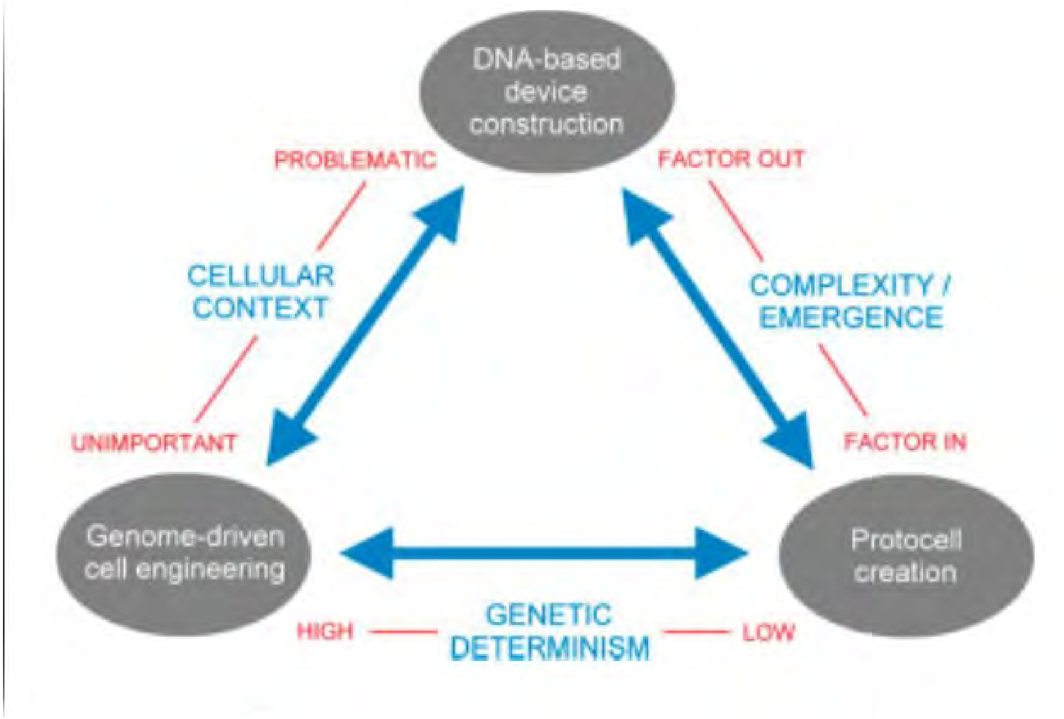

Figure 3: Epistemic dynamics in different approaches to synthetic biology. Reprinted from O'Malley et al. (2008).

to manipulate it. Indeed, the attempts of synthetic biology at manipulating biological systems has been interpreted under the guise of (an attempt of) standardising life (Calvert, 2013; Mackenzie et al., 2013), or at least *changing* it (Keller, 2009).

From the point of view of practice, the imagination of rational, clean control over biology has faced a hurdle in its unwieldiness; where design was meant to be, there was plenty of *kludge* (O'Malley, 2009). Yet, the driving ethos nevertheless can be said to have had an impact on practice and collaboration (Mackenzie, 2010). Despite these hurdles, synthetic biology is still firmly cast as *promissory science* (Hedgecoe, 2003). It is a field firmly shrouded in a promissory mantle. Still, promises run against the tyranny of time, which imposes a gradated temporality on their materialisation (Mackenzie et al., 2013); they also lock the field in a promise-requirement cycle (van Lente & Rip, 1998) as those promises are taken up by institutional actors

(Schyfter & Calvert, 2015). In fact, a literature on the expectations surrounding synthetic biology is emerging (ibid.; Hilgartner, 2015; Marris, 2015).

* * *

Moving back to an outline of synthetic biology, I now address iGEM. It is fitting to address it against the backdrop of promises, for the promise(s) of synthetic biology permeates iGEM. The iGEM competition is a key marker of synthetic biology. The competition, stemming from MIT in the early 2000s, is both firmly rooted in, and a key driver of a parts-based synthetic biology imaginary[4]. The competition is geared towards novices, who compete as teams, devising a synthetic biology project over a period of months (ostensibly the summer months), underpinned by the use (and subsequent contribution) of *BioBricks*. Biobricks consist of DNA *parts* conforming to a particular standard. iGEM constitutes a veritable sandbox for synthetic biology, with experimentation (and fun) being virtually constitutive of the competition. It is also an arena where practices are expected to go beyond the biology, driven by a reward system which promotes participation as a combination of lab bench work, but also dry lab work (notably modelling) and *human practices* work (a broad category, encompassing a range of practices which would be typical of ELSI, extending to practices expected of RRI).

The competition is *co-produced* (Jasanoff, 2004) alongside the Registry of Standard Biological Parts (registry) – a digital and material knowledge infrastructure, which holds the catalogue of BioBricks. The registry also serves as a bridge to a more modest (and less discussed) strand of iGEM – that of the iGEM Labs programme. If the competition addresses novices, the labs programme is an attempt to address es-

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[4] In the context of this thesis, I address the approach of modular, parts-based synthetic biology under the banner of parts-based synthetic biology (PBSB). This approach is also described under *regulatory circuits* (ERASynBio, 2014) or DNA-based device construction (O'Malley et al., 2008), which may in some senses deviate slightly from the PBSB approach/imaginary, but not in meaningful ways in the context of the themes I address in this thesis.

tablished researchers. Participation in the Labs programme is the only avenue for actors beyond the iGEM competition to access the BioBrick parts in the registry.

To my knowledge, there has been no examination of the iGEM Labs programme thus far. On the other hand, the iGEM competition has been robustly studied. From the point of view of student teams, the key contribution is an ethnographic study of two (concurrent) iGEM team entries (Cockerton, 2011). In a broader perspective, Frow (2013) examined what value means through the examination of the currency of the competition – BioBricks. Intersecting with notions of value, the ownership regimes in the competition have also been studied (Calvert, 2012) and linked to a *diverse ecology* among other prevailing regimes – a theme which is further addressed in the broad examination of commodification in synthetic biology (Calvert, 2008). The relevance of iGEM is brought to the fore again in a publication which argues the competition is altogether crafting a new moral economy for synthetic biology (Frow & Calvert, 2013). Not only that, but iGEM has been interpreted as *disciplining* the students as epistemic subjects (aligned with that moral economy) (Bulpin & Molyneux-Hodgson, 2013).

The last two contributions, along with Cockerton (2011) touch on the emergence and aesthetic of epistemic community in synthetic biology. They do so, however, only in the context of the iGEM competition. Beyond these, the community has been described as being grounded in its *referent disciplines* (Bensaude-Vincent, 2016); as encompassing three (sub)communities with different epistemic commitments (Schyfter & Calvert, 2015); through the lens of *community-making devices* (Molyneux-Hodgson & Meyer, 2009); and through accounts of its *placing* in the French and UK contexts (Meyer, 2013; Meyer & Molyneux-Hodgson, 2016). Thus, considerable gaps remain on the study of the emergence of epistemic community in synthetic biology – gaps well suited to empirical study. I move now to an outline of the research questions which underpin the work presented in this thesis.

1.4 RESEARCH QUESTIONS

This thesis aims to explore the emergence of community in synthetic biology, with a focus on its emergence in Europe. This is an exploration driven by two guiding research questions, as well as three interrelated sub-questions:

- What does community in an emerging synthetic biology look like?
  - In what ways do the global and the local intersect in the emerging of a European synthetic biology?
- How is a synthetic biology community emerging?
  - What role does governance (and, in particular, funding) play in the trajectory of the emerging community?
  - In what ways are the trajectories of European synthetic biology and of the European Union entangled?

I now finish this chapter with an outline of the thesis.

1.5 THESIS OUTLINE

This thesis is composed of nine chapters. In this section, I outline the contents of the following eight chapters, in tandem with the role they play in the overall thesis.

Part I encompasses two further chapters. In Chapter 2, I provide a review of the literature on whose shoulders this thesis stands. I start with an examination of the changing role of science in society, with emphasis on the way knowledge production has become associated with particular (socio-technical) imaginaries. I move to an exploration of the literature on the governance of science, with emphasis on contributions regarding the role of funding as a mechanism of governance. I progress further on this path, in sections addressing governance at different scales. I start with a review of literature on macro-scale changes to governance and how they link to research; I then move to a review of literature on the link between governance and scientific fields; and I finish the section with a focus on the micro-scale, examining the literature on governance and changes to research practice. In a third section, I address the literature on collectives in science. I outline the value of the conceptualisations of collective in the literature; I examine its problematisation and its use across languages; and I finish with a review of contributions on concept of epistemic communities in greater detail, in tandem with two key concepts for their study.

In Chapter 3, I provide the rationale for the methodology I employed, as well as an outline of what my multi-sited ethnography entailed. I do so with some playful engagement with the concept of *messiness*, which serves as the starting point of the chapter. I then move to address my positionality and the reasoning for my choices in object of study and research design (as well as the changes to plans). In the following section, I address the theory-method nexus which underpinned my work, to some extent encapsulated in the common STS (or, rather, ANT) motto of *follow the actors*. I then move to an account of how I conducted my multi-sited ethnography. I provide a rationale for / detail of the methods I employed in data gathering, as well as the process of analysis and writing. I finish the chapter with a reflection on ethics, as a bureaucratic, discrete hurdle, but also as process, and how that impacted on decisions during the course of the fieldwork and in the writing process.

I then move to Part II, which is concerned with an exploration of the making of European synthetic biology. This part is composed of two chapters. Chapter 4 is a brief introductory chapter, whose aim is to contextualise the twists and turns of research in the European sphere. I provide a brief account of a long-standing role for research in that sphere, and link it to the legalistic modus operandi of the European Union (and its predecessors), with particular emphasis on the concept of European Added Value, and how it was used to justify/bound research. I argue that a change in the definition of what constituted added value in the lead up to the Framework Programme 6 is of key importance for research / community with a dedicated European locus, and trace its further expansion into the Framework Programme 7, with further consequence for community. I finish with a link to the imaginaries which drove / enabled European research, and their own link to the EU bureaucracy, noting what that meant for European integration and the concomitantly changing role of science.

In Chapter 5 I provide an overview of the emergence of synthetic biology in the context of the European Framework 6/7 programmes, foregrounding issues of funding and entanglement with governance actors. I explore the emergence of epistemic community in three sections. Firstly, I address the imagination of community, in an interplay between researchers, governance actors and funding, leading to the leveraging of an epistemic community through a community of promise. Secondly, I explore the dedicated efforts for *making* a community (with an emphasis on human actors). I note the importance of the promissory background, and trace the ways in which community was being built, as well as who was being trained/enrolled. I further note a role for community-making that spilled over the geographic boundaries of Europe. Thirdly, I explore what the practice of synthetic biology in a European context entailed, with particular emphasis on what it *was to do* and what it *could not do*, through impositions of the governance regime. I argue that the changing governance regime, enacted through funding (restrictions) drove synthetic biology to different practices and outputs over time, thus affording funding a role in opening up/closing down trajectories for the epistemic community.

These chapters are followed by Part III. In this part, I address the European, Framework Programme 7 funded, synthetic biology project which was the key locus of my empirical work – CyanoBioFoundry. I also look back to the project that preceded it – CyanoH2Modules – and forward, to the multitude of potential futures which were considered. This part is composed of two chapters. In Chapter 6, I sketch out the structure of CyanoH2Modules and CyanoBioFoundry, how they were imagined to work, and how they were linked to the building of epistemic community, through training, enrolment and the contribution to a repertoire. I start with an examination of the CyanoH2Modules project. I analyse the ways in which the project was imagined and structured to fulfil its remit under the FP6 NEST programme.

Further, I argue that this remit can be traced to the outcomes / legacy of the project. I then move to a similar examination of CyanoBioFoundry. I note, however, that the more onerous conditions under which the project was funded required consistent negotiation against those (perceived) demands. I argue this was of consequence for what synthetic biology *was* in the context of the project. I finish the chapter with a reflection on how the projects converged and diverged in the making of epistemic community, largely in the context of the contribution to a repertoire and against the demands of funders.

In the ensuing Chapter 7, I address these projects once more, albeit in a shifted temporality. Chapter 7 is anchored in period between the end of CyanoH2Modules and the beginning of CyanoBioFoundry, and over the period of CyanoBioFoundry, as multiple successors / potential futures were imagined. As such, the chapter is focused on the reassembling of coalitions of actors for the continuation of synthetic biology research in the European sphere. Here, the questions of funding and the imaginaries funding was to promote take centre stage. I start with an examination of the assembly of the CyanoBioFoundry project. I note this was a protracted, challenging process due to the epistemic control exerted by the funding instruments made available by the European Commission, which required thorough reshaping of the project. I then move to the (many) ways in which a variety of potential new projects were being imagined and prepared over the course of CyanoBioFoundry, in a testament to the precariousness of a projectified, competitive model of research. I address the different strategies participants took in a bid to maintain access to resources, which were consistently made in recognition that a break up was inevitable, and also against potential funding avenues. I note a particular cultivation of a relationship with a researcher/project from Japan, and explore why it was cultivated. Lastly, I address community-making in this context as a combination of *movement* and the creation of *stickiness*, and argue that funding pressures were driving where to move or who to stick to; and I finish with a discussion of the way in which funding impacted on what was a *doable* synthetic biology project, by constraining what was a *findable* research project, with concomitant impact on the community membership and repertoire.

Next, I move to Part IV. This part addresses iGEM – the competition, the Registry of Standard Biological Parts, and the Labs programme. It is composed of a sole chapter. In Chapter 8 I address the ways in which epistemic community is built in iGEM broadly defined, with an emphasis on the concepts of community-making devices, repertoires, and disciplining. I start with a section tracing the trajectory of the iGEM competition until 2014, with its attempts to enrol and sustain membership. I then move to an exploration of the evolving and formalising ethos, set of practices and reward system in iGEM, and how that guided participation and promoted the creation of particular epistemic subjects. I then move my gaze beyond the competition, starting with the registry. I outline its trajectory and its tussles with the unwieldiness of biology. I note its downgrading from an imagination as a universal obligatory passage point in synthetic biology to one solely in the iGEM competition, which it co-opted in the fight against the unwieldy biology. I then address the Labs programme, with a brief examination of how researchers engaged with the programme, and a suggestion of a split in the community.

I finish the thesis with Part V. This is also composed of a sole, discussion / conclusion chapter. I start by restating the research questions and briefly outlining my key contributions. I then proceed to address them in more detail. I start with an examination of the link between iGEM and European synthetic biology, noting how the former became a de facto training ground for the latter. I also argue the link between iGEM and European synthetic biology is of epistemic consequence for the latter – not so much in the context of established researchers, but because it brings into the fold a generation of novices *disciplined* under an iGEM imaginary. I note further that this exposes a generational divide. I then move to an exploration of the co-production of a particular European synthetic biology and a particular European Union. I argue that the effect described on the epistemic community evidences the role and forcefulness of a mode of *governance by funding*. I finish the chapter with a reflection on the consequence of these environments in the trajectories of epistemic communities. I propose that against a mode of research which is projectified, temporally irregular, steered towards particular goals/outputs and where funding is recruited in the exertion of the authority of governance actors, a concept of community which addresses transience and instrumentality is of consequence. I propose such a concept, naming it "communities of need".

2 CHANGING COLLECTIVES, CHANGING GOVERNANCE, CHANGING SOCIETY – SCIENCE THROUGH THE MOTIONS

In this chapter, I provide an overview of the literature which is of particular relevance to this thesis. In section 2.1, I start by outlining existing literature on the role of science in society, with particular focus on the multitude of diagnoses of change and how the overall process of change is linked to (socio-technical) imaginaries. In the following section, I examine the range of contributions on the wider theme of governance of science, albeit with a focus on the literature addressing funding as a (governance) mechanism. Inevitably, I bring together science policy studies and STS and attempt to contextualise the literatures against each other. Section 2.2 is organised in three sub-sections according to scale. 2.2.1 maps the (science policy studies-heavy) work on macro-scale changes to governance and their link to research; 2.2.2 is focused on the link between governance in the context of scientific fields; and 2.2.3 explores the link between governance (largely via allocation of resources) and changes to research practice.

The last section of this chapter (2.3) is one I devote to the literature on the collectives in science. I start by briefly introducing the changing conceptualisations of and value attached to collectives in the sociology of science / STS literature. I then proceed with a brief detour through the problematisation of the concept of community, with particular emphasis on its use across language (2.3.1). In the final section (2.3.2) I provide a more focused account of epistemic communities as a key concept in the study of scientific communities, and finish with an examination of empirical work around the concept and two analytic tools which underpin the examination of epistemic communities in this thesis.

2.1 SCIENCE IN SOCIETY

Historically, the link between (the epistemology of) science and society is one that has only been reluctantly made. Polanyi's The Republic of Science (Polanyi 2000 [1962]) paints a picture of science as a self-contained moral economy, built on scientific criteria alone and, based on the latter, "guided as by 'an invisible hand' towards the joint discovery of a hidden system of things" (ibid. p. 3). In the Structure of Scientific Revolutions (Kuhn 2012 [1962]), Kuhn's model for the conduct of science – crystallised around periods of normal science and paradigmatic shifts – is restricted to the sites of pedagogy and research as locus, and to novices and scientists as actors. Merton's (The) Normative Structure of Science (Merton 1973 [1942]) is constructed around four principles which encompass the ethos of science – communism, universalism, disinterestedness and organised scepticism – which share in the same internalist focus.

Nevertheless, even in such internalist accounts, the link between science and society is drawn, if at the sidelines. Polanyi's essay was a sound rejection of administrative plans for greater control over research; this attempt at interfering with the existing moral economy is explicitly present in a vignette, where he describes (vociferous opposition to) a proposal to coordinate the appointments of university chairs across the UK in a bid to maximise the range of specialisms and minimise duplication. Conversely, Merton(ian)'s norms are presented as normative, but alongside / as having to contend with a reward system guided by criteria not (necessarily) congruent with the former. Still, if a bridge from the ivory tower to society at large was built, it remained largely uncrossed. The internalist focus of these studies of the role of science in society and the theory of scientific change was, over time, matched by competing studies with an explicit externalist gaze. This led to a protracted dialectic debate, an overview of which can be found in Shapin (1992). The debate is of relatively little interest for contemporary research, in that it is essentialist and reifies a border eschewed by contemporary STS[5]. Reference to the externalist studies is, however, relevant, insofar as their existence provides an explicit recognition of a role for actors beyond researchers in the trajectory of (the epistemology of) science.

Starting in the 1970s, studies which cut across the aforementioned dichotomy started to emerge. One such contribution merits attention, in that it contributes to contemporary diagnoses / debates. Elzinga (1985) proposed that institutional environments where pressures of accountability and *relevance* of research outputs are severe and conducive to what he dubbed "epistemic drift" (ibid.). That is, the criteria on which researchers relied to develop and maintain research agendas were no longer just *internalist*, but instead *drifted* to encompass criteria of political and administrative relevance. Hybrid research agendas, then, were created to satisfy both (potentially competing) pressures through a process of "'internalisation' of external norms" (Elzinga 1997, 439). This work alludes to a combination of an increasing interest in a symmetrical approach to the study of the nature and role of science in society, as well as changes to that relationship. In subsequent years, the interest in that object of study has grown, and a multitude of general diagnoses of (changes to) the role of science in society have been proposed. I now turn briefly to address those studies.

Over the past four decades, the shifts in the relationship between science and society have been diagnosed as (among others), the advent of *strategic research*; *post-normal science*; *post-academic science*; a *Triple Helix* model and a new typology of knowledge production with the introduction of a *Mode 2* of research. I will outline these diagnoses, and propose a broad typology at the end. "Strategic research" (Irvine and Martin 1984) is defined as "basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognized current or future practical problems" (Irvine and Martin 1984). It is peculiar amongst the other concepts for its focus on basic research and the decoupling of knowledge production and potential use. Yet, the ostensible epi-

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[5] In contemporary STS, both *internal* and *external* are deemed relevant, and addressed through different lenses. A key example is the concept of *co-production*, which I introduce below.

stemic freedom is diminished by an embedded expectation that the research is, ultimately, of potential relevance from a societal standpoint[6].

"Post-normal science" (Funtowicz and Ravetz 1993) embodies a prescriptive stance which has grown to a research agenda focused on scenarios where "facts are uncertain, values in dispute, stakes high, and decisions urgent" (ibid, p. 744). The allusion to "normal" science was deliberately chosen as a reference to Thomas Kuhn's (1970) description of paradigmatic science, which post-normal science rejects. For the latter, the conventional processes of knowledge generation of normal science are deemed unfit, and different coalitions of actors (with a focus on the public) and potential broad, transdisciplinary mode of epistemic practice are described as essential for the production of robust knowledge. In this way, "post-normal" science encompasses a form of input and review from an "extended peer community" (Funtowicz and Ravetz 1993).

"Post-academic science" (J. Ziman 2000; J. M. Ziman 1994)(or "post-industrial" science (J. Ziman 1996))is a concept Ziman progressively built and anchored around other diagnoses, with a particular focus on Mode 2. It is a term indicative of a "radical, irreversible, worldwide transformation in the way science is organised, managed and performed" (J. Ziman 2000, 67) away from a model which followed the Mertonian norms (Merton 1973 [1942]). In an homage to the latter, post-academic science can be broadly characterised against five principles: collectivism, with collaboration and the sharing of research instruments and infrastructure being dominant; asymmetry between the volume of funding requested and of that made available, which obligates the comparative assessment of requests; focus on societal relevance and/or economic return stemming from research activities; foregrounding of access to financial resources over traditional reward systems, which is prompted by a parallel foregrounding of science policy and increase in salience of conditions for funding;

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[6] Rip (2000, 2004) built on the original concept and extended it to a knowledge regime combining the focus on relevance with one on excellence. His strategic *science* regime was characterised by the creation and weaving of regional "centres for excellence and relevance" (Rip 2004) in the fabric of the research enterprise, combined with a reconfiguration of universities as loci of regional specialisation and focus on academic excellence (Rip 2002a).

and the industrialisation of science, with links between the academic-industrial divide strengthening and ultimately placing the latter driving the former. This diagnosis is particularly interesting in the context of this thesis for the direct link it makes between funding and changes to the science system:

> "The academic culture is sustained by a tacit 'social contract' between the scientific community and society. It is thus very susceptible to apparently innocuous changes in the terms of this contract. For example, as researchers become more dependent on project grants, the 'Matthew Effect' is enhanced. Competition for real money takes precedence over competition for scientific credibility as the driving force of science. With so many researchers relying completely on research grants or contracts for their personal livelihood, winning these becomes an end in itself. Research groups are transformed into small business enterprises. […] By accepting state patronage on such a large scale, scientists have become very vulnerable to the demands of their paymasters." (J. Ziman 2000, 76)

This passage illustrates the second and fourth principles of post-academic science. Ziman draws an explicit link between the changes to the prevailing social contract and the vulnerability of researchers to those changes, due to the foregrounding of and mediated by funding (instruments). These changes are posited to reconfigure the reward system of science and, by extension, the epistemic practice. I develop this theme further in section 2.2.

The "triple helix" (Etzkowitz and Leydesdorff 1995, 2000) is a(n empirically) heuristic model predicated on the increasing interdependence of the university, industry and government. Rather than having the university, industry and government as three separate societal domains, the authors argue the three spheres have become entangled, forming a *triple helix*. The specific configuration of the triple helix is contingent, requiring empirical investigation, and unstable, much like the biological configuration after which it is (deliberately) named. In any case, however, the interactions between the triad are posited to lead to the creation of hybrid institutions, sharing in the configuration of one (or both) of the others to varying degree.

Lastly, there is a proposition of a "Mode 2" of research (Gibbons et al. 1994; Nowotny, Scott, and Gibbons 2001). In The New Production of Knowledge, Gibbons et al. (1994) assert the existence of changes in knowledge production away from a traditional disciplinary model, but in a panoply of heterogeneous actors, models and contexts. This shift is crystallised in the proposition of research taking place according to two *modes*. Mode 1 is framed as one of traditional knowledge production. They contend this is knowledge produced in an academic context, within disciplinary boundaries, with the (epistemic) communities being autonomous and the knowledge produced (de)valued according to established epistemic hierarchies and canon. Mode 1 is then a model of knowledge production as *wissenschaft* – as an academic enterprise broadly defined (see Phillips (2015) for a brief overview of the concept and translation efforts). The core assertion of the book resides in the shift away from a Mode 1 in response to the inclusion of different actors and rationales in contemporary knowledge production, which they deem to be increasingly prevalent.

Mode 2 is presented as a stark departure. Under this model, "knowledge production takes place within and between open and shifting boundaries. It consists of the reconfiguration of knowledge and people. It is transgressively bounded because, in ways that still need to be spelled out in detail, a new kind of integration with the context is made possible" (Gibbons et al. 1994, 19). Mode 2 knowledge is thus framed as inevitably heterogeneous, and unable to be subsumed into existing repertoires (Leonelli and Ankeny 2015)) (a term I discuss in section 2.3.3). It is knowledge whose locus is firmly rooted in the "context of application" (ibid.), and not in existing epistemic communities. It is knowledge that, due to the organisation around the context of application, requires *transdisciplinary* ways of working, which are not reconcilable with existing *repertoires*. Through the inclusion of actors beyond those of the research community – another dimension of transgression – it incorporates different rationales for the conduct of knowledge production and different criteria for the evaluation of the knowledge produced. Rather than science conducted in an ivory tower, Mode 2 epitomizes a mode where "society now 'speaks back' to science. In this process science is being transformed [...] not only in its forms of organization, division of labour and day-to-day practices but also deep down in its epistemological core." (Nowotny, Scott, and Gibbons 2001, 94). Consequently, the emergence of

Mode 2 research is linked to far-reaching changes to the ontology, topology and epistemology of research.

This diagnosis is, by far, the most popular (Hessels and van Lente 2008) and the one which has been more roundly criticised[7]. In response to many of these criticisms, Nowotny et al. (2001) published a new volume, rebuking many and clarifying the analytic frame. A key clarification was an emphasis of the coexistence of Mode 1 and Mode 2 in the contemporary overall regime of knowledge production, rather than the replacement of the former. Of particular relevance to this thesis, however, is the extension of the notion of transgression to encompass institutions. So, not only was the production of knowledge seen as transgressive, but also the institutions which underpin it – be they policy rooms, funding bodies or universities. Furthermore, in a chapter aptly entitled "The Co-Evolution of Society and Science" (ibid.), the authors link the emergence of the "Knowledge Society" (W. W. Powell and Snellman 2004) and the "Risk Society" (Beck 1992) (and, later (Nowotny, Scott, and Gibbons 2003), of the "Audit Society" (Power 1997)) to the emergence of Mode 2.

A meta-analysis of these diagnoses suggests a shift away from the social contract which oversaw much of the XX century, epitomised in Vannevar Bush's "Science, the endless frontier" report (Bush 1945) and codified in the claim that "scientific progress on a broad front results from the free play of free intellects, working on subjects of their own choice, in the manner dictated by their curiosity for exploration of the unknown". (ibid., p. 7). In the report, Bush proposed that science was expected to deliver societal benefit, but those benefits would be best harnessed by ensuring the autonomy of the scientific enterprise. Instead, contemporary research is proposed to

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[7] Prominent critiques include the absence of novelty as a diagnosis (as "old wine in new bottles", in its proximity to the concept of finalisation science (Weingart 1997)) and of Mode 2 as a model (with Pestre (2003) describing knowledge production that fits "mode 2" as far back as the 16th century); the coherence of the model itself (Rip 2002b) ;as an overreach of the dismissal of disciplines by positing a loss of "their function as social organization and cognitive frame of orientation" (Weingart 1997, 596); as failing to take into account the heterogeneity of national contexts (Shinn 2002); and of treading a line between a diagnosis and a "political manifesto" (ibid.), or taking a form of "performative discourse" (Weingart 1997).

take place under a different contract – one which is oriented towards the production of "relevant knowledge" (Hessels and van Lente 2008).

A broad typology of the diagnoses described can be distilled as a rise to prominence of modes of knowledge production which move epistemic control away from researchers. Instead, the knowledge produced sits at the intersection of rationales, processes and outcomes which satisfy researchers and a varying pool of other societal actors. Through this process, *hybrid* or *transgressive* institutions emerge, which have an anchoring (and enduring) effect in redirecting knowledge production to varying conceptions of relevance or societal benefit. These conceptions are also not fixed, but moving targets; and wide-reaching in how they imagine societal reconfigurations in tandem with knowledge production. In this way, this mode of contemporary research can be said to be oriented towards and intimately linked to "socio-technical imaginaries" (Jasanoff and Kim 2009). That is, knowledge production is oriented towards fulfilling

> "collectively held, institutionally stabilised and publicly performed visions of desirable futures, animated by shared understanding of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff and Kim 2015, 120)

Taking Nowotny et al (2001)'s example, a Mode 2 of knowledge production in the European Union is linked to its reinvention as a Knowledge Society. Further, the tying of knowledge production to a particular socio-technical imaginary (or imaginaries) gives rise to the "co-production" (Jasanoff 2004) of science and society, for

> "Scientific knowledge [...] 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." (ibid., p. 3)

Thus, the renegotiation of the social contract which drove the rearrangement of the entities which made up the social world, as well as the links between them, also means a renegotiation of the ontology, epistemology and topology of science. I dedicate the following section to an exploration of that process and the resulting aesthetic. In the wider context of the thesis, this linkage to socio-technical imaginaries is of particular relevance to EU synthetic biology, and is a theme I explore in Chapter 4. Moreover, the co-production of a particular European Union and a particular (EU) synthetic biology is the focus of Chapters 5 and 7, and an important reflection in Chapter 9.

2.2 CHANGING GOVERNANCE, CHANGING SCIENCE

The aforementioned diagnoses bring to the fore the link between governance and knowledge production. I will show in this section how that link has been progressively strengthened. Governing science, however, presents a particular problem in the sense that the specificity and degree of specialisation of scientific research defies the direct steering of its content (Musselin 2007; Richard Whitley 2008). Thus, the governance of science has taken place mostly through the (de)legitimation of research, and the process of allocation of resources. The exertion of control over legitimacy of research is peripheral to this thesis (and in governance itself)[8]. As such, the allocation of resources stands as the key conduit for the interaction between science and the state.

The link between governance and knowledge production, particularly seen through the modes of allocation of resources has been in flux, as noted in the previous section. After the postwar period, there was a gradual embedding of public policy goals in science policy (Lepori et al. 2007; Hessels, Grin, and Smits 2011). In tandem, the increase in the volume of researchers (and the concomitant demands for funding) outpaced the growth of funding (Cozzens 1986), leading to what Ziman dubbed a “dynamic steady-state” (J. M. Ziman 1994) – an environment where the resources for science have stabilised at a ceiling and researchers must conduct epistemic labour against that limitation. These changes, coupled with an increasingly

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[8] Nevertheless, a notable (and poignant) example of control through delegitimation is the banning of embryonic stem cell research and human cloning (Isasi and Knoppers 2006).

active role of the state in steering research (outputs) has prompted the reinterpretation of relations of governance by a frame of "authority relations" (or relationships) (Richard Whitley, Gläser, and Engwall 2010; Richard Whitley and Gläser 2014; Gläser and Laudel 2016). Over this section, I explore how that authority was exercised (and resisted) and the resulting impact on the science system. I start with an examination of macro-scale changes to the science system, followed by work at the level of fields and, lastly, an examination of the dynamic at a micro-scale.

2.2.1 Governance and the science system

Over much of the XX century, the allocation of resources for the conduct of research was done through a model of recurrent funding of universities and other public research organisations (Richard Whitley 2010). That model, however, has undergone/ is undergoing (depending on national contexts) "a transformation from being allocated on a predominantly recurrent, block grant, basis for institutes and universities to being dependent on success in competitive bidding for project grants" (ibid., p. 4). As noted in the previous section, this shift is a symptom of / enables a wide-reaching reconfiguration of the science system. I will examine this reconfiguration through three main categories: the emergence of entities mediating the interaction between science and the state; the explicit incorporation of public policy goals in research; and the changes to the modes of organisation and temporalities of research.

The approximation of science and society led to the emergence of new entities. Amongst those, funding bodies emerge as a focal point in the governance of science, which decouples the state from science (Musselin 2014). Funding bodies have been proposed to impact on the "cognitive development" of science through the allocation of funding (Braun 1998; Rip 1994); these, however, were theoretical arguments with no empirical basis. Beyond these arguments, funding bodies have been widely studied, through the lens of intermediary agencies (Braun 1993) / boundary organisations (Guston 2001) – as entities which mediate the link between science and the state, performing a balancing act between the translation of political direction into research policy (and funding), and the epistemic practice, priorities and valuation of researchers; and through principal-agent theory (Braun 1993; Guston 1996; Van der Meulen 1998). This theory posits a link between the state, the funding body and the researchers as a *principal*, *agent*, and *third party*. Under this theory, the *principal* commands a set of resources, but lacks the required knowledge to appropriately transfer them to the *third party*. As such, it *delegates* that task to an *agent* which holds the required knowledge[9]. Through this sets of relationships, the theory proposes a move away from a conception of hierarchical structure, but rather one of interdependent relations between actors. Nevertheless, it has been critiqued as not adequate to describe the complex web of relationships between the funding bodies and the state / researchers (Morris 2003; Shove 2003).

The emergence of funding bodies has also been argued to enable the exertion of control over the conduct of research at a micro-level (Morris 2000). This argument has as its most salient conduit the formalisation of the evaluation of research, with concomitant creation of new entities and reshaping of funding councils and universities. While relevant for the trajectory of the science system, it is not the focus of this thesis[10]. While these studies provide insight into the dynamic of the links across scientists and the state, they offer little insight into the types or specific epistemic changes driven by the inclusion of such entities.

Beyond this effect on the topology of the science system, the increasing politicisation of research has been shown to impact the trajectory of the latter. Several salient examples are worth mentioning. In a study of the Dutch research system, the push of political priorities has been traced to the dissolution of non-priority areas (Laudel and Weyer 2014). From the point of view of health quality research, the expectation (or demand) of knowledge with policy relevance was perceived by researchers as diminishing of their autonomy and the ranges of epistemic paths which

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[9] Alternative conceptions of this model establish a link between the state as *principal* and researchers as *agents* (Guston 1996) and a double relationship with the state as *principal* and the funding body as *agent*, linked to another with the funding body as *principal* and the researchers as *agents* (Braun and Guston 2003).

[10] A review of the broad corpus of literature can be found in Rushforth & de Rijcke (2015).

were possible to tread (K. Smith 2010). Several other contributions have noted that funding priorities and peer review (and their expectation) drove researchers to topics which are low-risk, mainstream and applied (Morris 2000; Gläser 2010; Leišytė, Enders, and de Boer 2010). In the case of a Dutch research programme in nanotechnology, the practices within the programme were steered towards outputs of societal benefit through the use of "ideographs" (Bos et al. 2014). Thus, it is well established that authority relations exerted through funding priorities/restrictions can have an impact on research, from the large scale of a national science system to the smaller scale of particular research programmes. When coupled with the demise of the block grant, the incorporation of such goals become particularly salient, as

> "Moving away from recurrent block grant to project-based funding of research also facilitates state steering of research priorities in some [science systems], as ministries are more able to influence the selection criteria governing resource allocation on a project basis than is usually the case with recurrent funding of chairs and institutes." (Richard Whitley 2010, 19)

In this way, the state is able to more forcefully exert authority over the types of processes and outputs which are deemed acceptable and, by extension and at arm's length, over the conduct of research.

The incorporation / rise to prominence of political goals in science can also be traced to its organisation and temporalities. The rise of "big science" (de Solla Price 1963) perfectly encapsulates this point. The term was intended to identify transformations in modern science, offering a dichotomy between *little* science and *big* science. Unsurprisingly, scale is at the core of big science definitions. Most succinctly, Sklair (1973) described it as "Money and Manpower"; Galison (1992) proposed a more detailed definition, in that

> "the "big" in Big Science connotes expansion on many axes: geographic (in the occupation of science cities or regions), economic (in the sponsorship of major research endeavours now costing in the order of billion dollars), multidisciplinary (in the necessary coordination of teams from previously distinct fields), multinational (in the coordination of groups with very different research styles and traditions)" (ibid, p. 2)

This definition foregrounds a plethora of transgressions and transformations of prevailing practice in the shaping of big science. Beyond questions of scale, going *big* was linked to disruptive ways of working, in both the promotion of crossing disciplinary and national boundaries. Absent from these definitions, however, was the role of governance in prompting and steering big science. In a reflection of the integration of big science in "big history", Hevly noted

> "big science, drawing on earlier rhetorics concerning science and power, depends on the attachment of social and political significance to scientific projects, whether for their contribution to national health, military power, industrial potential, or prestige. This continuous process of justification, which requires the attachment of science to outside goals, has influenced the researchers' understanding of their work, and ultimately its intellectual content as well. (Hevly 1992, 357)

Big science, then, is a clear articulation of deliberate and explicitly governed science, with clear implications regarding epistemic practice through alignment with a multitude of "socio-technical imaginaries" (Jasanoff and Kim 2009). While a detailed examination of these phenomena is beyond the scope of this thesis, the articulation with the state can be illustrated in matters as trivial as the (interim) naming of the Hubble space telescope, with NASA administrators pushing back against a name of "**large** space telescope" (emphasis added) on the basis that the implication of opulence would prompt cuts to the agency's budget (R. W. Smith 1992); but also at the core of the conduct of research, such as in the case of the establishment of the microwave laboratory at Stanford. If the federal support was welcome, the researchers quickly found themselves in the situation where "the Navy began to issue lists of acceptable research subjects" (Pestre and Krige 1992, 75).

Research under this banner could then be further characterised by "politicization, bureaucratizaton, high risk, and the loss of autonomy" (R. W. Smith 1992, 186). The bureaucratization, in particular, was linked to a strict vertical hierarchy around a "*team*, led by a principal investigator-manager, with co-principal investigators, senior researchers, junior researchers, graduate students […]. Thus team is plugged into a facility […] with its own hierarchically organized structure". (Kargon, Leslie, and Schoenberger 1992, 335). Big science, then, encapsulates a mode of research with a forceful governance role and concomitant changes to the topology of research and its organisation (I reflect on the increasing prominence of projects below), with particular emphasis on the primacy of collaborative and multidisciplinary ways of working directed towards themes of societal relevance.

Considering wartime research was largely under the umbrella of physics (Kevles 1995) it is unsurprising that physics continued to be the focus of "big science" investments. Accordingly, most social studies of big science addressed big science in physics (e.g. (Crease 1999; Galison 1997)). It is, however, relevant for this thesis to consider *bigness* in biology. Biology has enjoyed the more orthodox image of "little science": of science that is carried out almost as a craft, on an individual scale or at most in small laboratories (Roberts 2001). Still, such an image was challenged by the establishment of the Human Genome Project[11]. This large enterprise signalled a turning point for how biology is carried out: it no longer seems research can be meaningfully done in small scale, but it relies instead on multidisciplinary collaboration (Glasner 2002). Biology was, then, "supersizing" - becoming "big biology" (Vermeulen 2010).

In a similar fashion to how big physics is generally characterised by "big machines" (Galison 1992), Vermeulen (2010) proposed big biology relies on (big) networks and the incorporation of information technology. It is, by definition, a distributed form of big science, hinging on collaboration. The study of big biology has been gaining momentum in recent years, with particular emphasis on modes of collaboration (Parker, Vermeulen, and Penders 2010; Vermeulen 2010, 2013). In tandem, the conceptualisation of contemporary life sciences under the banner of *bigness* has also been problematised. In the context of systems and synthetic biology, Calvert (2013) argued that the use of *big science* as an analytic category is anachronic, for its emergence and embeddedness in a post-war physics context. While concepts of bigness

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[11] This is not to say big biology started with the Human Genome Project. In fact, big biology can be traced as far back as the 17th century, when a concerted effort by naturalists allowed great strides in the accumulation and description of new species (Capshew and Rader 1992).

have some purchase, she argues they fail to capture the dynamic of a contemporary systems (and synthetic) biology that is not centred around singular project(s) and has an explicitly integrative focus, but which still commands considerable resources and is markedly collaborative. Instead, given contemporary orientation towards *grand challenges*, she proposes it may be appropriate to link these fields not to big science, but to the concept of "New Biology". This concept is most prominently linked to a US National Research Council report (entitled "A New Biology for the 21st Century") (NRC 2009). In broad terms, it offers a diagnosis of current life sciences as undergoing a re-shaping driven by an ethos of integration, and a vision for the use of these sciences towards addressing societal challenges. While this constitutes a departure from the concept of big science, it provides another example of normative orientation of research towards societal benefit, with concomitant (though implicit) governance mechanisms.

A third dimension of change in the science system, at the intersection of organisation and temporality, is the increasing preponderance of a mode of competitive funding where resources are allocated for defined goals and a defined temporal horizon. This trend has been described as the "projectification" of research (Vermeulen 2010; Fowler, Lindahl, and Sköld 2015). In a competitive environment, where science is afforded a prominent social role, "projects make it possible to connect scientific practice with government and industry, and that this directly affects scientific practice and the rhythm of science" (Vermeulen 2010, 12). Thus, projects are amenable to the incorporation of political and/or commercial goals. Vermeulen goes on to argue that the inclusion of these goals changes the dynamic of legitimation of research – both for the initial acquisition of resources, and also through the course and at the end of the project. From the point of research, she argued projects add steps to the conduct of research – which now must start with a grant proposal – and create "path dependence" (Arthur 1989), for deviations from the formal structure of the project are discouraged. Furthermore, the outputs of the projects become formalised (such as in deliverables) and constructed according to a shared logic of epistemic value and political/commercial relevance. Lastly, she argues that the setting of particular time limits to projects shapes the temporality of epistemic labour.

The temporality of projectification is further addressed in Ylijoki (2016). The author echoes Vermeulen's (2010) argument for the imposition of a particular pace of epistemic practice in the context of what she dubbed "project time" (Ylijoki 2016). While project time follows a logic of scheduled/clock time, "process time" is offered in opposition (ibid.). In contra, "process time does not follow the logic of scheduled time but is embedded in proper time, [...] the internal logic of research activity. Research and its phases take as much time as is needed to achieve results" (ibid. p. 14). Projects, then, are likely to create conflict between these two temporalities. Ylijoki makes a clear case for the potential of this conflict in shaping research practices, but her empirical work addresses this only peripherally. In any case, she identified tension in practices of reading research materials – which were halted because of the compression of time. A knowledge gap remains over the ways through which the projectification of research impacts on its conduct and outputs. I explore this over the chapters in Part III.

2.2.2 Governing (the emergence of) fields

From the vantage point of research fields, and for the reasons set out at the start of the section, efforts of direct steering from governance actors has traditionally been subdued. That, however, has also changed in recent decades. In a model of "de facto governance" (Rip and Voß 2013), policy-makers have started making a push for particular emerging areas / fields, at stages where their existence is nebulous, through the use of *umbrella terms*[12]. These are, in essence, devices which project a sense of coherence between disparate epistemic projects and traditions, covering them all by a single *umbrella*. The deployment of umbrella terms has been argued to have pro-

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[12] While the term has not been formally defined, it has been in use since at least 1998 (van Lente and Rip 1998) and has gained a foothold in the STS literature (e.g. to describe the [cultural] unification of science in the XIX century (Rip 2002b), the process of technological convergence (Robinson 2015), or the discussion of Responsible Research and Innovation (Rip 2014))

moted / impacted on the trajectory of materials science (Bensaude-Vincent 2016), nanotechnology (Rip and Voß 2013; Marcovich and Shinn 2014; Bensaude-Vincent 2016) and synthetic biology (Bensaude-Vincent 2016).

A different dimension of governance of fields is linked to change in their locus. The interconnected establishment of fields in a concurrent temporal frame and at a global scale presents a peculiar challenge for governance. Transnational governance has been studied in the case of nanotechnology, with two main contributions which locate transnational arrangements not in governmental alignment, but in standards and standard-setting bodies; both studies have addressed the issue of legitimacy (seeing as they are not accountable as states), but note this voluntary model has enjoyed support – including, of particular relevance for this thesis, from the EU (Kica and Bowman 2013; Kica and Wessel 2017). It has also been studied in the context of synthetic biology, albeit with a different focus. In the case of the former, transnational governance has been described as requiring a multipolar mode of articulation which acknowledge the embeddedness of uncertainty and the need for accountability across multiple and different types of constituencies across borders (Zhang, Marris, and Rose 2011; Zhang 2013). Particularly at this scale, governance was described not as a method, but as an *art* (ibid.).

While an international / global focus is particularly apt in the emerging fields mentioned, it is part of a wider trend. A trend for the "de-nationalisation" of science could be located as starting in the XIX century (Crawford, Shinn, and Sörlin 1993). Prominent examples of that process have been studied as the crafting of Antarctica as a continent and a space for (all) science (Elzinga 1993a), the emergence of molecular biology as a field through the sidestepping of national boundaries and academic traditions (Abir-Am 1993), or the collaboration of European researchers in space research (which would lead to a common European Space Agency) (Zabusky 1995). This trend has not abated, and it has grown to intersect with governance in a peculiar way. That is, through deliberate efforts to insert science in the context of international relations – a phenomenon conceptualised as "science diplomacy" (Royal Society 2010). While science has arguably been a tool in the swiss army knife of diplomacy from at least the XVII century (Daston 1991), the renewed interest in the practice belies the observation that, over the past two decades, the deliberate use of science in diplomatic contexts has greatly intensified, mostly driven by the imaginary of grand challenges (Flink and Schreiterer 2010).

As a field of analytic study, science diplomacy is still at an early stage. The eminent contribution thus far is a Royal Society /AAAS report, which defines three dimensions of science diplomacy: as "science in diplomacy", "science for diplomacy", and "diplomacy for science" (Royal Society 2010). The first describes the use of science in a supportive/informative role to diplomacy; the second the use of science in the promotion of diplomatic links; and the third the use of diplomacy in the pursuit of scientific goals. A typology of science diplomacy has proved elusive, in the face of dramatic heterogeneity in how the practice is exerted among nation-states (Flink and Schreiterer 2010). In a (single) study of the European Union case, López de San Román & Schunz (2018) linked the latter's diplomatic efforts to what they called images "of normative or market power Europe". Reinterpreted from an STS lens, efforts ranging from the use of European science to take the lead on global challenges, to the use of collaboration to place European research in a world-leading position, afford a clear role to science in the pursuit of (the multiple, overlapping, European) socio-technical imaginaries (Jasanoff and Kim 2009).

The increasing de-nationalisation of science and the emergence of science diplomacy constitute deliberate departures and/or transgressions from the national spheres as the relevant arenas for governance. It is important to note, however, that the latter remain the dominant locus for science. National spheres are characterised by a heterogeneous typology. Whitley (2010) proposed a classification of public science systems into 6 categories, taking into account the different role of the state, universities (and other loci of research) and scientific communities (with an emphasis on elites). Empirical work with similar drive has yielded the observation that different public science systems do, indeed, have different patterns of link between science, universities, research organisations, funding bodies and, ultimately, the state (Trow 1993; Wittrock 1993; Lenoir 1997). It follows, then, that national configurations impact on the ways (and ease) through which new fields become established, as illustrated by a comparative study of the emergence of the field of business studies in Europe and the USA (Engwall, Kipping, and Üsdiken 2010),

These configurations are an important dimension of the local articulations of research fields, even when they are ostensibly global. This very theme was identified as a gap and has received some attention in STS recently, with the organisation of a workshop and subsequent publication of an edited collection (Merz and Sormani 2016). The three contributions of the first section on that volume is of particular relevance for this thesis. The fist addresses fields from a national point of view. Gläser, Laudel, & Lettkemann (2016) explore the effect of generic governance instruments in the establishment of a field around *Bose-Einstein condensation* (in physics) in Germany and the Netherlands. They do so through the lens of (an adapted conception of) "protected space" (ibid.). They argued that such generic governance instruments impacted on the emergence of the field differently in the two countries due to the different temporalities, scope and barriers to the "protected space" required to kickstart a new field. Bensaude-Vincent (2016) examined the emergence of materials science, nanotechnology and synthetic biology in a European and American context. The author linked the diverging fates of materials science in the two blocks, and the mirroring of trajectory in the case of nanotechnology to the availability of relevant policy drives. Materials science in the USA was supported under a military policy drive, which has no equivalent in a European context. Nanotechnology, however, was promoted in both cases under the guise of competition – a dimension over which the EU holds (legal) competence. Meyer & Molyneux-Hodgson (2016) explored the *placing* of synthetic biology in a French and UK context. Their account traces the efforts of placing the emerging field not to researchers, but to the policy room. Placement, in the geographic dimension, was done according to different patterns – in a concentrated fashion around Paris (in the French case), and a distributed one across the UK, which the researchers link to different governance regimes and (e.g. the placing of synthetic biology in France under the CNRS, whose labs are situated in Paris, versus political pressure for decentralisation in the UK). Placing synthetic biology in these national contexts, however, was something the authors also described as a process of co-production (Jasanoff and Kim 2009) between the local, the national, and the international (or global). This is most poignantly illustrated by the incorporation of the iGEM competition into the making of national synthetic biologies.

While these studies provide valuable insight into the link between governance mechanisms and the emergence / configuration of local articulations of fields, they do not meaningfully address funding as a dimension of governance. This theme is either altogether absent, addressed in passing, or at a scale which impedes analysis. Therefore, a knowledge gap remains.

2.2.3 Governing research practice

I finish the review of literature on governance with an examination of the dynamic at the micro-scale. STS has long found its research objects at this level, so it is unsurprising that the impact of governance has long been identified in the field. Key examples are Knorr-Cetina's move away from the *scientific community* as the relevant site of knowledge production given the embeddedness in social structures and the relevance of *non-scientific* actors in that activity; the author argued instead for knowledge production to be examined in the context of a "transscientific field" (K. Knorr-Cetina 1981) and, later, a "transepistemic arena" (K. D. Knorr-Cetina 1982). Law proposed knowledge production as best examined through a process of "heterogeneous engineering" (Law 2012 [1987], 1994); he made the case knowledge stems from the messy entanglement of the social and material worlds, in a "relatively coercive (albeit ultimately revisable) scenery" (Law, 2012 [1987], p. 123); heterogeneity is framed as explicitly contingent. Governance makes an appearance in his study of the Portuguese expansion in the recognition of role of the (powerful) crown in the control of the (state) companies and wider organisation of the expansionary effort (ibid.). A third notable example is Latour & Woolgar's (1986) conceptualisation of the "cycle of credibility". The authors commodified the notion of *credibility*, positing the latter was the driving force behind and the reward of the conduct of research – credibility unlocked access to resources, which were then used to acquire equipment, run experiments, produce data and publish articles; the recognition associated with articles would convert to credibility, at which point the cycle would repeat. Governance is recognised in this model in the modes of how credibility was converted into resources.

Despite the identification of governance in the process of knowledge production, the conditions for / impact of funding (which I have shown is a key conduit of governance) was not addressed in these studies. In fact, this is an enduring knowledge gap, and one for which a research agenda was recently called on (Gläser and Laudel 2016). From an STS point of view, the impact of funding on knowledge production remains understudied. There is, nonetheless, one landmark contribution - Fujimura's (1987) analysis of the construction of "do-able" problems.

STS literature has long recognised the embeddedness of researchers in a particular repertoire(s) (Leonelli and Ankeny 2015), which guides problem choice, available artefacts and infrastructure (e.g. Knorr-Cetina (1981, 1995); Rheinberger (1994); Latour & Woolgar (1986)) Fujimura recognises that embeddedness, and expands the scope of analysis to include what she dubbed the "social world" (Fujimura 1987). The author makes the case that researchers take all these dimensions into consideration when devising research objects. Further, she argues that research problems become *doable* only if they enable "the alignment of several levels of work organization" (ibid., p. 258). Fujimura illustrates this point while reducing the complexity of embeddedness into three levels of work organization" - the experimental level, the laboratory level, and the social world level. Aligning these levels requires a*rticulation* work, as depicted in Figure 4. A *doable* problem, then, is only so if it is successful in aligning (through articulation) these different levels. Alignment, however, is not a discrete state. Reflecting on the example presented in the article, the author noted:

> "articulation included making experimental work respond to concerns in several social worlds in order to secure resources, and shifting task organization in the laboratory

when experimental results proved problematic in order to continue to respond to the demands of these relevant social worlds". (ibid., p. 283)

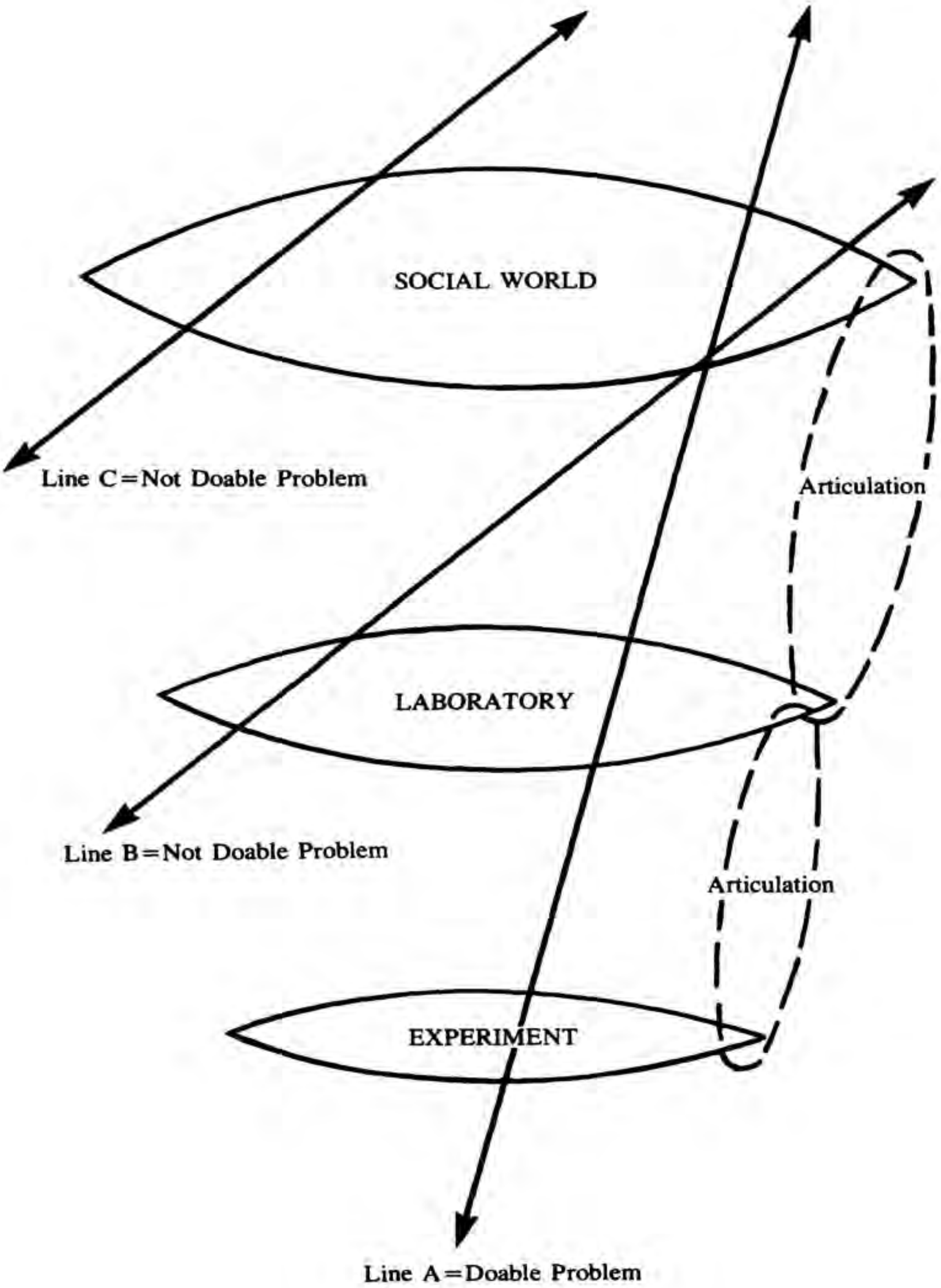

Figure 4: Aligning Levels of Work Organization to Construct Doable Problems. Reprinted with permission from Fujimura (1987).

Alignment is then presented as dynamic, requiring permanent (re-)articulation. In parallel, and of particular relevance for this thesis, is the relevance of the social world in demanding articulation. This point is illuminated in another passage, where Fujimura argued:

> “First, in planning their research programme, the scientists weighed their research subject options against sponsor demands. They then proposed a programme which incorporated their research interests within the constraints imposed by their sponsors”. (ibid., p. 266)

In this way, the alignment required to make a problem *doable* was closely tied to articulation work between the laboratory level and the resources at the social world level. A *doable* problem was, therefore, a *fundable* problem. Funding emerges, then, as an important consideration in the shaping of epistemic practice.

This dimension of *fund-ability* in the context of *do-ability* has been recognised as a useful analytic tool in literature on role of funding in the trajectory of research (Gläser et al. 2010; Leišytė, Enders, and de Boer 2010; Morris 2010; Gläser and Laudel 2016). Interestingly, empirical studies which trace the impact of funding at the micro-level make no mention of *fundability*. However, this is literature which describes strategies of articulation to preserve the former. It is to those studies I now turn.

From the standpoint of conditionality of funding, several strategies have been described. The strategy of alignment of existing research efforts to demands of funding without impacting on epistemic practice has been described as “window dressing” (Laudel 2006) or “symbolic compliance” (Leišytė 2007). A prominent example of this strategy is the reframing of research in research proposals, so that it is presented as complying with the funding restrictions/priorities, with no change to epistemic behaviour (ibid.). At the other end of the spectrum sits “accommodation” (Hackett 1987; Fowler, Lindahl, and Sköld 2015) or “conformity” (Leišytė 2007). This describes the researchers’ inability to sidestep the conditions on which funding is made available. Consequently, they adapt (or *align*) their practice to meet the demands of funding. In this literature, accommodation is not described as a stabilising strategy, but rather as a temporary (Hackett 1987) or partial (Fowler, Lindahl, and Sköld 2015) one.

Accommodation is also presented in tandem with “resistance” (Leišytė, 2007; Fowler, Lindahl, & Sköld, 2015). This has been described as directly fighting against a sense of *dirigisme* (Rip and Nederhof 1986), by means such as the refusal to adjust epistemic practice to funding conditions, or the mobilisation against a particular funding mechanism (Leišytė 2007). Fowler, Lindahl, & Sköld (2015) offer a more nuanced view of resistance, drawing of Goffman’s (1990 [1959]) notion of “frontstage” and “backstage”. Resistance emerges through *partial* accommodation; accommodation is contained to a frontstage, where interactions with funding agencies are mediated and managed by dedicated staff. Researchers operate on the backstage where, through the severing of a link to funding demands, the impact on epistemic practice is minimised. Lastly, a strategy of “manipulation” has also been described (Leišytė, Enders, and de Boer 2010). The latter is only available to scientific elites, and describes a process of changing the priorities and/or restrictions on research to *align* them with the elite researcher’s desired epistemic practice.

The interplay with funders has also been studied from the perspective of epistemic change. Grant funding has been argued to hinder shifts in research objects (or epistemic practice generally) due to the conditionality of funding on the existence of documented expertise in the object of study (Laudel 2006; Morris 2003). In other words, the funding environment promotes lock-in (Arthur 1989). Against this backdrop, two strategies have been described. From a reactive standpoint, Hackett (1987) proposed the notion of “bootlegging”. This refers to the use of existing projects as platforms on which to conduct (preliminary) research on a different topic. This process enables researchers to gather preliminary data and establish themselves as experts in a different topic while in this protected space; while increasing the likelihood of successful grant proposals in the new topic. From a proactive standpoint, Gläser et al. (2010) describe the “management of research portfolios”. That is, researchers take on multiple topics of research, which they manage against criteria of *fundability*. That is, research topics which become *unfundable* are amenable to being dropped; new *fundable* research topics started; and existing topics modified to maintain *alignment*.

Lastly, the increasing demands for justification for research, combined with a science system predicated on (socio-technical) future(s) have promoted the emergence of a particular style of (rhetorical) practice. That is, the creation of "expectations" (Brown and Michael 2003a; Borup et al. 2006). Expectations are *performative* – they drive the reconfiguration of the present, in the anticipation of a (or multiple) future(s). They are articulated through "promises" or (more fleshed out) "visions" - rhetorical devices which "act as both a means of enrolling support and resources into the emerging socio-technical network and as a guide to the physical design of artefacts" (Martin 1999, 520; Van Lente 1993). These enrolled actors constitute "communities of promise" with "mutually binding obligations" centred around the shared expectations.

Expectations cut across from the micro to the macro level; the link to governance, however, is most salient in the context of the "promise-requirement cycle" (van Lente and Rip 1998). The articulation of a promise creates shared expectation(s). This, in turn, *requires* action towards fulfilling the shared agenda. Thus, mobilising support by casting a particular field as "promissory science" (Hedgecoe 2003) binds the field (and, by extension, research practice) to the vision put forth, through the articulation of requirement via conditionality in the mobilisation of resources.

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Over the course of this section I outlined literature on the governance of science, with a particular focus on the dynamic of funding. Being a prime object of interest in science policy studies, institutional and a macro-scale analysis of the role of funding on the science system has strong contributions. As I moved towards the micro scale, however, knowledge gaps became evident. A similar observation has prompted the organisation of a 2015 workshop around the theme of funding and *the content of research*, and a subsequent publication which reads as a manifesto for a systematic study of this area (with particular emphasis on the linkage between the macro and the micro scales) (Gläser and Laudel 2016). I echo this observation in this section, though with emphasis not on the knowledge gap on research content, but on the link between funding and epistemic practice. Moreover, it is also apparent that the (emergent property of) the link between funding and the repertoires (Leonelli and Ankeny 2015) which ground research fields is a parallel knowledge gap. I return to this literature in Chapters 5 and 7.

2.3 ORGANISATION IN SCIENCE

Collectives in science matter. This has long been acknowledged in the history (and philosophy) of science tradition, which has largely addressed this through the lens of the discipline. A notable example is Kohler (1982), who argued that "disciplines are political institutions that demarcate areas of academic territory, allocate the privileges and responsibilities of expertise, and structure claims on resources" (ibid., p. 1). From a historiographic point of view, then, the study of collectives draws on the quintessential philosophical question of demarcation (Resnik 2000) (or, from a more sociological point of view, "boundary work" (Gieryn 1983)) of/between discrete entities in the scientific enterprise.

Traditional sociological perspectives on collectives have, on the other hand, proposed different articulations of collective. Notable articulations are those of "thought collectives" (Fleck 1981 [1935]), "invisible colleges" (de Solla Price 1963) and overlapping conceptions of *community* (Merton 1973 [1942]; Kuhn 2012 [1962]; Hagstrom 1965). Merton famously proposed a notion of the scientific community as a homogeneous entity, driven by a typology of shared norms (Merton 1973 [1942]); On the same vein, Hagstrom envisaged a scientific community as characterised by a pre-capitalist model of transaction (Hagstrom 1965). Such homogenising views on community, however, have been broadly refuted – science has been argued not to constitute a unit, but rather to be characterised by “disunity” (Galison and Stump 1996). Kuhn’s later articulation of community as “paradigmatic” (Kuhn 2012 [1962]) embodies this critique, and moves away from community in science as unitary, but proposes it to be organised around *paradigms*.

Despite the historical use of the notion of community in the analysis of the scientific endeavour, the concept fell out of favour around the 1980s. A notable and robust critique was penned by Whitley, who argued that

> “Whereas much research in the sociology of science assumes that specialist communities exist and are the appropriate unit of analysis [...] for many scientists working in full time research laboratories or field work units such relatively broad organizational units are largely irrelevant and often unknown.” (R. Whitley 1978, 427)

In this way, Whitley forcefully argued against the *specialist community* as the relevant locus. This argument was echoed by Knorr-Cetina, who posited that research took place in “variable transscientific fields” (K. Knorr-Cetina 1981):

> “a variable transscientific field is not primarily determined by characteristics held in common by its members, as in the case of a logical class. In addition to the scientist in the laboratory, it may include the provost of the university, the research institute' s administrative staff, functionaries of the National Science Foundation, government officials, members or representatives of industry, and the managing editor of a publishing house.” (ibid., p. 82)

This notion, later refined to “transepistemic arenas” (K. D. Knorr-Cetina 1982), betrays a clear departure in the analytic gaze over who the relevant actors are in the production of knowledge and their entanglements. It provides a clear rebuffing of a self-referential, internalist conception of community. Knowledge production is portrayed as the product of the entanglement of the scientific and the non-scientific, in arrangements which are porous (Gieryn 1983). Knorr-Cetina went on to eschew the notion of community or fields altogether, proposing instead the salience of “epistemic cultures” – “those amalgams of arrangements and mechanisms—bonded through affinity, necessity, and historical coincidence—which, in a given field, make up *how we know what we know*" (Knorr-Cetina, 1999, p. 1, emphasis in original).

While this scholarly work could ostensibly spell the demise of the concept of community in an STS context, this analytic frame has undergone a revival. Scholarly attention is on the rise – it was the subject of dedicated calls for the establishment of a research programme in 2010 in a special issue of Sociological Research Online (Meyer and Molyneux-Hodgson 2010) (including a contribution which explicitly argued for value in the study of epistemic communities beyond the reach of epistemic cultures (Lorenz-Meyer 2010)); of a session in EASST/4S 2016 and led to a subsequent workshop in 2017[13]. In parallel, the number of contributions alluding to community and the variations of the concept have multiplied – notable examples being those of "communities of promise" (Brown and Michael 2003b), "instrumental communities" (Mody 2011), "model organism communities" (Leonelli and Ankeny 2012), though the most popular concept being that of *epistemic communities*. I focus on the aesthetic and the making of these entities in the final section; in the immediate section, however, I make a brief detour through the examination of the concept of community and its variations in German.

2.3.1 Community – conceptual specificity across time and languages

The (academic) concept of community has a long trajectory, dating back to Tönnies (1963 [1887]). It has also been widely used and reconfigured, with close to 100 definitions identified by the 1950s (Hillery 1955). The ecology of conceptions and use of community has only grown, and prompted Brint (2001) to re-examine the concept and its trajectory. In a bid to introduce some coherence to the study of communities, he proposed a definition of communities as

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[13] I refer here to the EASST/4S stream T168 – (Techno)science by other means of communality and identity configuration; and to the STS Austria "Community and Identity in Contemporary Technosciences" workshop, which took place in the 15-16th February 2017 in Vienna.

> "aggregates of people who share common activities and/or beliefs and who are bound together principally by relations of affect, loyalty, common values, and/or personal concern (i.e., interest in the personalities and life events of one another" (ibid., p. 8).

This (re-)definition was swiftly dismissed by Gläser (2001) on the basis that several contemporary accounts of community were not rooted in affective links (as was the case of scientific communities). In the context of this thesis, Brint's definition is notable not for its substance, but for its intent of bridging two disparate German concepts which fall under the umbrella of community (in the English language) – *gemeinschaft* and *gesellschaft* (a thorough comparison and trajectory of which can be found in the original paper). This difference in conceptual specificity has led to different understandings of *community* in English and German literature, and is furthered amplified by the conceptual granularity enabled by the different patterns of nominal composition between the languages. This difference is sometimes explicitly bridged, as in a case where *gemeinschaft* and *gesellschaft* were recruited to study the organisational aspects of innovation (P. S. Adler 2015); or in the translation of the terms into English, with *produksgemeinschaften* entering English language literature as "producing communities" (Gläser 2001, 2006).

This detour through German is one I make for the analysis of the case study presented in Part II. To explore a process of community-making with a markedly utilitarian character, I draw on the rich conceptual granularity of the German language. The modular character of the language is readily evidenced by, for example, the composition of the noun *gemeinschaft* (community) with the noun *forschung* (research); this results in the term *forschungsgemeinschaft* (research community). In the case at hand, however, the relevant compound word is *zweckgemeinschaft* – a term that defies translation into English. The first component, *zweck*, has no direct translation; its meaning can best be approximated as purpose or intent. Dictionary translations of the term offer *partnership of convenience* or *community of purpose* as English equivalents, but neither fully captures the concept; in particular, there is a sense of forcefulness which is both key and absent in the English translations.

To better understand this concept, I offer two brief examples of *zweckgemeinschaft* in use. The first one is its use in the context of the history of Austria. In an examination of how the process of nation-making in the medieval period had been recorded, Pohl (2013) charts a path between a naturalist conception of monarchic empowerment and expansion to Austria as a changing *zweckgemeinschaft* over centuries; from a process of gradual submission to a ruler, to a messy process of articulation of nations under a ruler. Medieval Austria, unlike its current conception, was a changing assemblage of nations with different identities and, to a large extent, split across ethnic divides. In this context, Austria is presented not as an overriding (national) identity, but as a structure which imposes a shared legal framework; not as a nation, but as an "artificial edifice" (ibid., p. 48) which, over the centuries, offered a sense of fellowship that sidestepped national identities.

The second example is that of the genesis (and reconfiguration) of the NATO military alliance. A key component of Kirchner & Sperling's (1992a) conceptualisation of NATO at its origin is that of a *zweckgemeinschaft*; NATO was a creation borne out of the a shared sense of urgency in the preservation of the independence of European states, faced with a potential military assault by the USSR. Despite this veneer of unity, the alliance was not built on a shared foreign policy agenda, but on multiple, disparate and conflicting ones. The inherent tension, however, was tolerated because of the (shared) perceived importance of rebuffing the military threat. In tandem, some of that tension was alleviated over time through the shaping of NATO's agenda in a way that would further the interests of participants. Of particular relevance to this thesis is an ancillary point regarding the future of the alliance, which Kirchner & Sperling (1992b) develop in greater detail in a contemporary contribution. They argue that, after the reunification of Germany, the consensus underpinning NATO was put into question. From the point of view of the USA, it remained a valuable tool for the promotion of American interests; for an economically recovered and integrating Europe, coupled with the demise of the USSR (and the potential military threat), the driving force of NATO had run its course and European and American interests diverged. Avoiding the disbandment of the alliance was predicated on replacing (or re-imagining) the *zweckgemeinschaft*; NATO would no longer be centred around a Soviet threat, but around ensuring stability in the European continent (both against German dominance and instability in the newly independent Central and Eastern European states).

This exploration of the nature of community is one I return to in Chapter 8 (and it is implied in Chapter 7). I now move to the examination of literature on more conventional concepts of community, with particular emphasis on how these assemblages have/can be studied.

2.3.2 Conceptualising and studying epistemic communities

With the concept of community regaining currency in STS circles, several variations of the concept have risen to prominence. In particular, this includes the notion of "communities of practice" (Lave and Wenger 1991), "communities of promise" (Brown and Michael 2003b), and *epistemic communities*. My thesis is predicated on the latter; as such, I will now briefly examine its origin and use. The current articulation of epistemic communities emerged from work in the international relations / global policy tradition (Haas 1989; E. Adler 1992; E. Adler and Haas 1992; Haas 1992)[14]. A now classic definition is proposed in Haas (1992), in the context of a study of the coordination work which underpinned the Montreal protocol. There, an epistemic community is presented as "a network of professionals with recognised expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge" (ibid., p. 3). Under this definition, epistemic communities are clearly and closely linked to the policy room. Knowledge is valued insofar as it contributes to politics. Communities emerge around policy problems, and (ostensibly) at the bequest of who defines those problems. This articulation of the concept has remained popular in the field, and has grown to a research programme – see Cross (2013) for a review.

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14 This is not, however, the first articulation of the concept. See Meyer & Molyneux-Hodgson (2010) for a brief outline and links to the literature by Holzner and colleagues.

Outside international relations, however, the concept was problematised and shaped to meet different research agendas. In organisation studies, epistemic communities are presented as one category of “knowing in action” (Amin and Roberts 2008). This particular paper demarcates Epistemic communities from communities of practice, presenting the former as explicitly transient assemblages, driven together by a problem which defies resolution in the context of the latter. Further key features of epistemic communities are the a priori possession of specialist knowledge by the epistemic subjects, which is combined in a heterogeneous arrangement from which new, useful knowledge is expected to emerge. Consensus, however, is not implied or necessarily achieved – such communities are expected to revolve around “boundary objects” (Star and Griesemer 1989). While some of these features contribute to the STS conception(s) of epistemic communities, the scale, temporalities and demarcation present in this notion prove incongruent with the former.

From a sociology of science perspective, Elzinga, (1993b) linked epistemic communities to “epistemic drift” (Elzinga 1985) (reviewed in section 2.1) and argued for the differentiation of two types of epistemic communities. Communities under the pressure of epistemic drift, whose trajectory was guided in direct articulation with policy pressures, constituted “hybrid epistemic communities”; these contrasted with those which were not under such pressures, and could “follow the more traditional patterns of academic behaviour” (Elzinga 1993b, 142), constituted “disciplinary epistemic communities” (ibid.). While this dichotomy is disputable (particularly against a backdrop of a changing contract between science and society), Elzinga’s notion of hybrid epistemic communities foregrounds the heterogeneity of actors which make up an epistemic community. It is particularly notable how those actors intersect with those in Knorr-Cetina’s “variable transscientific fields” (K. Knorr-Cetina 1981) mentioned in 2.3. These notions are well aligned with a proposition by Meyer & Molyneux-Hodgson (2011) of four key features of epistemic communities (in STS):

> 1. Epistemic communities produce and "act with" knowledge. They produce, publicise and police knowledge; they communicate and distribute it; they create multiple forms of repertoires for accumulating and stocking that knowledge.

> 2. Epistemic communities are made and stabilised. They are produced, reproduced and ordered by devices or events which aim to produce the community (like journals and scientific conferences); they are realized and made explicit at the same time they produce knowledge.
> 3. Epistemic communities are dynamic. They change and are situated on trajectories, and therefore articulate diverse histories, futures and possibilities; they differentiate, change and transform themselves; they can become places of political work; they vary according to the temporalities, the intensity of interaction, and the strength of the links that unite them.
> 4. Besides producing knowledge objects, they also produce knowledge producers; they shape, delimit and articulate the identities of current and future knowledge producers and they shape the individual and collective trajectories along which they navigate. (ibid., p. 150-151 translated from French)

Epistemic communities, then, provide a relevant locus for research which was deemed absent in self-referential notions of community. As noted above, they are *variable* – in their temporality, their trajectories, the actors involved and how (and how strongly) they are linked; and they are also "transepistemic" (K. D. Knorr-Cetina 1982), in that they are constituted by actors at the bench and far from it, and incorporate labour from the technical to the (explicitly) political. They are also best seen as "moving targets" (Meyer and Molyneux-Hodgson 2010), not bound to any specific location or mode of ordering. In the remainder of this section, I link the substance of these categories to the empirical work on the aesthetic of epistemic communities, as well as the processes through which they are (re-)produced.

Lorenz-Meyer (2010) provides an interesting entry point into empirical work on epistemic communities by noting what it is *not*. In two vignettes of empirical work in two labs (in different fields), the author describes her search for community. She notes that, while that is an adequate site to investigate "epistemic cultures" (K. Knorr-Cetina 1999), it is only *part* of an epistemic community; that while partial and local articulations of community may be present, the dynamic of the epistemic community is out of reach.

Two other contributions to the epistemic communities literature foreground the political work involved. Akrich (2010) describes a conversion from a community of practice into an epistemic community[15] in the context of a health activism discussion group. The author traces the way the discussion group is transformed from a medium for mutual support around experiences of childbirth and becomes a key site of resistance to the knowledge from medical professionals. However, the group moves beyond resisting the professional knowledge and makes use of the experiential knowledge shared to move to an activist role. Knowledge stopped being produced (solely) for the group, but the texts were circulated among entities which oversaw the medical practice. In this way, the group became a producer of *lay* expertise, which contended with other forms and sources of knowledge, and therefore an epistemic community. Meyer & Molyneux-Hodgson (2016) describe how a more conventional epistemic community in synthetic biology was *placed* in the UK and France and how those trajectories diverged (geographically, epistemically and temporally) through their articulation between (epistemic) subjects; in particular, the articulation between particular governance regimes and vision(s) for the field. This has led to community which is more geographically centralised in France, and dispersed in the UK; community where social scientists are kept at bay in France, but embedded in the UK; and community which operates at different temporalities in the policy room and at the bench.

The extensive account of the emergence of synthetic biology at the periphery by Balmer, Bulpin, & Molyneux-Hodgson (2016) provides a robust overview of the making of an epistemic community from the point of view of the periphery. In the context of a collaborative project with the water industry, the authors describe the negotiation of knowledge to be produced between the scientific and extra-scientific actors, which took place in parallel with permanent negotiation between the practice of synthetic biology at the core and the periphery. This contribution also addresses novices, though they are the focus in Bulpin and Molyneux-Hodgson (2013). Here,

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[15] While this process may appear to constitute a hierarchisation of epistemic communities above different allied concepts, in this thesis I follow Meyer & Molyneux-Hodgson's (2010) argument "that cross-linking between different ways of accounting for collectives is needed. Describing the many kinds, forms and dynamics of communities means to widen, rather than restrict, our understanding of what the terms epistemic and community might come to denote." (ibid., p. 2.7)

the authors outline the "disciplining" (Foucault 1977 [1975]) of novices in the context of the iGEM synthetic biology competition. They argued that participation in the competition was a disciplining activity, which shaped the practices, values and identities of the budding researchers; driving them towards interdisciplinary, collaborative ways of working, an ethos of openness, and identities at a crossroads of iGEM*mers* and synthetic biologists. A similar examination of the *production of knowledge producers* in the context of synthetic biology is described in Calvert (2010). The author describes an interesting interplay between the development of an identity of *systems biologist* and the development of a particular epistemic arsenal. In a field characterised by interdisciplinary ways of working, novices were expected to embody that interdisciplinarity; that is, they were expected to develop "individual interdisciplinarity" (ibid.) (thus, explicitly shaping the trajectory of the field through the shaping of identities and epistemic arsenal of novices). Lastly, asymmetries along the career ladder are epitomised in Bartlett, Lewis, & Williams' (2016) study of interdisciplinarity in bioinformatics. They argued that (identities and attitudes towards) interdisciplinarity in the field was strongly stratified according to the stage of field development at which the researchers were enrolled; this led to what they described as "generations of interdisciplinarity" (ibid.).

Lastly, a contribution by Cain (2002) foregrounds creation and circulation of knowledge, alongside the temporality and trajectory of an epistemic community. He looked at the establishment of a committee at the borderland of palaeontology and genetics at around the second world war. The author argued that, in the context of that committee, knowledge amalgamating both perspectives was negotiated and circulated in a number of conferences and (news)letters. The committee was framed as a "transient community" (ibid.), providing a space for articulating the aim of working together, and the work towards that effect (including a particular focus on aligning novices to this budding endeavour). The committee itself was dissolved after a number of years, but by then an enduring epistemic community had been established.

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The proliferation of empirical work addressing / touching on epistemic communities, albeit modest, is a positive development in this research agenda. It has also yielded some new conceptual tools for their study, which I employ in Chapters 6, 7 and 8. It is noteworthy, however, that the emergence of epistemic communities remains understudied, and only a single contribution addresses (albeit partially) explores the articulation with funding (Meyer and Molyneux-Hodgson 2016). I finish this section by addressing two concepts which will guide my exploration of the emergence of (a) synthetic biology epistemic community: "community-making devices" (Molyneux-Hodgson and Meyer 2009) and "repertoires" (Leonelli and Ankeny 2015; Ankeny and Leonelli 2016).

Through the telling of four tales, Molyneux-Hodgson & Meyer (2009) present the concept of "community-making devices". Very briefly, community-making devices are important in the trajectories of epistemic communities in that they "help make, or at least articulate the need for, community" (ibid., p. 139). The authors locate devices as present at all levels, from the global to the local; or from the watershed moments/practices in the trajectory of a community, to the banal routine. These devices are also proposed to operate through two (overlapping) mechanisms: the induction of "movement" and the creation of "stickiness" (ibid.).

Movement indicates a process of convergence towards a shared space. In the context of synthetic biology, Molyneux-Hodgson & Meyer proposed that the multitude of policy documents, grant calls, or various configurations of networks constituted community-making devices; but also less tangible ones, such as the rallying around a name and the (origin) narratives which underpinned the past, present and future visions for the community[16]. This movement can be traced as the shift of political priorities and the (re)allocation of resources, at a high level, but also to

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[16] The importance of naming a field has been acknowledge in the literature, for its relevance as a beacon for the (emerging) collective and in the trajectory of the field (Molyneux-Hodgson and Facer 2003; A. Powell et al. 2007).

changes to patterns of interaction, modes of working and a drifting sense of belonging. *Stickiness*, on the other hand, indicates a process of stabilisation in a shared space. The authors argue that events, associations, journals and particular narratives are used to make the collective *stick* – they provide material, rhetoric, and epistemic reference points which "create a sense of a global collective of people and practices enrolled" (ibid., p. 143)[17]. Community-making devices, then, can be seen as both beacons for an epistemic community, and key ways of building it.

If community-making devices provide a useful incisive analytic tool to interrogate process, they are best complemented by pairing with a tool which interrogates aesthetic. To that end, I draw on the notion of *repertoires*. Ankeny & Leonelli (2016) define repertoires as

> "well-aligned assemblages of skills, behaviors, and material, social, and epistemic components that groups may use to practice certain kinds of science, and whose enactment affects the methods and results of research, including how groups practice and manage research and train newcomers." (ibid., p. 20)

So, if community-making devices promote *movement*, a shared repertoire is a destination; and if they promote *stickiness*, the repertoire is what is glued together. Betraying the hangovers of the philosophy of science debate on appropriate referents regarding the organisation of science, the authors further argue that

> "repertoires include procedures and norms specifically aimed at stimulating institutional and financial support, such as promissory discourse and marketing strategies designed to increase the funding appeal of specific projects; they are permeable and mutable entities, which are constantly adapted to the broader research and funding environment (indeed, they owe much of their resilience to this flexibility)" (Leonelli and Ankeny 2015, 702)

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[17] The narratives around the origin, past and the future of fields have also argued to be key in understanding their stabilisation around particular understandings and trajectories (A. Powell et al. 2007). One particular narrative style can be singled out for its role in promoting and sustaining the collective, through mobilising and circulating important achievements in the field – dubbed "success stories" (Felt 1993).

Based on these articulations, the concept was critiqued (from a philosophy of science perspective) as one which could be interpreted as an expanded version, but still a version, of a Kuhnian conception of community; one where theory is replaced by a wider range of metrics – from artefacts to promissory discourse; but one which was still internalist (Sample 2017). While there is some merit to this critique, it is contingent on the casting of the concept of community. In the first article, Leonelli and Ankeny (2015) address community as stemming from research projects where the researchers developed a shared repertoire; and in Ankeny and Leonelli (2016) the authors reference the *research community*. By not explicitly defining community (as extending beyond the bench), the authors did not close the door on such readings. From an STS perspective, however, this is a debate which has largely been resolved. As I note at the start of this section, STS has long acknowledged that an adequate locus for community must look beyond the researchers themselves. Thus, over the course of this thesis, I address community as epistemic community which, by including all actors who produce knowledge, negates a critique of internalism.

Turning the spotlight back to the concept itself, repertoires, then are what grounds (epistemic) communities. They are not a homogenising force, and there is no expectation that an ideal type repertoire is articulated locally. Indeed, the opposite is true. Local enactments of repertoires are expected to be heterogeneous (in an acknowledgement of the embeddedness on and dissimilarity of local contexts) and need solely to remain identifiable as belonging to the wider corpus.

The authors go on to argue against the notion of communities being grounded on a single repertoire (Ankeny and Leonelli 2016), in a nod to epistemic pluralism (Chang 2012)[18]. A suggestion of multiplicity of repertoires has particular salience in the study of synthetic biology – a field which has been argued to encompass three communities (Schyfter and Calvert 2015). Moreover, it also has the potential to constitute a useful analytic tool in the study of the emergence of epistemic communities,

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[18] Arguably, this is a point that requires elaboration and qualification, on the basis that it problematises the concepts and links between repertoires and (epistemic) communities. While an interesting philosophical problem, however, it is beyond the scope of this thesis, for in the case of emerging communities that assertion is not problematic.

where competing repertoires battle for prominence – as has also been described was the case in the early days of synthetic biology (Bensaude Vincent 2013).

These two analytic concepts guide my analysis of the process of community-making and the resulting aesthetic. As such, they are weaved throughout the thesis, starting in Chapter 5. Overall, in this section I aimed to place the notion of community in its trajectory in STS debates. In particular, I sought to foreground how the concept of *epistemic* community has gained currency in the field, as well as how it has / could be studied. I have also established that the emergence of communities has enjoyed very little study from the perspective of its entanglements with funding – a gap which I aim to address with this thesis.

3 MESSY METHODS IN THE STUDY OF A MESSY WORLD

The preceding chapters already provide strong clues as to the methods which I employed in the conduct of this PhD project. Here, I delve into methodological detail, and link the latter to the research questions outlined in Chapter 1. From a bird's eye view, in this thesis I am concerned with the emergence of synthetic biology; the aesthetics of (epistemic) community, as well as the process of community coming into being. I see that study as best served by a qualitative approach; an approach which would enable me to glean robust insights into practices, tools, narratives (both present and absent), shared meanings, languages, etc. that came to characterise the repertoire(s) (Leonelli and Ankeny 2015) which ground epistemic communities, and the trajectory of those repertoires.

Studying emerging epistemic communities raises a multitude of methodological points, which I will address throughout this chapter. I start in this introductory section by drawing a parallel to the study of scientific controversies; in the case of the latter, Latour argued that the "entry into science and technology will be through the back door of science in the making, not through the more grandiose entrance of ready made science" (Latour 1987, 4). In this dichotomy, ready made science is offered as science which has been stabilised and *black boxed* (ibid.); the process through which it became so being out of reach. In contrast, science in the making is science in flux. Science whose material, narrative and epistemic foundations are yet (or in the process) of being laid.

As an emerging field, synthetic biology provided an arena where the community (and the *repertoire* on which it was grounded) were undergoing explicit negotiation and contestation. Thus, it provided a window to study science in the making in a *community* in the making. Unlike in Latour's argument in the context of scientific controversies, the making of community cannot exclude or be decoupled from the social world. Indeed, science, community and society are best conceived of as intrinsically linked in a permanent process of *co-production* (Jasanoff 2004). To study the emergence of an epistemic community is to operate at this messy nexus, with a concomitant (albeit implicit) commitment to the middle range – linking the macro and the micro scales, but reifying neither the detail at the bench, nor the vastness and complexity of the science (and social) system.

Indeed, it would not be inappropriate to argue that messiness was a constant presence in this thesis. At its core, this work "tries to describe things that are complex, diffuse and messy" (Law 2004, 2). The making of epistemic communities, even if only a minute articulation of a wider world, defies systematic bounding, auditing or ordering. As such, I have no ambition to make authoritative statements about what the synthetic biology epistemic community(ies) is, but to study it instead as a *moving target* (Meyer and Molyneux-Hodgson 2010); to pay attention to articulations of community, to see towards where (and/or what) it *moves*, what *sticks* and what becomes shared. I do so with particular attention to actors in / the process of governance (a constituency often omitted from STS work (Gläser and Laudel 2016)), which further amplifies the messiness of my research object.

I conducted this research as a multi-sited ethnography – a topic which I discuss in greater detail below. In my initial engagement with the methods literature, ethnography emerged as a tonic, able to engage with and make sense of a messy world. Its account was systematic, its progression (admittedly complex) methodically standardised (e.g. (Hammersley and Atkinson 2007b)). Now at the other end of the research process, dear reader, it is a jaded ethnographer who greets you. The cleanliness of the presentation of methods in much of the pedagogically focused literature does not match their messy performance. Drawing on Law once again, the notion that a *clean* articulation of method is adequate for investigating a messy world is but a fiction (Law 2004). Instead, "we need to understand that our methods are always more or less unruly assemblages" (Law 2006, 15), conforming to neither a checklist nor a meaningful idealisation of process. They are contingent on the messiness they are to address. As they are contingent on the researcher who applies them.

Indeed, methods need to be learned. It is less clear to what extent they can be meaningfully taught, but developing expertise ultimately hinges on practice. Arguably, an iterative process of practice and reflection. Thus, to embark on this process is to embark on a "very messy but exhilarating business of learning to 'do it'" (Ely 1991, 1). This "learning to 'do it'" conflates both method and the research process / outcome. Here, too, messiness is a constant presence, with entire volumes dedicated to managing the roadblocks and pitfalls of the research process (e.g. (Townsend and Burgess 2009; Streiner and Sidani 2010)). This was a salient issue in the conduct of my research project. As an unintended testament to messiness, much did not go according to plan.

In spite of the ode to messiness of the preceding paragraphs, to make this chapter intelligible I must impose (a fiction of) order in my exploration of the multitude of personal, technical and theoretical dimensions which overlap, converge and ultimately aggregate as my method. I will start by addressing my positionality and delineating my reasoning for choosing these particular objects of study (and how that changed) (3.1). I then move to the theory-method nexus where I outline and justify my approach to research (3.2). Next, I address how I conducted the project, with reference to the methods which underpinned my multi-sited ethnography (3.3). Lastly, I finish with a reflection on ethics in the process of research (3.4).

3.1 PLACING MYSELF, PLACING A PROJECT

My PhD project was funded as part of a synthetic biology network established at the University of Sheffield, entitled *PhD Network in Synthetic Biology for Human Healthcare*. It was ostensibly centred around the 3 PhD projects which it funded. The network was expected to come together in regular meetings and was additionally afforded a small budget to host events dedicated to the promotion of synthetic biology.

As to its composition, it included members whose institutional homes were as disparate as the faculties of medicine, engineering, social sciences, and humanities. The supervision model of the PhD students was explicitly designed to bridge across faculties. My supervision was to be mainly conducted by an academic in the department of sociological studies and supported by another based in the department of history. The two other students were attributed projects overseen by academics based in the dental school and the department of chemical and biological engineering. In one case the main supervisory duties fell upon the academic in the dental school and in the last one the roles were reversed.

The explicit cross faculty character of the network was no accident, but belies an institutional history and ambition, as well as a particular imagination for what synthetic biology was and how it was practised. The University of Sheffield had entered the UK synthetic biology scene early, being awarded dedicated BBSRC funding for their initial, exploratory round of networks in synthetic biology. By 2012, research council funding had been directed at other institutions, leaving the University of Sheffield in the *periphery* (Balmer, Bulpin, and Molyneux-Hodgson 2016). In some meaningful ways, the network emerged as an arena to explore ways of bringing the university back into the centre.

While the network was designed for a membership of seven, its membership was opened up in practice. Another STS PhD student became a de facto member of the network, as did another in the Department of Chemical Engineering, while postdocs (with varied domains of expertise) yo-yoed in and out. This network became a linchpin of my (changing) research design. As I set out to “follow the actors” (Latour 1987), I realised that productive actors to follow were right at the doorstep. Before I link the network to my work on the CyanoBioFoundry project and iGEM, I shall make a detour to place them in the trajectory of my research design.

As noted in the first paragraph, my PhD project was conceived as a bridge between STS and history. I quickly latched on the study of community as a cornerstone of the project, and dedicated most of my first year to uncovering what that meant in the context of bringing STS and history together from an epistemic and methodological point of view. This trajectory, however, was abruptly truncated with the departure of my second supervisor from the institution. My new supervisor was another STS scholar, which meant my thesis moved towards more canonical STS aims. However, in a parallel to an argument I make in the conclusion, this reshaping of research links and aims did not completely erase my engagement with the discipline of history. Similarly to what Rip argued was the case in changes to science policy, *residue* (Rip 2000) of the previous arrangements remained. Alongside the sociological gaze I developed over the course of the PhD, I conserved a(n admitted rudimentary) *historical* gaze as well. This came to manifest over the course of the research, informing my choices of sites of where to look for epistemic community, the *sensitising concepts* (Blumer 2009) I would come to adopt, and even the temporal frames I explored.

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The synthetic biology network included members of the CyanoBioFoundry project. As I reconfigured my project along STS lines, my interest in those actors grew. I was conscious that the literature on synthetic biology had a clear geographic focus on either American or ostensibly global (in the case of iGEM) actors / initiatives. Moreover, the literature was also concentrated on the emergence of synthetic biology in the context of its *core set* (Collins 1985) and, at the other end of the spectrum, novices (again, in the context of iGEM). This opened up a theoretical space for the study of the emergence of community with a different geographic focus, and somewhere between the core set and the periphery. CyanoBioFoundry appeared to provide a fruitful object of research which addressed these gaps. I discuss the project (and its past a potential futures) in detail in Part III, but I will note here that CyanoBioFoundry was a collaborative project, funded by the EU FP7, broadly aiming to use synthetic biology to modify cyanobacteria so as to increase its production of hydrogen (in their framing, a biofuel). It involved ten research groups spread out across Europe, with a shared budget of roughly four million euros to be spent over a period of three years. It included researchers with a wide variety of backgrounds and expertise, which collided in a project where synthetic biology was to be *co-produced* alongside the bioreactors which enabled the epistemic practice. The choice of this project as an object of study was thus at the intersection of *opportunistic* and *purposive* sampling (Patton 2001, 240; 230). It was opportunistic in the sense that this was a project where the barrier to access was low, and about which I had previous knowledge (themes which I discuss in greater detail below). It was purposeful because these were actors *worth following*; this was a project of synthetic biology *in action*, away from the drives towards epistemic purism which were described in the literature, and in a different geographic location.

Despite the usefulness of this case study, my entry into the field brought into sharp relief the need to amend the research design. The reasons for this were two pronged (albeit connected). For one, my first immersion in observation and an intense round of interviews made clear the conflict between *process time* and *project time* (Ylijoki 2016). That immersion made clear the longitudinal nature of the emergence of epistemic communities, made more salient by the design of the CyanoBioFoundry project, which pushed the (potentially) more meaningful engagements between participants to the later parts of the project (and was deliberately designed in a way that avoided engagements deemed non essential). I first attempted to mitigate this conflict through a plan of immersing myself more deeply in the project, with particular emphasis on the groups for whom meaningful collaboration was unavoidable. This proved problematic, for CyanoBioFoundry being a European project, it meant spending extended periods of time abroad, and my grant fell far short. The ESRC overseas fieldwork allowance, which would usually cover such expenses, was out of reach, for my grant was from a different source; and alternative funding pots were scarce, and the response negative. Alas, it is all too fitting that a research project that explicitly addresses the role of funding in the trajectory of epistemic communities has had its trajectory changed due to the unavailability of resources.

For explaining the new direction in the research project, I turn back to the synthetic biology network. Around the spring of 2013, several of the wet lab based PhD students in the network expressed interest in taking part in an *iGEM competition*, in a presentation during one of the network meetings. At that point, I was aware of iGEM, but only vaguely aware of what the competition entailed. Over the next few months, I came to grasp iGEM as a titanic competition for an emerging field, and one which was driving the epistemic development and, more broadly, the repertoire of a particular type of (parts-based) synthetic biology (PBSB). What is particularly peculiar about iGEM, is that it is driving community through the recruitment of novices; novices who are grouped into teams, develop a project, modify biological organisms guided by a PBSB ethos, and who converge at the end of the competition in a large, international(/global) gathering. I discuss iGEM, its trajectory and structure in greater detail in Chapter 8.

By the autumn, the PhD students and senior researchers agreed to enter the 2014 competition, and I was invited (and volunteered) to join the team as well in the capacity of *advisor*[19]. As alluded to in the previous paragraph, participation in iGEM was being spearheaded by the PhD students. Joining the team, I joined the cohort and their (and then our) self-assigned tasks. I was closely involved in the setting up of the participation: the imagination and recruitment of the team, as well as the applications for funding. It is noteworthy that my first engagement with issues of governance and funding – and the concomitant sensitisation – took place here, and not in the context of CyanoBioFoundry. Reflecting over my growing engagement with these themes, it strikes me that they gained some salience even before any fieldwork in the context of CyanoBioFoundry, but through process of applying for funding in departmental, faculty, university, local, national and European structures.

My participation extended over the entire life course of participation in the iGEM competition. I also attended the iGEM jamboree 2014. My engagement with iGEM drove my incorporation of study of the Sheffield 2014 iGEM team, and iGEM more broadly (to include the registry of standard biological parts and iGEM labs) in my research. I became a(n intermittent) resident participant observer as the team

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[19] *Advisor* in the context of the iGEM competition a mid-tier hierarchical category, between senior researchers as instructors, and the novices as team members.

prepared, conducted and presented their project in the iGEM jamboree. I interviewed the team members. I was a participant observer in the iGEM *meet-ups*, as well as in the iGEM 2014 jamboree. I analysed documents and (recorded) presentations produced by the iGEM team, as well as iGEM organisers (in the context of the competition, the registry of standard biological parts and iGEM labs).

In this thesis, however, I omit the totality of the data collected in the context of the study of the Sheffield 2014 iGEM team. I do so with a heavy heart, but do so to contain the textual and thematic sprawling in this thesis. Nevertheless, this research still informs my understanding of synthetic biology and the emergence of an epistemic community as I discuss it in this thesis. This omission was a decision I struggled with, when perusing the whole breadth of data collected. It points to a broader difficulty of "studying the particular, there is a problem of closure, to determine how to bound a case temporally and spatially" (Meyer 2006, 68). In my thesis, the twists and turns of research design, coupled with the messiness of the work and the process of learning to do research, mean that some of that bounding is only taking place post hoc. While I have no doubt that a good thesis could be written which explored the making of synthetic biology in CyanoBioFoundry and an iGEM team, *following the actors* in the context of the former brought me to to theoretical and thematic lands which I believe are of greater academic interest (at least for this researcher).

Over the course of this section, I positioned myself as a researcher, both in an institutional context and as a novice, struggling with the design of a research project. In tandem, I allude to the trajectory of that project and the inherent messiness which the multiple adjustments to design entailed. I suggest that I moved from a historical focus, to the study of the emergence of epistemic community in CyanoBioFoundry, and then iGEM, only to *follow the actors* back to more diverse sites and a different temporal frame. As such, this illuminates a struggle with bounding the thesis, which led to the omission of the research on the Sheffield 2014 iGEM team. I finish this more reflexive section with an examination of my relation to the field and the extent to which I was an insider and/or an outsider.

In some meaningful ways, it is hard to escape the notion that I was an *insider*. I was originally trained in biochemistry, which affords me a window into the world of (some of) the participants. More than that, I (briefly) worked at the margins of the project which preceded CyanoBioFoundry, meaning I have a grasp on the lab (epistemic) culture and practices. Consequently, I knew many of the participants in one wet lab biology group, and witnessed their drift towards synthetic biology in real time; I was also vaguely aware of some of the collaborators. Indeed, I was construed as an insider by most of the project participants. They spoke to me about the technicity of their work (even after being well aware my research was in the social sciences). I was included in the mailing lists. My project and I were even referenced in some of the project's deliverables and in the final report. Yet, the most salient indication of my insider status came during my first experience of fieldwork with CyanoBioFoundry, in the context of the first year project meeting. There, one academic external to the project, expected to speak on the last (open) day of the meeting, was mistakenly invited for the private portion of the meeting. That led to a tense situation, with the academic leaving after the first coffee break, and stern words being exchanged about the inappropriateness of having *outsiders* in the meeting. Clearly, I was unable to disguise the extent to which that boundary had startled me, for two PIs discreetly approached me over the following break, to reassure me I *belonged*. That was both an unexpected (and most welcome) act of kindness, and an early indicator of the insider role I would come to be afforded.

Yet, having ingratiated myself as part of the project and negotiated access to the more sensitive portions of the yearly meetings, my inability to find my way into the mid-term review meeting provided a rude awakening as to the limit of my insider status. That meeting, I was told, was an *internal* review meeting. I was to remain on the *outside*. A second example of my treatment as an outsider was unexpected, for it was a boundary drawn by (the) researchers with whom I had pre-existing social ties. I was accepted as part of the project, but as an outsider within it. In several instances where I was introducing myself to new participants, the researcher(s) jokingly referred to me as now doing *fake science*, in opposition to the *real science* I had performed before. In other instances, I was referred to as *the spy*. From a personal standpoint, again, in some meaningful ways, it is hard to escape the notion that I was an outs*ider*. I did not perform wet lab biology, mathematical modelling, bioinformatics, proteomics or process engineering. I was not involved in collaborative work. My research interests and epistemic practice are those of an STS researcher.

The inherent tension to the overlapping positioning as insider and outsider suggests that a dualism is inadequate to address it. More broadly, this is a distinction eschewed in the method on which I base my work – multi-sited ethnography. This ethnographic genre is not

> "practiced in the primary, dualistic "them-us" frame of conventional ethnography but requires considerably more nuancing and shading as the practice of translation connects the several sites that the research explores along unexpected and even dissonant fractures of social location"(Marcus 1995, 100).

Indeed, this suggests a move away from an interest in pinning down the dichotomy of roles, but that it is instead more rewarding to "try to work creatively within its tensions" (Acker 2001, 156; Kanuha 2000). These passages above also signal contingency in the framing as insider and outsider. As such, I reject the common methodological call of finding and sticking to a position somewhere in the spectrum between insider and outsider, but contend instead that to work with that tension is also to perform being an insider or an outsider to different extent in different circumstances.

So, while it is imperative to keep distance from the people studied, how far away to place oneself is a determination that is contingent. I address this theme further in the following sections, particularly in the context of the different styles of observation I employed.

3.2 FOLLOWING THE ACTORS: A MULTI-SITED ETHNOGRAPHY

> "[I]n situations where innovations proliferate, where group boundaries are uncertain, when the range of entities to be taken into account fluctuates, the sociology of the social is no longer able to trace actors' new associations. At this point, the last thing to do would be to limit in advance the shape, size, heterogeneity, and combination of associations.
> [...] Your task is no longer to impose some order, to limit the range of acceptable entities, to teach actors what they are, or to add some reflexivity to their blind practice. Using a slogan from ANT, you have 'to follow the actors themselves'"(Latour 2005, 11–12)

In this thesis, I address messy processes of emergence of distributed, poorly defined and porously bounded assemblages. As such, I take the (Latourian/ANT) maxim of *following the actors* as the key guiding principle (at a methodological/theoretical nexus) of this thesis. This stance also implies the application of a principle of *symmetry (Callon 1984)*, which I advocate. That is, I follow the actors without presupposing any given epistemological stance is to be valued above others; more than that, I reject the subordination of non-human actors to human actors treating them instead in a level playing field. The question of symmetry is salient in the study of synthetic biology, where different visions for the field (still) operate, where different communities operate under the same banner (Schyfter and Calvert 2015)) and different epistemological stances coordinate and conflict even within the communities. It also informs my focus on the choice of *repertoires* (Leonelli and Ankeny 2015) as an analytic tool, for it brings into focus a (I will argue, important) role of non-human actors in the emergence of the epistemic community.

In underpinning this study in a drive to *follow the actors*, I make a tacit rejection of any ambition to provide whole, systemic and definite analysis of the emerging synthetic biology epistemic community. It also provides a tacit acknowledgement that I start this study *in media res*. As I entered the field, synthetic biology had been undergoing a process of coming into being for over a decade. It had moved from laboratories in American institutions to small and large laboratories around the world. Multiple (iterations of) conferences on synthetic biology had been organised.

Synthetic biology journals had been established. The iGEM competition was routinely drawing thousands of students in each yearly competition. Much historical, philosophical and STS work had been conducted. Any attempt to tell a rich story of this longitudinal, distributed, conflicting and dispersed process would prove an intractable fool's errand, at a practical and, above all, an epistemic level.

Conversely, a focus on the micro-scale, in the well established tradition of laboratory studies, would also prove intractable. As Lorenz-Meyer (2010) pointed out in her exploratory study on epistemic communities: "I would answer the question whether the chemistry laboratory is an epistemic community in the negative" (ibid., para. 5.6). Instead, she went on to argue,

> "Contours, distributions and textures of an epistemic community cannot be studied at a single analytical site. [...] What appropriate research sites may be in such mobile and connective ethnographies the researcher cannot assume prior to the investigation" (Lorenz-Meyer 2010, para. 6.3).

In rejecting a priori definition of appropriate sites, Lorenz-Meyer makes a tacit case for *following the actors* as one studies epistemic communities. In tandem, she also makes the case for the rejection of a micro-scale approach to this study. In a recognition of the distributed character of epistemic communities, she calls for their investigation in multiple sites. To follow the actors, yes, but as a meso scale.

Bringing together these theory-method underpinnings, I elected to conduct my research project in the ethnographic tradition, for "ethnography lets us see the relative messiness of practice […] to try to understand the often ragged ways in which knowledge is produced" (Law 2004, 11–12). While ethnography affords the researcher a way into the investigation of messiness, that messiness is reflected in the method. Ethnography is neither clean, nor simple, but instead

"Doing ethnography is like trying to read […] a manuscript – foreign, faded, full of ellipses, incoherencies, suspicious emendations, and tendentious commentary, but written not in conventionalized graphs of sound but in transient examples of shaped behavior." (Geertz 1973, 10).

An ethnographer must, then engage with a multiplicity "which he must contrive somehow first to grasp and then to render" (ibid., p. 10). It is my view in this thesis that this *thick description* (ibid.) is an appropriate and fruitful way of engaging with the messy process of emergence of epistemic communities. As alluded to above, however, an ethnography of epistemic communities cannot be productively conducted in a single site. As such, I conducted a *multi-sited* ethnography. The move from a(n ostensibly) single site to multiple ones is more than a simple question of arithmetic, but carries theoretical and methodological implications, for

> "Multi-sited research is designed around chains, paths, threads, conjunctions, or juxtapositions of locations in which the ethnographer establishes some form of literal, physical presence, with an explicit, posited logic of association or connection among sites that in fact defines the argument of the ethnography" (Marcus 1995, 105).

In this way, multi-sited ethnographies are not bounded to any site; they are not bounded to any actor. Instead,

> "Multi-sited ethnographies define their objects of study through [...] practices of construction through (preplanned or opportunistic) movement and of tracing within different settings of a complex cultural phenomenon given an initial, baseline conceptual identity that turns out to be contingent and malleable as one traces it" (Marcus 1995, 106).

As such, the performance of a multi-sited ethnography presupposes a commitment to *following the actors*. This implied epistemological stance also means that such methods do not attempt to provide a holistic view of any system. Nevertheless, this is not to say that such ethnographies negate or ignore the global. "The global is an emergent dimension of arguing about the connection among sites in a multi-sited ethnography" (Marcus 1998, 83). Thus, this method enables an analysis of how the global comes to be configured in the local (and, arguably, the local comes to be configured in the global, in a mechanism of *co-production*). To conduct multi-sited ethnographies, then, is to occupy the middle ground. It is to "embody the middle range" (Hine 2007, 669) and, as such, is enabling of the production of middle range theory which has been called for teasing the link between funding and research practice (Gläser and Laudel 2016).

In sum, this is a method particularly fruitful for the study of the emergence of synthetic biology. It enabled me to *follow the actors* as I searched for epistemic community in synthetic biology. It was permissive (and supportive) as I transgressed the boundaries of the CyanoBioFoundry project, looking at the past, the future, and the sites/actors which tied the emergence of community with issues of governance. Furthermore, it enabled me to articulate the local in connection with the global, tracing how a (global) repertoire was enacted, negotiated, resisted and modified in the process. I turn now to a more tangible account of my multi-sited ethnography, through the lens of how it was conducted.

3.3 CONDUCTING A MULTI-SITED ETHNOGRAPHY

Due to the constraints I described in section 3.1, I inadvertently conducted this multi-sited ethnography under a model of "yo yo fieldwork" (Wulff 2002). I went through periods of continuous, intense engagement with the field, after which I moved away from it by returning home. This peculiar temporality has moulded my ability to be *in* the field, but it did not prevent me from *following* the field. Wulff noted a similar pattern in her study of dance in Ireland, noting

> one gets information about what is happening when one is off field, so to speak. [...] During off-fieldwork the fieldworker is temporarily physically away from the field, but not mentally. [...] I get e-mails and post mail, both formal introduction from organisations and also informal letters from key informants about what is going on. I keep up with web pages of Irish newspapers and dance companies, and spend a lot of time watching dance videos that my informants give me or send me, or that I buy in Ireland" (ibid., p. 122).

There is a clear parallel to be drawn between Wulff's experience and my own. When I was away from substantive fieldwork in the CyanoBioFoundry project, I was still on its mailing list. I looked for deliverables as they were made available. I followed the publication of relevant EU work programmes / calls for proposals. And, above all, I was in constant informal contact with one PhD student in CyanoBioFoundry, who was also an advisor to the Sheffield 2014 iGEM team. Indeed, in this model of fieldwork, despite the physical distance, "the field is always present, at least in the back of one's mind. [One] keep[s] thinking about theoretical questions, plan methodological manoeuvres" (ibid., p. 126). I depart from Wulff's description only in the bounding of the sites. For her, the *off field* periods were periods of reflection and support of future, far away, fieldwork opportunities. In my case, however, they gained a life of their own, with my documentary analysis veering towards elements at the borderlands of *archival* ethnography (Merry 2002) and *trace* ethnography (Geiger and Ribes 2011)– morphing into a new site where to *follow the actors*.

The work I present here is underpinned by three methods: participant observation, semi-structured interview and documentary analysis. I address those now, and finish with a brief overview of data analysis.

3.3.1 Participant observation

Participant observation is the cornerstone of my empirical work. As I note in section 3.1, I was unable to engage in the field to the extent I would have preferred to. Yet, the richness of the data I collected in the field took me by surprise. I experience in actu the benefits Bryman (2012) (catalogues and) attributed to the use of participant observation, when compared to the use of qualitative interviews. Participant observation was key, in that it enabled me to "see through others' eyes", learn "the native language" and the develop "sensitivity to context" (ibid., pp. 493-494). While I was in some ways an insider, the very notion that viewpoint is transferable – i.e., that I would have been able to export my reading of what being an insider means onto others – has been dismissed, or at least strongly curbed (Fay 1996). Moreover, I was never an insider beyond the lab. There was much to learn about different epistemic stances. As was there much to absorb about what it meant to work in an EU project.

From a different viewpoint, Bryman also described benefits as being able to access "the taken for granted" knowledge/practice, which is hidden in an interview context, the ability to witness "deviant and hidden activities", and the possibility of "encountering the unexpected" (Bryman 2012, 494). I came across all three categories, particularly through access to the *backstage* (Goffman 1990 [1959]) of CyanoBioFoundry. I now move to detail the fieldwork opportunities, and I finish the subsection with a reflection on *how* I conducted observation.

In the context of iGEM, I performed participant observation in the 2014 iGEM jamboree. The majority of my participant observation, however, took place in the context of the CyanoBioFoundry – and its project meetings in particular. These were yearly gatherings which spanned several days, where the consortium came together, working as somewhat formal process monitoring points. They were iteratively organised by different PIs, and were thus run across Europe. These meetings were intense affairs which followed a broadly similar structure, with the first few days being a private, internal meeting. I observed the long presentations groups delivered on the progress of their tasks; the bureaucratic meetings of consortium committees; the time off the clock (which mostly revolved around meals); and the sessions where the meetings became not about progress, but about preparing futures. These project meetings were also peculiar in that they included one (final) where the focus was not internal, but operated instead as public events. I participated in these events as well.

Beyond the physical project meetings, I also took part in one videoconference meeting which took place on the second year of the project, for the purpose of sustaining links /organising work between formal events. In addition, I also followed the project over the course of two student exchanges, performed under the guise of collaboration / experiential learning. I followed the PhD students as they navigated the laboratories (in two countries), and engaged with each other / each other's work, as well as the wider lab (and the lab's *epistemic culture* (Knorr-Cetina 1999)). I provide a list of participants, matching their pseudonyms to their area of expertise / career stage in Appendix A[20].

From a methodological point of view, I first approached observation explicitly driven by the a principle of "fighting familiarity" (Delamont and Atkinson 1995), in order to ensure I maintained a productive analytic distance. I carried Salk's "anthropological probe" (Latour, 1987, p. 12) with me as I entered the field. As such, I implicitly acknowledged the value in taking part as a "naïve observer" (ibid., p. 254); as an observer who carried no a priori knowledge of the phenomena she was to observe, treating therefore the scientific enterprise as if a(n esoteric) tribe. As an observer who took nothing for granted, but instead interrogated all and any practices *naïvely*. I conducted this type of observation during the entirety of the fieldwork (not always as a fiction). However, as I progressed, it became increasingly clear that this approach to observation had clear shortcomings, particularly in the context of the negotiation of a repertoire. Indeed, the lack of engagement with the substance of scientific practice has been deftly critiqued, on the basis that

> the naïve "'observer' is presented only as a literary fiction, and not as an exhaustive methodology, and the account which resulted from their inquiry is far more comprehensive and detailed in its access to technical practices than could possibly have resulted from the 'observer's' initial man-from-Mars posture towards the work of lab members" (Lynch 1982, 507).

Lynch posits, then, that a fully naïve approach would have been unable to elicit the nuanced observations upon which Latour and Woolgar's argument was built; a sentiment echoed by Laudel & Gläser (2007), who note the inability of a naïve observer to recognise *modalities* or the principles for constructing and repeating an assay.

Diametrically opposite a naïve approach sits the *native* observation stance championed by a number of prominent authors over time (e.g. (Edge and Mulkay 1976; Pickering 1986; Merz and Cetina 1997)). This was an approach which was out of

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[20] This is a partial list of project members, due to the fact that I neither met not interacted with all members; but also as an attempt to obfuscate and resist identification. I address some of the issues with anonymity and how I grappled with them in section 3.4.

reach (if I could be deemed a native, I would ever only be a *partial* native), at odds with my research aims, and which carried epistemological issues. This left a middle position, that of *informed* observation, which I, at points, adopted. In informed observation, the researcher acquires (a varying degree of) competence in the object of study, which enables her to engage with the substance of science. Collins (1984) provides a methodological discussion of the conduct of informed observation; interestingly, he conflates informed observation and participant observation (which he dubs participant comprehension). While the conflation is, in itself, problematic, it points to an epistemological stance that meaningful engagement with the substance of the objects of study requires an informed approach. Arguably, following Lynch's critique above, Latour and Woolgar veered away from their naïve position to an informed one at points in the study. I did the same.

To illustrate the added value of this type of observation in my study, I draw on an example from a CyanoBioFoundry meeting. A presentation by one of the SMEs elicited a discussion of brands, degrees of purity and additives to be used in cultivating the cyanobacteria. The SME PI argued for a given set of standards; wet lab group PIs argued for a different one. From the eyes of a naïve observer, this was mundane discussion, of little (if any) interest. Seen from the standpoint of an informed observer, however, this constituted an epistemic struggle. For the SME PI, this was a proxy discussion of cost; his focus was on having a process which worked well enough, and was as cheap as possible. For the wet lab PIs, this was a proxy discussion of validity; success was measured against publication, and empirical results drawn from cultivation in conditions other than those accepted by the peer community would result in the rejection of their research.

As I navigated the project, then, I performed the role of naïve observer and informed observer at different times, faced with different sites and different actors. In conducting this work, I also became sensitised to issues of language at the core of the EU project – a discussion of which I concentrate in the interview section below. Lastly, if these experiences of observation were incredibly rewarding from the standpoint of the data that I was able to gather, they also pointed to the data that I was missing. While collaboration was explicitly put on display in these events, there was much I became conscious I was missing. Collaboration took place in emails, ad hoc video calls, (other) student exchanges, and the shipping of artefacts (physical and digital) across national lines. Considering the relevance of collaboration for making the project (and consequently synthetic biology) work, as well as how it informed the aesthetic of the repertoire which was being enacted / built, a sole focus on observation would be inadequate.

3.3.2 Interview

I conducted 14 semi-structured interviews with CyanoBioFoundry project members. With one exception, these interviews took place during / in the days preceding / following the CyanoBioFoundry project meetings; or student exchanges. As such, they also conformed to the same pattern of “yo-yo fieldwork” (Wulff 2002), being conducted largely in batches, over three periods in 2013, 2014 and 2015 (see Table 1). In selecting interviewees, I aimed to include informants at different career stages – whose engagement in epistemic practice I expected to differ – and to include informants from wet lab, modelling, bioinformatics, ‘omics and SME/industry groups. In this way, selecting appropriate interviewees proved unproblematic.

Table 1. List of interviews

Participant	Interview date
Early career researcher 1 (wet/dry lab)	15th November 2013
Postdoctoral researcher 1 (wet lab)	25th November 2013
Early career researcher 2 (wet lab)	26th November 2013
Postdoctoral researcher 2 (wet lab)	26th November 2013
Early career researcher 3 (wet lab)	27th November 2013

Participant	Interview date
Senior researcher 1 (wet lab)	28th November 2013
Senior researcher 2 (wet lab)	10th December 2014
Senior researcher 3 (wet lab)	10th December 2014
Early career researcher 3 (dry lab)	17th December 2014
Early career researcher 4 (dry lab)	18th December 2014
Senior researcher 4 (dry lab)	29th September 2015
Senior researcher 5 (industry)	1st October 2015
Senior researcher 6 (dry lab)	14th October 2015
Early career researcher 1 (wet/dry lab)	17th November 2015

Two participants refused my request for an interview. Everyone I else approached, however, was surprisingly enthusiastic. I followed a canonical model of (*informed*) interview, guided by the process described in Laudel & Gläser (2007). I tailored each interview to the participant. I revisited the work reported in / field notes from the project meetings; I looked for recent publications and grants; I perused their lab webpages; and I drew on previous personal interactions. Based on this information, I drew a skeleton set of questions, around which to base the interview. In most cases, one or two prepared questions were left unasked, but in all cases that absence was made up by follow-up questions and the interviewee providing answers that went in unexpected, though fruitful, directions. The interviews lasted for between thirty minutes and two hours, with most falling around the one hour mark.

In preparation for the interview process, I attended a short course (provided by the Faculty of Social Sciences, as part of a programme of PhD training) in the matter of interviewing *elite* subjects. The course was predictably focused on addressing a power imbalance between a junior interviewer and an elite interviewee, providing strategies for eliciting information and keeping the interview moving and on track. As such, I was braced for potentially arduous interviews. However, these fears proved unfounded. I was left surprised with how smooth the process was; I drew on that training to bring some interviewees back to my topics of interest, but that was the main intervention I made in managing the interviews. Interviewees were obliging and engaged.

13 of the interviews were conducted in person, with one conducted via video conference. This interview was originally planned to be face-to-face, being postponed at the last minute. This change of plans is but the tip of an iceberg of hurdles in making interviews happen. In my original plan, I did not intend to conduct interviews during the project meetings. I was aware these were intense, long, tiring days, with relatively few gaps and a multitude of tasks/interests competing for time. Instead, I had aimed to conduct these interviews in a more relaxed environment, during extended periods of fieldwork with several of the research groups, which I had chosen to coincide with visits / exchanges with other groups. When that proved impossible, I attempted to schedule interviews during the *off field* periods, but that proved difficult – participants were willing to be interviewed, but pushed the interview to an opportunity where it could be conducted face to face. Invariably, this meant the project meetings. Making the interviews happen during project meetings, however, also proved challenging. Two interviews I had scheduled for the 24 month meeting were postponed to the last meeting, as a consequence of being unable to find a window in which to conduct them – sessions overran, reducing the time between breaks; conversations carried on from the sessions, which made it difficult to whisk the interviewee away; and even when I succeeded, in two occasions the interview was gatecrashed as I was preparing to begin. Indeed, with the exception of the first batch of interviews, which I held in the research institute of the partner who organised the (first year) meeting, the interview process was characterised by a struggle with noise, interruption, short time windows, and the absence of private rooms.

As I prepared for the last batch of interviews, I recognised this issue and attempted to mitigate it. I was more forceful in scheduling a specific time for the interview, and keeping the interview happening on time. I scouted the hotel where the meeting was held thoroughly, to find spaces as far away from other participants (to avoid the interviewee being overheard) and as quiet as possible. Still, even in this case, one of the interviewees was a no show (and nowhere to be found). They were apologetic, and later explained they had been in an impromptu discussion of potential collaboration with one of the external speakers (a theme which I then explored in the interview). We rescheduled this interview to conduct over video chat. In retrospect, these struggles with my interview strategy belie a collision of process time and project time – the key themes to address only became clear around the 24 month meeting mark; but they also put on full display my status as a novice ethnographer. I should have been more nimble in devising interview opportunities; and I should have been more forceful in sticking to those interview opportunities (sooner).

I conducted the interviews in English, Portuguese and a mixture of Portuguese and Spanish. I recorded all the interviews, and subsequently went through the long, tedious, but ultimately rewarding process of transcribing them. I transcribed the interviews in the language(s) in which they were conducted. The issue of language was one ever-present in my work. While the CyanoBioFoundry project's official language was English, I came into contact with a total of seven languages over the course of my fieldwork, even if only fleetingly. This manifested in interviews as well, with interviewees retreating at points to their native language, motivated by either a lack of proficiency in English to express a particular sentiment, or the absence of tools in the English language to convey specific meanings. In the cases where I was proficient in the second language such hybridity was unremarkable in the context of conducting the interview: if there was any disruption it was quickly resolved and the flow largely maintained. In the situations where the terms (and the languages) were alien to me, however, I often opted to elicit clarification[21].

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21 Some allusions to languages other than English were intelligible in the wider context of the interview. When their meaning was not particularly clear, but their relevance for illuminating the

Translation indicates an important way through which I inserted myself in the process of knowledge production. Researchers "have accepted to varying degrees the view that meaning is constructed in rather than expressed by language" (Barrett 1992, 203). Thus, the process of translation was not so much one of finding equivalent words, but one of matching the *cultural meanings* in the original and translation languages. This process bore particular fruit in my engagement with the notions of community in German, as I allude to in Chapter 2 and operationalise in Chapter 9. Methodologically, it has been argued to be good practice to interview translators / interpreters when those are used, to understand how their own positionality colours their engagement with the research objects (e.g. (Stanley 1990; Bradby 2002; Duranti 2003)). In my case, I alone wore the multiple hats of translator, interpreter and researcher. Thus, rather than interviews, I engaged with the question of my own perspective regarding (moving across) languages in action.

3.3.3 Documentary analysis

Initially, I focused on collecting and analysing documents produced by members of the CyanoBioFoundry consortium. These included project documents, journal publications and grey literature that became available. Such documents were invaluable because they place the researchers' activities in a bigger context: they reflect the researchers' own rationale for working in the way they chose to work in and how researchers intend for their research to be accomplished. In response to my experiences in the field, and as I adjusted the research design, as described in 3.1, my focus expanded to the past, and to different sites and actors, which I accessed mostly via documentary analysis. In the vicinity of CyanoBioFoundry, I expanded my strategy to look for similar sets of artefacts relating to the CyanoH2modules project – a project which was an antecedent to CyanoBioFoundry in the long-term research line of the use of synthetic biology to modify cyanobacteria for the production of particular

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themes of the interview appeared limited, I opted to avoid drawing attention to the terms. As alluded to in the paragraphs above, the time constraints of interviews were a larger concern.

outputs. I used these documents to inform my approach to fieldwork, in developing *sensitising concepts*, and in my analysis.

I also widened my focus to beyond the specific projects. This was a gradual move, propelled by the increasing salience of governance – mediated by funding instruments – over the course of my work with CyanoBioFoundry. As such, I engaged with the EU framework programmes' calls for proposals, work programmes, and the (grey) documents prepared by the European Commission in the context of research programmes and the (then in preparation/negotiation) EU-Japan free trade agreement. As I did so, my sampling gradually *snowballed* (Patton 2001), as it became increasingly clear that making sense of the situatedness / process of epistemic community-making in the context of the EU project(s) was closely tied to a nexus of making a particular, European, synthetic biology and a particular European Union.

In this expanded role, I traced the synthetic biology projects funded by the European Union up to FP7. I delved into the documents produced by the EU projects with a community making focus, which included formal abstracts, deliverables, periodic and final reports; but also a plethora of less formal outputs, namely websites, draft documents and presentation slides. In tandem, I also explored the intricacies of the EU funding programmes under which synthetic biology projects received support, through calls for proposals, reference documents and work programmes, as well as reports and formally articulated visions. I also addressed more general documentation which tied in with those funding programmes – namely documents produced by the KBBE-NET expert group, documents addressing the ERA and document focused on the KBBE / Bioeconomy.

In the case of iGEM, I performed a similarly forensic examination of the competition, the registry of standard biological parts, and iGEM labs. This was mostly centred around existing (and archived) webpages and documents on the iGEM website. Indeed, the iGEM website proved to amass a large amount of historical information, for it retained much of the content as it was produced in the context of each yearly competition[22]. Moreover, the wiki format of the website meant that not only was the final version of a webpage available, but also many of its interim configurations. As iGEM (in all three branches) relies heavily on the website as a central, organising source, the latter provide a fruitful site for *following the actors*.

In this way, my documentary analysis went beyond playing a supporting role to interviews and participant observation, but took a life of its own as I traced the "documentary construction of reality" (Atkinson and Coffey 2010). As such, it veered towards incorporating much of the ethos of an "archival ethnography" (Merry 2002), as I reconstructed the detail of (recent) past events. Nevertheless, this was not research conducted in formal archives. The Internet Archive, on which I relied at points, came closest to a formal archive, but it was neither the sole focus of my practice, nor did it share much of the characteristics of historical archives (namely, it was not meaningfully curated). Arguably, then, my multi-sited ethnography veered instead to the borderlands of an archival ethnography – whose ethos it came to partially incorporate – and a "trace ethnography" (Geiger and Ribes 2011) – whose practice it incorporated.

3.3.4 Data analysis (and writing)

As implied throughout the chapter, I subscribe to an epistemological stance that rejects ethnographers are merely in the business of collecting *facts*. The methods employed in research "not only describe but also help to produce the reality that they understand"(Law 2004, 5). Further, the "researcher is a central figure who influences, if not actively constructs, the collection, selection and interpretation of data" (Finlay 2002, 212). Thus, method, data collection and data analysis cannot be productively disentangled. This applies also to their temporalities. I did not interpret data at the end, after exiting the field, in a dedicated step. Instead, data analysis was a constitutive part of the performance of research. It went in and out of focus as I pro-

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[22] A notable exception is the 2006 competition, where the iGEM competition was supported by a long expired website. This drawback was mitigated by access to archived versions of the webpages in the Internet Archive (http://www.archive.org).

gressed through the research process. In particular, I analysed data in an iterative fashion, following with my consecutive engagements with the field. As such, data analysis informed subsequent deployments of method, and consequently also the new data produced.

I do not, however, intend to reify data production and analysis as purely inductive. While informed by theory, I went into the field conscious I would be "encountering the unexpected" (Bryman 2012, 494), carrying with me a number of (revolving) sensitising concepts (Blumer 2009). I did not insert theory for limiting the range of observations I made, but instead followed the trails of actors, wherever they led. As such, in this thesis I aim for the middle ground once again. I acknowledge that theory (and method) cannot be extricated from the process of analysis, but neither is it all encompassing; this affords a role to a deductive approach to analysis (and concomitant theory-making).

On a practical level, my data mainly consisted of a number of different textual inscriptions – handwritten (field) notes, digital (typed, field) notes, paper and digital documents. Alongside these, I also drew on audio and video recordings of interviews and presentations, as well as audio recordings of my experiences in the field, as reflections and as audio field notes. These raw materials required *processing* – ranging from the clean up of texts to the conversion of materials in audio and visual media into textual inscriptions (and, in the case of the interviews, much clean up as well). Cleaning up the research materials, then, was a process of editing, re-interpreting handwritten notes (which required considerable amounts of squinting), clarifying meanings of inscriptions, as well as correcting errors as they appeared.

In operationalising data analysis, I drew on grounded theory principles. I *coded* the written materials. In analysing the first batch of documents, field notes and interviews, I conducted *open coding* (Strauss and Corbin 1998, 101). That is, I approached the materials in the absence of any pre-existing themes. Instead, the themes would emerge in the process of (detailed) analysis of the materials. This elicited a large number of codes, as would be expected. I addressed the cacophony by a combination of critical examination of the codes against my research questions; and their grouping under a model of *axial coding* (ibid., p. 123) and, where appropriate, the merging of codes. I then performed a second pass analysis, based on the narrower list of codes (a process which I repeated as new relevant codes emerged along the research process). In working with these codes, I created text documents (and later moved to processing them under the NVivo 10 software package, exporting the codes in text documents for [literal] manual processing) where I compiled the relevant passages; and I created mind maps (both digital and hand prepared) where I inputted a distilled version of the codes. Lastly, I should note that this was not a process entirely detached from theory. Alluding to the middle ground once again, where existing theory and data were aligned, that is what I applied.

Seen through this lens, data analysis could be cast as a somewhat removed process. That is not the case. Indeed, data analysis is interwoven with writing, culminating in the production of a written thesis. As Latour notes

> "Can the materiality of a report on paper, a story, or rather a fiction—there is no need to abstain from a word that is so close to the fabrication of facts—extend the exploration of the social connections a little bit further? [...]. While there exists no material continuity between the society of the sociologist and any textual account—hence the wringing of hands about method, truth, and political relevance—there might exist a plausible continuity between what the social, in our sense of the word, does and what a text may achieve" (Latour 2005, 128).

In this way, data analysis culminates in the process of writing a final draft. Yet, the process of writing itself (in its many iterations) is a process of data analysis. Invariably, reflexive ethnography brings us back to the theme which permeates this chapter – it produces messy texts,

> "texts that are aware of their own narrative apparatuses, that are sensitive to how reality is socially constructed, and that understanding that writing is a way of "framing" reality. Messy texts are many sited, intertextual, always open ended, and resistant to theoretical holism, but always committed to cultural criticism" (Denzin 1997, 224).

However, this messiness clashes with what is expected as a final output. This is particularly salient in the context of a thesis – where a word count is prescribed; and a standard format which includes an introduction, a review of the literature, a reflection on method, several instances of presentation of results, as well as their discussion and a general conclusion is all but prescribed as well. A chasm then emerges between the iterativeness and messiness of the research process and the presentation of the finished thesis. The process of writing up, then, was a process of finding ways to bound the messiness of research, in a way to maximise the *continuity* between the latter and the written word.

3.4 ETHICS

The conduct of this PhD project sits against a background of what has been dubbed to be an *ethics creep*:

> "a dual process whereby the regulatory structure of the ethics bureaucracy is expanding outward, colonizing new groups, practices,and institutions, while at the same time intensifying the regulation of practices deemed to fall within its official ambit" (Haggerty 2004, 394).

It is thus not surprising that ensuring the PhD constituted an ethical piece of research had in its first hurdle the bureaucratic process of receiving ethical approval in the context of the academic department. This required the submission of an application demonstrating the consideration of standards of *professional integrity* and adherence to *ethical principles*. While ostensibly a local process, evaluated and decided by a departmental ethics committee, the determination of what constituted ethical principles (and, consequently, ethical research) was made at the intersection of the committee and three key documents: the Statement of Ethical Practice for the British Sociological Association (British Sociological Association 2002), the ESRC Framework for Research Ethics (FRE) 2010 (Economic and Social Research Council 2012) and the UK's Data Protection Act (1998). In its gatekeeping role, the departmental ethics committee enforced the regulation of practice to that deemed acceptable in all three documents.

This project was deemed to meet those requirements and was awarded ethical approval by the ethics committee of the Department of Sociological Studies of the University of Sheffield (Appendix B). Alongside the application for the project, the committee also reviewed and approved an information sheet to be given to research participants (Appendix C) and a consent form for participation in the research project (Appendix D)[23]. Following the dispositions of formal ethical approval, paper copies of the consent forms were kept in a (locked) locker in the department, for which only I and a relevant member of administrative staff held keys. Paper copies of field notes were also kept in the same locker. Digital recordings of interviews were scrubbed from the voice recorder shortly after being conducted, and sound files were encrypted and held in password protected cloud storage. Ancillary files – interview transcripts, digital versions of field notes and documents produced by the projects – were also kept encrypted and held in password protected cloud storage. Those files were accessed only by supervisors and myself, in the university IT system and/or in computer terminals where files were encrypted during the synchronisation process and also encrypted *at rest* (i.e., when the computer terminals were turned off) using strong TLS1.2 / full disk LUKS (TKS1 compliant) encryption.

As I note in section 3.3, my thesis relied heavily on observation, particularly in the context of the annual project meetings. The membership in these contexts was also variable, with new participants (particularly junior participants) appearing at every event. This raised issues regarding consent, particularly for new potential participants. Formally requiring each of the potential participants to sign consent forms would prove difficult, given my peripheral role, and to embark on a fiction of consent as a one-off, formalised procedure. Here, I followed Murphy and Dingwall's argument that "informed consent in ethnographic research is neither achievable nor

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[23] The departmental ethics committee also reviewed and approved a revised information sheet and consent form for the use in the context of the iGEM competition. However, as noted in section 3.1, that data is not presented in this thesis and, as such, the documents are also omitted.

demonstrable in the terms set by anticipatory regulatory regimes". Moreover, I acknowledge that "fully informed consent is often neither possible nor desirable in ethnographic (or, for that matter, other) research" (Hammersley and Atkinson 2007a, 42), given the twists and turns of the conduct of ethnographic research (a particularly salient point in the trajectory of the work described in this thesis).

To acknowledge these shortcomings, however, does not negate the importance of information and consent in the conduct of research. I maintain it is of paramount importance to work towards maintaining such consent over the course of the research project. In doing so, I address consent as imagined by Katz & Fox, who argue:

> "informed consent among researcher and research subjects [is] fundamentally *relational* (interpersonal and social), *experiential* and *performative* [...], and *processual* (i.e., unfolds or happens over time) (Katz & Fox, 2004, p. 21, emphasis in original).

This is an approach which I followed for observation over the course of my fieldwork. Rather than a one-off, tick boxing exercise, I treated consent as an integral part of my presence in the field. I did so in multiple ways. At the start of every physical consortium meeting, when the participants took turns in presenting who they were and with which group they were associated, I (arguably broke the mould) and introduced myself and the research project which I was conducting. I noted there that participation in the project was voluntary, making myself available for answering any questions and/or discreetly striking any potential participant off my work, if they so wished. I also drew attention to the information sheet I had prepared with details of my PhD project. At each fieldwork opportunity, I took a small stack of these documents, which I scattered around the meeting room, the coffee break tables, and gaffer taped on the meeting room doors.

I also directly asked researchers about their willingness to take part in the research project, in one to one conversations and when appropriate in context. Further, I kept the researchers appraised of the trajectory of my work (and its changing focus) over subsequent fieldwork opportunities, particularly in group conversations which took place after the main, formal meetings had been adjourned for the day.

Lastly, I implicitly negotiated consent in tandem with the negotiation of access to particular sites, over the course of the fieldwork. The latter also bundled together issues of consent and ethics in research more broadly, which I will discuss shortly.

In contrast, in the context of interviews I followed a more formalised, bureaucratic approach. I approached potential interviewees via either email or in person, over the course of a project meeting / student exchange. In either medium, I provided a more detailed overview of my research project, its aims, and why I felt that input from that participant would be illuminating of the broader dynamic of the making of epistemic communities. All but one of the interviews were conducted in person, with the exception taking place over a video call. In all cases, I provided the interviewee with a (physical or digital) copy of the information sheet, and asked them to sign the consent form.

3.4.1 Ethics and research in progress

Over the course of my fieldwork with the CyanoBioFoundry project, I was privy to sensitive information about the project, plans for the future, and interpersonal relationships. Being construed as an insider and an outsider; as a participant and as a (sociological) fly on the wall, I was able to access spaces and discussions which were closed off to other participants. Beyond those spaces, the participants also shared sensitive information in small group settings where I was present, and directly, in one to one interactions. As a whole, these interactions have been incredibly fruitful, shaping my understanding of the project, its place in a broader undertaking of biohydrogen production using synthetic biology, and its links to the wider epistemic communities. They have also, however, raised ethical questions.

My role as an errant social scientist in a *real science* (a dichotomy often employed) project was not lost on anyone. However, particularly in more formal sensitive discussions, my marginality made me fade into the background; only to be brought back into the fore by a darting glance in my direction and a chastising expression towards a PI who had raised a point not deemed appropriate for my ears.

This was most salient in the first project meeting I attended, but faded away as I brokered personal relationships with the participants. The strengthening of links with participants also raised a diametrically opposite ethical qualm – one where it was not the case that I was not privy to the discussion, but that *only I* was privy. In these contexts, it is unclear whether the participants had misconstrued my promise of anonymity, but instead came to expect confidentiality. This was an issue which was exacerbated by the desire several of the participants expressed of reading the finished thesis. Even if not directly identifiable (an issue in itself), some of the data raised potential issues for the links between participants.

In navigating this grey area, I was guided by a passage which I held on to as a maxim. It posits that, even when access is successfully (and repeatedly) negotiated, that

> "authorization does not constitute license to invade the privacy of others. The value of the best research is not likely to outweigh injury to a person exposed. Qualitative researchers are guests in the private spaces of the world" (Stake 2005, 459).

Conscious of my role as a guest, I struck off any reference in my field notes to material collected in these private spaces where it was clear it distressed (any of) the participants implicated. For clarity, this data was removed from analysis altogether. A further category of concern is related to data which was sensitive, but only temporarily so. These mostly related to potential instances of collaboration – discussions which were moved to a public forum at a later date; a move which swiftly resolved any ethical quandaries regarding their substance. Lastly, there were themes of relevance to my work which remained in this (potentially confidential) sphere. In these cases, I either address them implicitly, with the use of different sources; or I included them in interviews with the relevant participants, which were guided by a strict framework of participant consent.

A further dimension of dynamic ethical assessment is related to how the research could be perceived / used by parties beyond the participants. Here, the formal guidance from the British Sociological Association is relevant, in that it states

> "Sociologists have a responsibility both to safeguard the proper interests of those involved in or affected by their work [...] They need to consider the effects of their involvements and the consequences of their work or its misuse for those they study and other interested parties" (British Sociological Association 2017, 4).

Here, the focus was on the relationship between the participants and the funders. I describe in Chapter 7 the extent to which funding had a forceful presence in the preparation and execution of the projects. My research has yielded rich data over how that presence was handled and resisted, and in early drafts I describe these processes in some detail – including instances of resistance via *bootlegging* (Hackett 1987) and *manipulation* (Leišytė, Enders, and de Boer 2010). As the thesis was taking shape, however, the issues with ensuring anonymity were gradually brought into sharp relief. If not problematic in themselves for the participants, in the sense that this was practice which was common in collaborative projects / common practice for elite researchers, I was forced to contend with the fact that these are not practices condoned by funders. While the conduct of such practices may constitute a (wide) open secret, to conduct ethical research was also to consider the potential *misuse* of my study of the practices of community-making by third parties. Even if the possibility of harm for participants was remote, I aimed to mitigate any potential (envisioned or unexpected) harm by anonymising the projects and the participants. Further, when I discuss dynamics or interactions I do so deliberately vaguely, to dissuade attempts at reconstructing identity. Yet, I must consider the fact that the anonymisation process could prove little more than a fiction for actors embedded in that domain of research (and its governance). I addressed this potential pitfall by removing reference to processes where identification would be unavoidable; and by changing how I addressed bootlegging in the written thesis. Where relevant, I removed direct quotes / references to participants, describing bootlegging through my eyes instead.

Thus, the performance of ethical research was not restricted to a single, bureaucratic hurdle. It proved instead to be a dynamic process, manifesting in the types of data that were (not) collected and analysed, and how that data was presented in the finished thesis.

3.5 CONCLUSION

In this chapter, I invited the reader to peek behind the curtain of the finished thesis. I started with a brief introduction positioning my focus on the emergence of epistemic communities in conversation with method. In the discussion of the method, I articulated how I related to the research object and process, as well as the twists and turns the latter took. I provided a justification for following an ethnographic approach, and in its positioning in the middle range. I outlined what the performance of my multi-sited ethnography entailed, with reference to the methods I employed and the link between theory, method, analysis and writing. Lastly, I reflected on questions of ethics, moving from a discrete, unitary bureaucratic process to a dynamic one, which required constant adjustment.

Throughout the chapter, I weave the notion of messiness. I trace some of the ways in which messiness was associated with my role as a novice, and the questions of learning to navigate ethnography as process, as well as the adjustment of research design. However, I also argue that messiness is *built-in* – in the objects of study, the methods, the analysis, the writing. Thus, I note messiness is indissociable from the process of research, and instead outline what it meant to work *with* the messiness. I now move to the three parts of the thesis where I outline what resulted from working with the messiness. In Part II, I explore the making of a European synthetic biology community. I start now with Chapter 4, as an introductory chapter to contextualise the changes to the role of research in the trajectory of the European Union over time.

PART II

EUROPEAN SYNTHETIC BIOLOGY

In the STS tradition, epistemic communities are conceptualised as including actors well beyond the scientists (e.g. (Meyer & Molyneux-Hodgson, 2010, 2011)). Actors who would not be able to tell the difference between a pipette and a centrifuge; who would not care about the technicity of or difference between proteomics and metabolomics; or for whom a mathematical model would be as alien as long-forgotten language. Yet, when it comes to exploring the role of these actors in the study of epistemic practice (and collectives), they are often relegated to the background. Their importance has been long recognised in STS research, as I note in Chapter 2 (e.g. with Knorr-Cetina's (1981, 1982) reconceptualisation of communities as *transscientific*, or their abandonment and replacement with *transepistemic arenas*). This is particularly poignant in the case of governance (actors), as noted in Gläser & Laudel (2016) – in most cases, if those actors are recognised, they are acknowledged and left to languish in a footnote, or their role is not meaningfully investigated, being relegated to the margins.

This is a particularly salient issue for synthetic biology. Synthetic biology has been roundly accused of not being a field borne out of the scientific community. Accusations aside, it is clear that synthetic biology has been extensively (and aggressively) roadmapped, that visions for the field have been (ever)present from the very early stages of its emergence, and its (anticipatory) governance widely debated. This has taken place at national (e.g. (Technology Strategy Board, 2012)), regional (e.g. (NEST High-Level Expert Group, 2005)) and global levels (e.g. (The U.S. National Academies, 2009a)). These activities have involved scientists committed to the epistemic project, but also other actors – such as social scientists[24] (sometimes as *agents*

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[24] Not always with great success, as Marris & Calvert (2019) recount.

(Guston, 1996) of policy-makers, as I will show was the case in the TESSY project) and policy-makers. Indeed, policy-makers have been weaved in the trajectory of synthetic biology, both as participants in these activities and as their commissioners. In many ways, this landscape reflects the changing contract between science and society, and how that contract is being (re)negotiated at these different levels. Indeed, over these activities and in more or less explicit ways, synthetic biology has been tasked with making meaningful contributions to society.

In Part II, I address some of the ways this engagement of actors in governance in a more active role in the (emergence of) epistemic community, impacted on its trajectory – the aesthetic of the collective, the process of making the collective, and the resulting repertoire. I do so with a focus on the European landscape. In particular, I link the process of European integration to a reimagining of the role of research in the European Union, and trace what that meant for the emergence of a European synthetic biology. I am conscious, however, that the European Union is a vast, arcane, legalistic bureaucracy. One who touches upon the European sphere in matters mundane and esoteric. As such, I start this section of the thesis with an attempt to cut through that complexity. Chapter 4 is brief introductory chapter, which aims to contextualise the changing roles of research in the European sphere in the process of European integration. There, I provide a brief account of the prevalence of *a* role for research since (before) the inception of the successive modes through which a European community became established. I describe the legalistic framework under which European research operates, and link the expansion of the types and modes of research possible in the European sphere to the expansion of the dimensions of the concept of European Added Value (EAV). I note that a change in those dimensions for FP6 was key in enabling the emergence of community with a dedicated European locus, and outline the programme under which (European) synthetic biology came to be funded. Moreover, I outline the *socio-technical imaginaries* (Jasanoff & Kim, 2015) of particular importance for the development of the European synthetic biology community, and briefly link them to the changes to the legalistic conditions of

European integration and the changing role for science in driving that integration / the wider imaginaries.

In Chapter 5, I trace the emergence of a European synthetic biology, against this legalistic governance framework, bringing actors in governance (and the use of funding) to the foreground. I explore the emergence of the epistemic community in three steps: in the imagination of the community, in an interplay between committed (elite) researchers and actors (/*agents*) from the European Commission. I note the creation of expectations and their performative character (even when the governance framework faltered), in a dance between the establishment of a synthetic biology community and the attempts to materialise particular socio-technical imaginaries. I then address the dedicated efforts for *making* an epistemic community, against that promissory background; I note *how* community was being built, with focus on *who* was being enrolled / trained and the spillover of making a European community across the geographic boundaries of the block; I argue that through these activities, the (European) epistemic community became enshrined as closely aligned with the parts-based synthetic biology imaginary. Lastly, I address what *doing* (European) synthetic biology meant, in the context of a changing governance regime (epitomised in the move from FP6 to FP7); I note that the funding restrictions in the heavily projectified environment where research was undertaken led to the production of different synthetic biology over time – with concomitant impact on its repertoire – thus foregrounding the importance of funding in opening up/closing down trajectories for the epistemic community.

4 A CHANGING ROLE FOR SCIENCE IN THE EUROPEAN PROGRAMMES AND IMAGINARIES

Research at the European level has been characterised by the tension between the national and the supranational spheres. Establishing and / or moving research activities to the latter has been the object of fierce negotiation over the years, which has required consistent and ongoing justification. In this section, I sketch the path to establishment and the rise to prominence of European research. I do so with a particular focus on the long term aim (and use) of research as a driver for European integration and its continuous entanglement with the (socio-technical) imaginaries for what the European Union was to be(come). I do so in four main steps. I start by providing a background to the emergence of the framework programmes and how research was justified in their context, in 4.1. I then address the crystallisation of the justification of research under the concept of European Added Value, in 4.2. In 4.3 I explore the imaginaries which pervaded the FP6 programme, as well as the NEST programme, as the first programme dedicated to the support of fields with a dedicated European character. In 4.4 I briefly address the shift from FP6 to FP7, in both the context of the programme and relevant imaginaries. I finish with a quick summary as 4.5.

4.1 MAKING EUROPE, MAKING SCIENCE – RESEARCH IN THE PROCESS OF EUROPEAN INTEGRATION

Through the process of building Europe since the end of the second world war[25], research has consistently been afforded a role. That took the form of dedicated (big) science endeavours such as CERN and an early organisation which is now part of the European Space Agency, but it was also more broadly linked to the treaties which enshrined the many versions of what is today the European Union.

As early as 1951, the treaty establishing the European Coal and Steel Community contemplated the creation of European level research programmes, provided they furthered the technical, economic or safety aspects of coal and steel production. Still in the same decade, the treaty establishing the European Atomic Energy Community – Euratom – raised the profile of research yet again, with the first chapter of the treaty being devoted to research. These treaties, alongside the treaty of Rome (which made little allusion to research), provided the basis for research at a community level. However, they did not provide a strong framework for developing a research programme. Nevertheless, from the 1970s on, the allusions to research at a European level multiplied.

What could fall under the umbrella of a European technology push was, however, the subject of tension. This tension was in no small part due to questions of sovereignty and national interests: in what ways and to what extent were each of the individual member states (MS) willing to relinquish control over their own research programmes and agendas to a supranational body. Over the remainder of the decade, the attempts to coordinate national policies, proved a Sisyphean task. It was only later that a first attempt at meaningful transnational collaboration would materialise, in the context of the first Framework Programme (FP).

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[25] Although the exacerbation of the trend of building a European dimension to research since the postwar period makes it a useful starting point for the narrative in this thesis, Kohlrausch and Trischler (2014) offer an excellent account of efforts to build European research dating back a further century than is the starting focus of this thesis.

4.1.1 The rise of the Framework Programmes

The path to the first framework programme was not an easy one. In the early 1980s there was still no agreed upon Community-level policy for research. Member states continued to be unwilling to relinquish enough control over their own national research policies to allow for the establishment of a Community-level research policy (and the associated research programme). There is a complex history to how that resistance was progressively worn away which I omit; the point to retain is that research in a common frame was accepted only through a very specific range of formalised criteria. Indeed, in the first FP actions at a community level were *justified* in the following cases:

> "— research on a very large scale for which the individual Member States could not, or could only with difficulty, provide the necessary finance and personnel,
> — research, the joint execution of which would offer obvious financial benefits, even after taking account of the extra costs inherent in all international cooperation,
> — research which, because of the complementary nature of work being done nationally in part of a given field, enables significant results to be obtained in the Community as a whole for the case of problems whose solution requires research on a large scale, particularly geographical,
> — research which helps to strengthen the cohesion of the common market and to unify the European scientific and technical area and research leading, where the need is felt, to the establishment of uniform standards." (Council of the European Economic Community, 1983)

These selection criteria – which came to be known at Riesenhuber criteria, after the German minister under whose administration they were introduced – have become a cornerstone of European research programmes, as I will shortly show. Nevertheless, in subsequent programmes, the range of criteria (and, consequently, the potential justification of research at a European scale) expanded.

The second framework programme emerged after a revision to the Treaty of Rome that came into force in 1987, known as the Single European Act. The act set the Community the goal of converging on a single market within the following half decade – one of the current markers of European integration. Research was to play an increasingly prominent role in both European integration and in the European economy(ies), and that was acknowledged via the introduction of a new section dedicated to research on the European scale. Research at this level was to have the overarching goal of "strengthen[ing] the scientific and technological basis of European industry and to encourage it to be more competitive at international level" (Single European Act, 1987). Research is framed as having a European dimension insofar as it supported European industry to regain a technological edge over the world's advanced (and advancing) economies. The focus was less on harmonising research policies, but rather on moving towards common goals; it was less about building commonality in research, but more about moving "towards a European technology community" (ibid.).

In addition, the Single European Act enshrined into the treaties the principles of cooperation and coordination in research, principles which were framed as key in the creation of a single market and the concurrent economic success of the Communities. These principles trickled down to the successive framework programmes, largely as dimensions of EAV, as I will show in the following section.

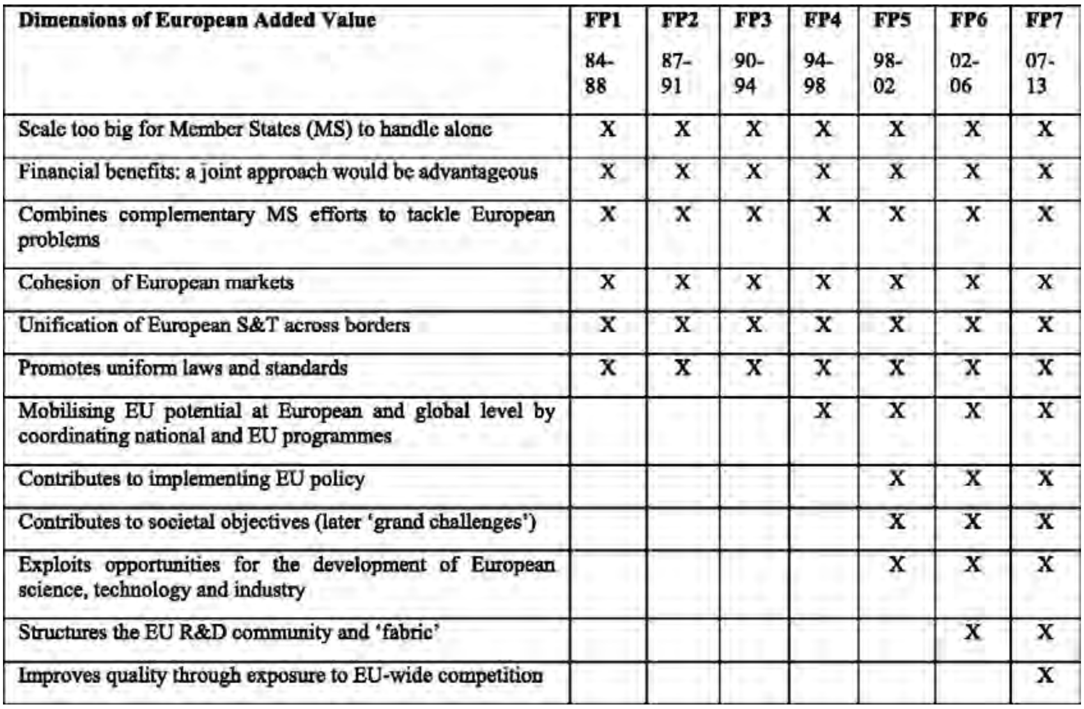
4.2 EUROPEAN ADDED VALUE (EAV) AND FRAMEWORK PROGRAMMES

The aim of having research at a community level play a different role to activities run within member states was made explicit in the preamble to the selection criteria of the first framework programme, which reads:

> "Community action can be justified where it presents advantages **(added value)** in the short, medium or long term from the point of view of efficiency and financing or from the scientific and technical point of view as compared with national activities (public or private)" (Council of the European Economic Community, 1983) (emphasis in original)

It is difficult to overstate the importance of the notion of (European) added value: for one, all four of the selection criteria described in the previous section can be boiled down to different dimensions for creating *added value*. It is also indicative of the mood for framing the relations between MS and with a supranational body, which was later enshrined into the Maastricht treaty as the principle of subsidiarity (Treaty on European Union, 1992).

This framing of research in the Community became institutionalised in subsequent FPs (before and after the Maastricht treaty). Indeed, the FP1's project selection criteria have been present in the selection criteria of subsequent FPs. The mandate of generating (European) added value has endured over time. What constitutes European added value, however, has been the subject of significant (and consistent) contention and negotiation. In a longitudinal analysis of the framework programmes, Arnold (2012) suggested that EAV could be identified in different (and increasing) dimensions over the different FPs (Figure 5).



Dimensions of European Added Value	**FP1** 84-88	**FP2** 87-91	**FP3** 90-94	**FP4** 94-98	**FP5** 98-02	**FP6** 02-06	**FP7** 07-13
Scale too big for Member States (MS) to handle alone	X	X	X	X	X	X	X
Financial benefits: a joint approach would be advantageous	X	X	X	X	X	X	X
Combines complementary MS efforts to tackle European problems	X	X	X	X	X	X	X
Cohesion of European markets	X	X	X	X	X	X	X
Unification of European S&T across borders	X	X	X	X	X	X	X
Promotes uniform laws and standards	X	X	X	X	X	X	X
Mobilising EU potential at European and global level by coordinating national and EU programmes				X	X	X	X
Contributes to implementing EU policy					X	X	X
Contributes to societal objectives (later 'grand challenges')					X	X	X
Exploits opportunities for the development of European science, technology and industry					X	X	X
Structures the EU R&D community and 'fabric'						X	X
Improves quality through exposure to EU-wide competition							X

Figure 5: Dimensions of European Added Value (EAV) identifiable in the EU's Framework Programmes. Reprinted with permission from Arnold (2012).

The first six dimensions listed in Figure 5 make up the Riesenhuber criteria. As indicated in the table, these dimensions have been retained through each subsequent framework programme, as have all dimensions subsequently introduced. I call the reader's attention to the second to last dimension (*structures the EU R&D community and 'fabric'*). It is this dimension which is key for research with a dedicated European locus. I explore what that dimension of EAV – alongside two key imaginaries – meant for research in the context of FP6.

4.3 SIXTH FRAMEWORK PROGRAMME – RECONFIGURING THE EU'S ECONOMY THROUGH SCIENCE

The European Union's 6th Framework Programme for Research and Technological Development (FP6) was established at a point when the role of research in the EU was undergoing considerable change. 2000 saw the launch of the Lisbon strategy – a ten year programme designed to turn the EU into "the most competitive and dynamic knowledge-based economy in the world" (European Commission, 2000). The social contract between science and society was being explicitly renegotiated. Thus, at the point in time when the sixth FP was being prepared, in the eyes of EU policymakers, knowledge changed from being a by-product of the conduct of research to being a key economic resource.

This transition towards a knowledge economy was to be enabled by the introduction of a "new open method of coordination [...], coupled with a stronger guiding and coordinating role for the European Council to ensure more coherent strategic direction" (European Council, 2000). This signalled a profound change for research in the EU sphere. By enabling the (voluntary) coordination of research policies and systems, as well as giving the European Council a higher degree of authority over the trajectory of the (increasingly unified) European research arena, research stopped being the sole domain of the member-states. It was now a(n increasingly) shared competence.

The knowledge economy was also breathing new life into old ideas. The ideal of creating a united arena for research was no longer far-fetched, as it had been when proposed in the 1970s. On the contrary, the creation of a European Research Area (ERA) became legitimised as a key component of the (transition towards a) knowledge economy[26]. As the Lisbon strategy was being prepared, so was the ERA being imagined. By early 2000, the EC made the first formal call for the ERA, with a document entitled "Towards a European research area" (European Commission, 2000). This sense of gradual movement is further articulated in the text, but alongside a sense of urgency. The EC diagnosed European research as stalling, and in the absence of intervention, the current trajectory would "lead to a loss of growth and competitiveness in an increasingly global economy. The leeway to be made up on the other technological powers in the world will grow still further. And Europe might not successfully achieve the transition to a knowledge-based economy" (ibid.). The ERA is framed under a *salvation* narrative. Successfully creating the ERA would prevent the EU from falling behind in a global race; failing to do so, would prevent the transition towards a knowledge economy. In tying the materialisation of the vision for the knowledge economy to that of the creation of the ERA, the EC performs promissory work (Pollock & Williams, 2010). As argued by the sociology of expectations, by carving a role for the ERA as what will deliver the knowledge economy, the EC sets the requirement for the relevant actors to *create* the ERA; the attribution of such a role is thus performative (Brown & Michael, 2003).

The 6th Framework Programme then became a key site to experiment in the making of the ERA and the transition towards the knowledge economy. For one, it encompassed a new dimension of EAV. Research could now be supported on the basis that it contributed towards the structuring and/or strengthening of the ERA (European Parliament, 2002). For another, while the first five FPs were organised around the support of specific areas of research, this was not the case in FP6. The potential for (social and) economic dividends promoted the concentration of EU re-

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[26] The ERA agenda also grew to be legitimised as a beacon of European integration.

search under the seven priorities. These were "the critical research areas for tomorrow" (Work programme for the specific programme of research, technological development and demonstration, n.d.), where investment was to bear the most fruit. Concurrently, research in these areas was also to weave together the (epistemic) communities (and their repertoires) which operated under the thematic priorities. However, while the key areas of "tomorrow" were ostensibly well covered, the focus on a small number of themes was framed as falling short of identifying the "opportunities for the day after" (ibid.). That is, research fields and avenues which were only then emerging – and thus rooted in fragile communities, if at all – could be missed. Being able to identify such areas was a key requirement for building the European knowledge economy, so FP6 was also set up with an eye to such potential opportunities. I will now address the key instrument devised for keeping up in that (global) race – the NEST programme.

4.3.1 The NEST Programme

The New and Emerging Science and Technology (NEST) programme was one of the research activities[27] which, combined with the seven thematic priorities, made up the block of actions under the banner of "Focus and Integrating European Research" (European Parliament, 2002). While the thematic funding overshadowed that of all other activities, NEST (as the materialisation of the aim of "anticipating scientific and technological needs") was still endowed with a(n indicative) budget of roughly 500 million euros. This lofty budget, however, was matched by the programme's aims. It was expected to support

> "research in emerging areas of knowledge and on future technologies, outside or cutting across the thematic priority areas, in particular in transdisciplinary fields, which is

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[27] A number of disparate activities were envisioned to fall under this heading, and different activities were to build Europe in different ways – e.g., a research programme dedicated to SMEs was justified on the basis that this stronger industrial fabric would contribute to the transition towards the knowledge economy.

> highly innovative and [...] that have significant potential for major industrial and/or social impact, or for the development of Europe's research capabilities in the longer term". (ibid.)

Thus, research to be supported under NEST was subject to a high tally of requirements. It was to be cutting-edge and novel, with an explicit preference for the inclusion of knowledge that cut across multiple disciplines; and it was to be research which combined the qualities of being *innovative* and having potential for *impact* (measured as social and/or economic). Moreover, NEST was also to be the programme tasked with being adaptive enough to "respond to unexpected major developments" (Work programme for the specific programme of research, technological development and demonstration, n.d.). NEST was then a programme which was to support the transition towards the knowledge(-based) economy set out in the Lisbon strategy. Its aims and structure make an inexorable link between knowledge production and economic outcomes in two key ways. For one, the foregrounding of (inter/)transdisciplinary research with a concomitant (explicit) link to innovation is a feature of narratives of monetisation of research; interdisciplinary research is framed as inherently more innovative, and thus of greater value to a knowledge economy. For another, the ability to recognise the potential of and capitalise on particular research avenues ahead of others is a key feature of an economy driven by knowledge. The vision for a particular Europe is thus articulated in the NEST programme.

On a practical level, the programme was organised around three strands: "Adventure", which would support high-risk, high reward projects in any (emerging) area; "Insight", which would support research to investigate the potential societal risk posed by novel artefacts or observations; and "Pathfinder", which would provide dedicated support for a number of specific emerging fields / approaches which were deemed particularly relevant. In the interest of brevity, I will focus my gaze on the latter strand.

While the formal decision establishing the FP6 and the NEST work programme envisioned the Pathfinder strand as one which would support the emergence of a limited number of fields / approaches, these were not defined *a priori*. Instead, these were to be defined in conversation with the scientific community, over a complex interplay of open invitation of suggestions, workshops with experts, analysis of foresight exercises, and deliberation with(in) the EC(European Commission, 2003). Still, the remit for Pathfinder meant any suggested topic would need to be evaluated against several criteria, three of which are of particular relevance for the case at hand: the potential for future social / economic impact; the possibility of pushing European research in the topic to be world-leading; and the existence of an emerging community within Europe, which would enable transnational collaboration. In measuring the potential topics against such criteria, the Pathfinder strand explicitly constrained the potential range of topics to those which would be in a position to contribute both to the knowledge economy (KE) and the ERA agendas. The topics chosen would necessarily be ones which would be able to contribute tangible outputs for the (social and) economic benefit of the EU, particularly in competition in the world stage; and ones which would be able to provide EAV, as measured by the creation of EU-wide research communities.

4.4 SEVENTH FRAMEWORK PROGRAMME – MORE SCIENCE, LESS FLEXIBILITY

Great fanfare accompanied the new programme, which was the largest and most lavishly funded framework programme thus far; and one which would further progress down the path set by FP6 of moving away from the funding of research fields. Alongside this (further) crystallisation of emphasis, FP7 was also the first framework programme after the dimensions of EAV had expanded to include the increase in research quality concomitant to EU-wide competition (Arnold, 2012). This development enabled the creation of a funding body of European scope, which took the form of the European Research Council (ERC). Such an entity had been desired for some time; and in the making over the course of FP6. However, the establishment of the ERC also meant the death of the NEST programme. It was the team responsible for the latter which brought the former into existence – a fitting end, considering the NEST programme was seen within the EC as a stepping stone towards the ERC (Luukkonen, 2014).

While under the NEST programme there was dedicated funding with little requirement other than to *do* synthetic biology, that was no longer the case in FP7. The requirements for research under FP7 were strict – research funded under the "Co-operation" programme would need to address the societal needs articulated in funding calls (and provide solutions for those needs); research funded under the "Ideas" programme (which included the ERC and Marie Skłodowska-Curie actions) would need to aim for excellence, which was the main criterium in these calls. Considering the instrumental role of the NEST programme in the making of European synthetic biology in FP6, the changes in the funding environment suggest a step change in how community in synthetic biology could be made under FP7. Still, the break was not total; Luukkonen (2014) goes on to argue that, towards the end of the FP7, the FET (Future and Emerging Technologies) instrument came to play a (reduced) role not too dissimilar from that of NEST.

FET is a scheme which has been part of the (various guises) ICT funding programme since the third FP. As the name suggests, it is a scheme designed to support the development of technologies which were not mature enough to attract support under the mainstream funding mechanisms, but which may come to yield benefits in a hypothetical future. Research approaches were expected to be radical (or at least unorthodox), as was the expected potential for benefits. As I will show in Chapter 5, FET calls were key a home for synthetic biology research beyond dedicated schemes for the support of synthetic biology (with FET calls materialising when the latter were absent). I finish this section, however, with an examination of the changing economic imaginaries in FP7.

4.4.1 Changing imaginaries in FP7

As noted in the previous section, the knowledge(-enabled) economy was a robust, formal imaginary. Indeed, being at the root of long-term EU planning, and being afforded a transformative role of the geopolitical entity, it is warranted to frame it as an overriding socio-technical imaginary (Jasanoff & Kim, 2015). After the transition from FP6 to FP7, an offshoot of this larger imaginary emerged – that of the Knowledge Based Bio Economy (KBBE).

KBBE occupied an awkward space – it could neither be defined as a fully-fledge imaginary, nor could it simply be subsumed into the role of an R&D agenda. If the knowledge economy imaginary was pervasive in the EU sphere, the KBBE imaginary did not travel much beyond KBBE itself, if at all. Still, this recasting of the knowledge economy was justified by the ostensible fragmentation of activities within the scope of KBBE across Europe. As such, alongside KBBE, the European Commission made a strong push for (what is standard operating procedure in cases such as this) the establishment of a network of experts from each EU country, who were expected to devise strategies to integrate the activities across the continent. The network that came into being was then named KBBE-NET. In the interest of clarity, I note that KBBE-NET, like all "-NET" activities (including ERA-NET, which I also address in the following chapter), operates at the margins of the EC; the goal in such networks is to integrate the European nations through their weaving together, rather than in a centralising mode.

Lastly, I make reference to the quick demise of KBBE. A charitable reading is that KBBE was ahead of its time. As the temporal horizon of the Lisbon strategy waned, a new socio-technical imaginary was devised that was of particular contemporary salience. Thus, the KBBE was swiftly and thoroughly replaced by the Bioeconomy. Not even the ERASynBio project (which I address in the following chapter), an ERA-NET action under the umbrella of KBBE, references the agenda.

4.5 CONCLUSION

Over the course of this chapter I made a number of historical calling points in a bid to help situate the reader for the following chapter. In particular, I provided a glimpse of the legalistic modes of operation of the FPs and the justification of research under the concept of EAV. I note the expansion of the dimensions of EAV enabled the push for single, transnational European (epistemic) communities, and that this constitutes a considerable step change from previous FPs and is tied to the reimagination of the EU – on an economic and integrationist level. I also outline the NEST programme, for its role in the support of such communities, and problematise the transition to FP7. I finish with a quick account of the relevant FP7 imaginaries for the synthetic biology case I address in this thesis. It is to that case I now turn to.

5 MAKING EUROPEAN SYNTHETIC BIOLOGY

In this chapter I start an exploration of the emergence of synthetic biology in a European context, with particular focus on the development of an epistemic community, and the role governance (largely articulated through funding) plays in the development / steering the trajectory of the field. I have split this examination in three sections. In section 5.1, I address the imagination of European synthetic biology, as a process involving formal visions and roadmaps, but also less formal promises and expectations. I outline the interplay between researchers and actors in governance and argue that an epistemic community was leveraged through a community of promise.

In section 5.2, I move to an examination of the attempts to build an epistemic community. I explore the ways in which the projects planned the training of novices, with iGEM competition coming to the fore, and trace the ways in which established researchers were also enrolled. In 5.3, I then move to explore what conducting synthetic biology research in the highly projectified context of the European Framework Programmes entailed. I note that different synthetic biology was produced over time, and link that changing focus to the changing (or absent) dedicated funding programmes and the role of the latter in shaping what was *doable* (European) synthetic biology. I finish with a reflection on the complex interplay between different actors, changing governance regimes and promises/expectations of synthetic biology; and what the impact of these arrangements is in the resulting European synthetic biology epistemic community.

5.1 IMAGINING EUROPEAN SYNTHETIC BIOLOGY

Synthetic biology was taking its first steps as European Union's sixth framework programme was also coming into existence. Indeed, it is within the context of FP6 that the tale of European synthetic biology began. More specifically, the FP6's NEST programme became the key site for imagining and articulating European synthetic biology at this early stage. As noted in Chapter 4, one of the key tenets of the NEST programme was the support of research which could become key for the European economy of the future. With that aim in mind, NEST was characterised by considerable thematic freedom, which contrasted with the restrictive nature of the rest of the Cooperation programme.

As also noted in the previous chapter, there were different strands to the NEST programme. Synthetic biology was overwhelmingly supported under the Pathfinder strand[28]. This was not, however, by design – NEST Pathfinder themes were not defined *a priori*, but through a mixed process of engagement between the research community (broadly defined), scientific organisations and the European Commission. Thus, the proposal for such a synthetic biology programme stemmed from (and/or was supported by) the research community, and was in turn supported by the EC in its role as the funding organisation. Yet, ultimately, the decision remained the EC's to make. It is noteworthy that synthetic biology was the sole theme to feature across all three iterations of the NEST Pathfinder programme. A programme which was designed as explicit support for (what the EC deemed to be) themes displaying particular promise / relevance for the EU in the long-term. The consistent funding of the synthetic biology research programme under NEST provides the first example of (material) institutional support for the budding field; and can be interpreted as a tacit endorsement of (a) synthetic biology which would be of benefit to the EU.

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[28] In the interest of brevity, I will omit an examination of the small number of projects funded which preceded the Synthetic biology Pathfinder programme, on the basis that they are peripheral to the trajectory of EU synthetic biology when compared with the latter.

Some insight into how that benefit was imagined came in the guidance documents for the first call for proposals of the synthetic biology NEST pathfinder. Synthetic biology was imagined as a field of crucial “interest to Europe from the perspective of future economic and social benefit” (NEST Programme, 2003). It constituted “an arena in which open and public scientific knowledge will be progressively embedded in technological and engineering “solutions”, with vast implications for the ownership and control of intellectual property, and for economic development more broadly in areas such as health, energy, environment or materials” (ibid.). This was then a field being poised to provide technological solutions to Europe’s societal problems; but, above all, as a field which would support the European economy of the future. In addition, synthetic biology was also “technical endeavour that, for its success, will imply the creation of fully interdisciplinary networks of expertise in Europe, interfacing science and engineering.” (NEST Programme, 2003)[29]. Thus, this was a synthetic biology poised to contribute to the transition of Europe to a knowledge economy and to a unified European research area (ERA) – both outcomes envisaged under the FP6 in general, and under the specific remit of the NEST programme.

What synthetic biology would deliver these benefits was to be, however, was less clear. The first call for proposals came at an early point in the history of synthetic biology. This was explicitly acknowledged in the guidance documents, which argued that, at the time, synthetic biology “represents a vision, rather than a reality” (ibid.). In this document, synthetic biology was imagined as “the technological counterpart to the emerging science of systems biology” (ibid.). Synthetic biology was thus imagined as productive; as an approach concerned with *doing*, in opposition to systems biology’s concern with *understanding*. A “**‘hierarchical module-based’ approach**” (ibid., emphasis in original) would be the underpinning of synthetic biology. In the long-term, this approach would enable the creation of “a new area in which engin-

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[29] While the phrasing as the need to build networks *in* Europe may create some ambiguity regarding the envisioned geographic distribution of those networks, it is clear from the context of the programme and the conditions for participation – which I reference later in the chapter – that *in* is used in the sense of *across*.

eered modules will be used as versatile "building blocks", with standardised functionality and interfaces, in the form of a technological system not unlike that of electronics/ICT today" (ibid.). The reference to a modular approach and allusion to an ICT imaginary align the European synthetic biology firmly with the synthetic biology that has since spun out of MIT. This is a synthetic biology driven by an engineering ethos, where genetic material is abstracted from its biological context and manipulated in the direction of its modularisation and standardisation. DNA becomes packaged in ways that are imagined as analogous to the components of electronic circuits – and combined in a way that was deliberately (and rationally) designed.

Despite its positioning as an approach driven by an engineering ethos, the ambiguities around what synthetic biology was (or could become) still loomed large. So, following on Pathfinder's general aim of elucidating the potential of the areas addressed, the EC convened a high-level expert group (HLEG) and tasked it with clarifying what synthetic biology was and developing a strategy for the emerging field. This expert group included researchers based in institutions in several European countries and with different approaches to synthetic biology, as well as Randy Rettberg – an engineer based in MIT, which was closely involved with the popularisation of a parts-based, modular synthetic biology approach[30]. The development of European synthetic biology was, in this way, to be imagined while deliberately tethered to the (American) MIT approach.

The key output of the HLEG was a report which defined and provided a strategy for the budding field. The need and urgency to build a European community were articulated multiple times in the report. For making synthetic biology successful in Europe

> "What is needed, and is not established in the US either, is a framework for coordinating the current research, fostering a community of researchers (particularly among younger scientists) and creating a forum for the establishment of clear goals, shared tools and agreed standards." (NEST High-Level Expert Group, 2005)

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[30] I explore Randy Rettberg's involvement with the development of synthetic biology in greater detail in Chapter 8, as part of his role in the iGEM competition.

Making an epistemic community in Europe, with (young and old) bodies, a shared vision and practice would enable synthetic biology to bear fruit. The explicit allusion to young researchers is also telling of the hurdles the working group saw in the way of synthetic biology, and how they envisioned overcoming them:

> "The interdisciplinary nature of synthetic biology creates a need for educational initiatives at all levels, from undergraduate to experienced researcher, in order to foster the skills and shared language needed for the discipline to thrive. Specialists in different disciplines will need to develop a working knowledge of each other's modus operandi, and in the long term it would be desirable to create a new breed of researchers who are familiar both with fundamental biology and with the methodology of engineering, as well as having requisite skills in areas such as computational sciences and chemistry." (NEST High-Level Expert Group, 2005)

This set out synthetic biology as a field for whose a community was altogether absent. Community would need to be trained or re-trained. The epistemic arsenal the future members would be expected to have at their disposal was both broad and explicitly bring together ways of working before largely set apart. Synthetic biology was dealt in the language of hybridisation.

The vision for synthetic biology set out in the HLEG report was incorporated into the guidance documents of the 3rd call – refining what synthetic biology was to be and its purpose, thus highlighting the performative character of the expectations set out. However, it would be to mischaracterise the process of emergence to frame the researchers (even the elite researchers) as spearheading synthetic biology alone. The inclusion and role of the European Commission – through its officers – is encapsulated in the presentation slide shown as Figure 6.

In five short bullet points, a strong role for the EC in the trajectory of European synthetic biology shines through. The critique of the HLEG report as *not ambitious enough* is particularly interesting, in that it speaks to the way in which synthetic biology was, within the EC, incorporated into the core imaginaries for the EU. It makes a tacit endorsement of a grand narrative for synthetic biology – one where the latter was recruited in enabling the EU's transition to a knowledge economy. Interestingly, the critique of the vision produced is accompanied by two salient points in a(n arguably institutional) vision for synthetic biology. That is, the inclusion of ethics/safety as part of doing European synthetic biology; and of the importance/need of dedicated efforts to ground European synthetic biology in a (European) community. It is also noteworthy that projects addressing each of these themes were submitted for the 3rd call and were awarded funding. .

EUROPEAN COMMISSION

Community Research

Issues not covered
(1st and 2nd Call)

- Limited number of STREP proposals
- A lot of proposals not regarded as within the scope of the Call
- Lack of ambition in terms of the « technology vision »
- No particular interest in safety issues linked to the topic
- No Coordination Action(s)

Specific Activities covering a Wider Field of Research New and Emerging Science and Technology

Figure 6: Slide from presentation of European Commission officer with responsibility of overseeing the synthetic biology NEST pathfinder programme (Krassnig, 2005).

This was not, however, a stroke of luck. One of the projects funded in this 3rd call was TESSY (Towards a European strategy for synthetic biology). This project was created to devise a detailed plan for European synthetic biology. In reflecting on the origins and aims of the project, one deliverable of the project states:

> “research activities [in synthetic biology] are scattered across European regions and across scientific disciplines and are concentrated in a relatively small number of working groups. To overcome these obstacles the Specific Support Action TESSY (Towards a European Strategy for Synthetic Biology) was initiated by the European Commission

> which aims to fill this gap by setting up an expert based, investigative and participative process for the further development of SB in Europe." (Toward a European Strategy for Synthetic Biology Consortium, 2008a, p. 10)

The involvement of the EC in guiding the trajectory of synthetic biology is made explicit. While TESSY was to be conducted independently, it owes its very existence to the EC's push for building a synthetic biology that was both (technologically) productive and European. TESSY was, in this way, enrolled as an *agent* (Guston, 1996) . Given its remit, the project became another key site for imagining European synthetic biology. Yet, TESSY did not imagine synthetic biology alone. It specifically targeted researchers who were participants in the NEST programme, whom it attempted to recruit for a number of workshops. Indeed, it pursued this strategy aggressively, piggybacking on events of synthetic biology projects – namely events of EMERGENCE and the SB4.0 conference.

Two key outputs of TESSY merit attention – one for its relevance in the trajectory of synthetic biology, and another one for its symbolic value. The former is the key output of the project – a formal roadmap for synthetic biology, produced in articulation with elite researchers over the aforementioned workshops. The roadmap produced was a visually dense diagram (as would be expected for the task it was to address), setting out the timelines for activities under four main headers: scientific milestones, knowledge transfer, funding and regulation. For the purpose of this thesis, the complexity of the roadmap can be sidestepped, for its content is encapsulated by a passage from an earlier document:

> "Activities that are necessary in this field are the set-up of national networks that are linked among each other by a European network. It is essential to integrate SB in existing curricula and develop information material that helps in educational activities at all levels. Emphasized by all experts was the need for increased interdisciplinarity. This should be achieved both on the level of research but also within funding and funding agencies [...] According to the experts' assessment funding for this context activities (ELSI analyses, teaching) should be in the range of 5 – 10 % of total funding" (Toward a European Strategy for Synthetic Biology Consortium, 2008b, p. 16)

It is striking that the vision set out in the roadmap further crystallises synthetic biology as a European endeavour; national programmes were expected to fit under / articulate with a European-wide endeavour. This leads me to the output of the project which is of symbolic significance: the "SB Self Assessment Tool (SynBioAssess)" (Toward a European Strategy for Synthetic Biology Consortium, 2008b, p. 22). This tool was devised by the consortium as an aide to national funding bodies / institutions in guiding their investment in synthetic biology. It took the form of a spreadsheet, with a large number of variables (such as "timing, "maturity of SB research and development" or "expected impact on economy" (ibid.)) which were computed against a formula, and would return a numeric value, which was measured against a pre-defined threshold. What is particularly interesting about this tool is that the variables/calculation were slanted, for the benefit of the establishment of national activities which fit appropriately under a European umbrella. Once more, the European sphere came first.

A final point on the roadmap is linked to the way it travelled. It is clear expectations over what synthetic biology was / to do / become institutionalised in the EC. This was made particularly visible for the roadmap and several ancillary materials produced under TESSY became embedded in how different EC officers presented synthetic biology in written materials, as well as presentations. I now move to explore the trajectory of synthetic biology as the NEST programme came to an end, albeit starting still in the context of TESSY.

5.1.1 Synthetic biology in no man's land

As FP6 drew to a close, it became clear the NEST programme would not carry on in the following FP, as noted in Chapter 4. The discontinuation of this programme, coupled with the absence of dedicated funding streams for synthetic biology (under any other guise), meant there was no clear avenue for supporting synthetic biology in FP7. The coming funding shortfall was quickly described as potentially problematic for the development / future of synthetic biology. TESSY reported a consensus between researchers, national and international policymakers consulted, who felt

> "SB has a strong European dimension which led to the question why SB funding was not continued in FP7 on a similar scale as in FP6. [...] continuous support of an emerging field is important and that the strategy of the European Commission to build up and catalyze a certain development without a sustainable and mid-term strategy would [...] not adequately allow to address the European/international character of SB" (Toward a European Strategy for Synthetic Biology Consortium, 2008c)

Later, a report produced by EASAC – an organisation which brings together the national academies of science of EU countries – argued that the NEST "Commission funded projects were completed in 2008 and, if less funding is made available in Framework Programme 7, there is danger of a loss of momentum at the EU level" (EASAC, 2010). These two high-profile articulations of anxiety over the trajectory of synthetic biology are two examples of *negative* expectations (Borup et al., 2006). In this case, the absence of action over the funding of synthetic biology over FP7 is framed as deterring the promise of the field. Not only is the promise of synthetic biology in Europe linked to the development of a field which has a clear European (as in transnational) character, but the development of such a field is made contingent of an appropriate funding provision. Such expectations promoted action by actors ranging from the synthetic biology researchers to European institutions. In the interest of brevity, I will only address one main outcome: the reshaping of the KBBE theme of FP7 to enable the direct funding of SB.

5.1.2 A new home in KBBE

As I note in Chapter 4, around the transition to FP7, the (socio-technical) imaginary of the knowledge economy had an offshoot with biological emphasis – the Knowledge Based Bio Economy (KBBE); and attached to that imaginary was a high level network of experts – KBBE-NET. The negative expectations outlined above had a mobilising effect at the KBBE-NET / KBBE EC officers nexus. As I will argue below, this involved some significant course correction – as well as some creativity in the interpretation of the legal framework which bounded the FP7 funding theme to which KBBE was attached.

Still, while the synthetic biology (being) supported under the framework programmes could fit under the KBBE theme, this was not its only possible home. As a key member of the KBBE, responsible for synthetic biology in FP7, noted:

> "you could have imagined that synthetic biology can fall between different disciplines. One can be health, the obvious one. The other is the food and environment. The other one can be nano-materials or new materials. However, it was a matter of choice. Some of these programs did not really respond to this kind of provocation of the new times, but some others they did." (The U.S. National Academies, 2009b, p. 99)

When it came to dedicated support for synthetic biology, KBBE was the only theme that adjusted to the *new times*. It did so in no small part via the action of the KBBE-NET. The successful casting of synthetic biology as *promissory science* (Hedgecoe, 2003) brought it to the attention of the network. KBBE-NET's interest in synthetic biology grew formalised in 2008, when a number of participants created a collaborative working group (CWG) in the subject. This CWG was the basis for closer engagement with synthetic biologists. Prominent synthetic biologists (several of which were key figures of the EMERGENCE project) were invited to specific meetings to make a case for dedicated support for synthetic biology. The network green lit the strategic support of synthetic biology, and started exploring ways of funding research in the field.

Dedicated funding for technical research in synthetic biology had been lacking in KBBE (and, as I argued in the previous section, in FP7 as a whole). There had been a single call for a coordination action, which was to bring together synthetic biology researchers specifically working on environmental applications, a project with an indicative budget of €1M. There had been no calls for synthetic biology at all in the 2008 work programme. However, after the pledge of support from the KBBE-NET, calls for the specific support of technical research in synthetic biology materialised in 2009, 2011 and 2013; these calls were allocated a (combined indicative) budget of €40M.

Moreover, and of greater consequence than the sums of money made available, the KBBE-NET collaborative working group in synthetic biology formalised the interest of (several) EU states in developing a shared, unified strategy on synthetic biology. As work within the KBBE-NET progressed, it revealed there was appetite for laying the groundwork for a synthetic biology that transcended the national borders. Thus, the KBBE work programme for 2011 included, in the list of (sub-)topics addressing synthetic biology, a call for an ERA-NET project in synthetic biology. Funding would be made available for a single project, which is consistent with the purpose of ERA-NET projects. ERA-NET is a scheme explicitly created to further the ERA imaginary, by promoting the alignment or fusion of national (or regional) research programmes, ultimately into a common, European, programme. Participation in such projects is open only to the entities which define and/or manage regional or national research programmes; typically national ministries and research councils. I now turn to the synthetic biology ERA-NET which emerged out of KBBE funding.

5.1.3 EraSynBio

One synthetic biology ERA-NET – named ERASynBio – was successfully funded. It ran for three years, from the start of 2012 to the end of 2014. Its sixteen members were spread over fourteen European countries[31]. The project was awarded almost €2M in funding from FP7, but none of those funds were to be used to support synthetic biology research. Instead, in ERA-NET projects, the funding pot made available by the framework programme is to be used towards improving the coordination

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[31] ERASynBio brought together funding bodies from Austria, Denmark, Finland, France, Germany, Greece, Latvia, Netherlands, Norway, Portugal, Slovenia, Spain, Switzerland and UK. It is striking that only two states from beyond the EU15 (and associate countries) participated in ERASynBio. This observation further suggests an East-West split and concomitant interrogation of the asymmetries within European synthetic biology.

of national programmes, with the expectation that “the coordination element gradually deepens” (DG Research, 2003) over time.

As ERASynBio started, however, many of the participating countries did “not yet have dedicated national programmes in Synthetic Biology, but [were] in the process of developing such national initiatives” (ERASynBio, 2014a). Thus, rather than have coordination as the ultimate goal, ERASynBio sought to “integrate emerging national activities directly into a coordinated European effort thus building a sound European research community avoiding national fragmentation from the very beginning” (ERASynBio, 2014b). The ERA-NET project would push synthetic biology (further) into being as a common endeavour, where the national spheres were the pieces in a larger, European, puzzle.

In order to accomplish such a goal, ERASynBio aimed to address the making of synthetic biology from many different dimensions. It aimed to create a common understanding of synthetic biology – its definition, its goals, its relationship with society. It promoted the establishment / development of research programmes in the national spheres (as well as infrastructures) in a common sphere, guided by a common vision for synthetic biology. It established dedicated funding calls for synthetic biology research. And it also explicitly nurtured the research community which was to bring the vision for synthetic biology to life.

The formal *vision* for synthetic biology was thus a cornerstone of ERASynBio. The consortium devoted considerable effort towards creating such a *vision*, which was materialised in 2014 as a document entitled “Next steps for European synthetic biology: a strategic vision from ERASynBio” (ERASynBio, 2014a). The white paper started being prepared within the consortium, but its final form relied on “a strong steer from the outcomes of the ERASynBio 1st Strategic Conference” (ERASynBio, 2014a, p. 11), as well as refinements from a second ERASynBio strategic conference. Nevertheless, the preparation of the vision was in the hands of actors belonging to the funding bodies.

The ERASynBio vision, at 32 pages long, is the most robust vision for synthetic biology produced thus far. In contrast to previous articulations, the vision puts particular emphasis not only in what synthetic biology can do, but also in what synthetic biology can do *for Europe*. A key articulation of this emerges early in the report, in stating that

> "The historical ambition of Europe is to become a peaceful, knowledge-based civilization, one of the dreams of the Enlightenment. If this report can contribute to this undertaking, the whole mission of the ERASynBio ERA-NET will have been thoroughly achieved." (ERASynBio, 2014a, p. 3)

In this passage, the link to making Europe – as a political and economic entity is stark. While not as hyperbolic, multiple other references to what synthetic biology can do *for Europe* are present in the text (e.g. the framing of training novices under the contribution to the "workforce"). In the interest of brevity, I will omit analysis of the call for European, transnational community (as that was, by definition, the remit of the project), and focus solely on two key points from the document.

The first of those points is the place of prominence of the Responsible Research and Innovation (RRI) imaginary in the report. The conduct of research under the principles outlined by RRI is one of the five recommendations from the document. This reflects the prominence that RRI has gained in EU circles; and its inclusion implies the linking of synthetic biology with reflexive ways of conducting research.

The second point is the definition of synthetic biology outlined in the document. It reads as follows:

> "many different definitions of synthetic biology have been proposed and are in common use. The ERASynBio definition is drawn from recent reports developed by high-level scientific bodies (...), as well as through consultation with leading European experts. Based on this, ERASynBio defines synthetic biology thus:
> Synthetic biology is the engineering of biology: the deliberate (re)design and construction of novel biological and biologically based parts, devices and systems to perform new functions for useful purposes, that draws on principles elucidated from biology and engineering." (ERASynBio, 2014a, p. 6)

Two interrelated elements of this definition are worthy of particular attention. Firstly, synthetic biology is framed as driven by an engineering ethos; this is in line with prevalent practice and consistent with the multiple articulations of visions since the 2003 NEST reference documents. Secondly, this definition has clear echoes of the popular definition of synthetic biology, which is linked to a parts-based synthetic biology imaginary (PBSB) ('Synthetic Biology - OpenWetWare'). The two are matched word for word in allusions to the *design and construction of new/novel biological … parts, devices and systems*; and that the ultimate goal is to perform these manipulations *for useful purposes*. As articulated, the definition suggests a commitment to PBSB.

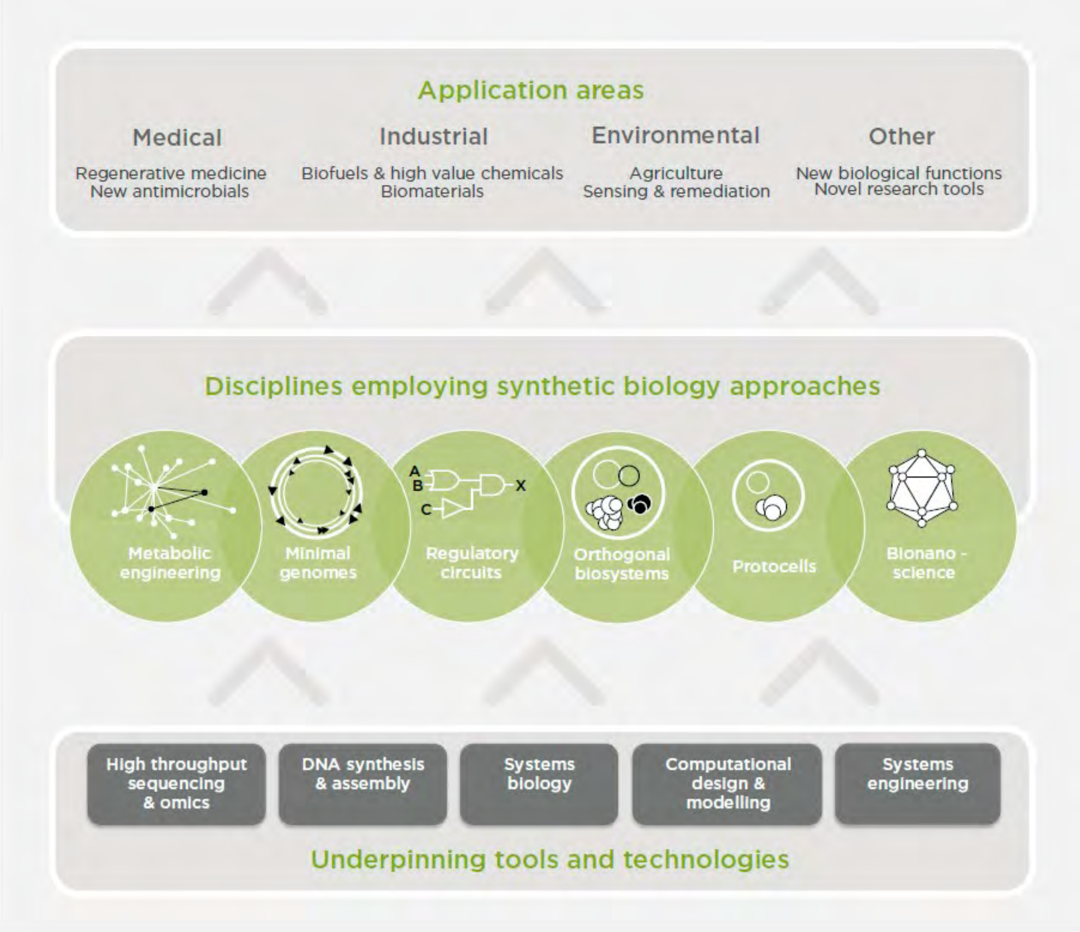

Figure 7: Approaches to synthetic biology. These approaches are contextualised in a conceptualisation of the role of synthetic biology in the process of knowledge production / use (ERASynBio, 2014b, p. 7).

However, Figure 7 paints a different picture. Following the conceptual path from the EASAC report mentioned in 5.1.1, the ERASynBio vision recognises the use of synthetic biology in those six *approaches*. This range of approaches includes a *regu-*

latory circuits entry which is, arguably, a direct reference to PBSB. Thus, the vision operates in a space of ambiguity regarding epistemic practice. Where there is no ambiguity, however, is in the drive for *useful purposes*, for the document notes

> "While the ultimate goal of synthetic biology research does not have to be commercial output, the development of 'new functions for useful purposes' is an important part of the synthetic biology approach, which sets it apart from other, more descriptive, biological research fields" (ERASynBio, 2014a, p. 5)

The production of useful purposes was, then, a constitutive part of the vision for synthetic biology proposed herein. I explore this tension further in section 5.3.6, where I note how the ambiguity was addressed in the context of the ERASynBio funding calls.

* * *

Over the course of this section, I have outlined some of the important themes in the interplay between researchers and governance actors in the making of a European synthetic biology community. I have argued that the synthetic biology imagined encompassed a broad range of approaches, being guided instead by the drive to produce *useful* outputs. Moreover, I argue that the researchers' promises of such outputs were successful enough that synthetic biology captured the attention of the KBBE-NET, and thus became integrated as a driver of the KBBE. This, in turn, drove the reshaping of the funding programme to accommodate dedicated synthetic biology funding streams – which, as I will argue in 5.3.5, brought new expectations. In this way, the successful deployment of promises, which bound the researchers in an iterative promise-expectation cycle matches the pattern described in Schyfter & Calvert (2015).

I have also shown how the European synthetic biology community was leveraged through a (particular articulation of a *community of promise* (Brown & Michael, 2003), as a) *community of vision* (Kastenhofer, 2013). In addition, I have argued that formal articulations of visions have impacted on the trajectory of the epistemic community for they became incorporated in the criteria against which grant proposals were evaluated for funding. Further, I have outlined the ways in which governance actors have taken an active role in the support / steering of the trajectory of the epistemic community, in no small part through the promotion of a single, transnational unit. This proactivity provides another indication of the role of relevance synthetic biology (and its European epistemic community) has under/in expectation of support of prevailing European imaginaries.

5.2 MAKING THE (ABSENT) EUROPEAN SYNTHETIC BIOLOGY COMMUNITY

I start this section in the context of the NEST programme, with a further reference to Figure 6. In particular, to the final bulletpoint in that slide, which reads: "No Coordination Action(s)". In the eyes of the commission officer, this remained an outstanding *issue* for the successful conclusion of the Synthetic Biology NEST Pathfinder programme. While the pathfinder initiative mostly revolved around the support of technical projects, that was not its sole focus. Ultimately, the goal of the programme was to support a European synthetic biology which, in turn, would contribute to the transition to a European knowledge economy. So, alongside the technical development of the synthetic biology, the pathfinder initiative contemplated actively building community in synthetic biology. These aims were to be fulfilled via the dedicated funding of *co-ordination actions* (CA). These were projects which

> "should aim to provide not just a mechanism for the research projects funded under the synthetic biology initiative to cooperate and interact with each other, but also to build extended networking within the EU on a cross-national and cross-disciplinary basis. They should aim to network European activities in relevant fields around the theme of synthetic biology, in order to create a "community of knowledge" with a common perspective on the development and goals of the discipline." (NEST Programme, 2005)

CAs were then imagined as a vehicle towards a synthetic biology community which was effectively European. Arguably, the NEST reference document calls for the development of a community closest to Kastenhofer's (2013) notion of "communities of vision"; the epistemic community being placed somewhat downstream, and leveraged through this community of vision.

Over the course of the NEST programme, two projects were funded with an explicit aim of making community in synthetic biology. Despite the narrative bounding of community-making to CAs, the first of those projects was of a smaller scale than envisaged for CAs and was funded under a different instrument; its aims were straightforward and reflected (if truncated) in its name – SYNBIOCOMM. A CA in synthetic biology was funded in the following year – EMERGENCE. The latter continued along the path carved by the earlier project, while involving a larger set of actors and activities aiming at building a European synthetic biology. If SYNBIOCOMM was a small, focused action, with tangible goals of enabling participation in iGEM and the organisation of the SB3.0 conference, EMERGENCE was a larger endeavour. For one, it crossed the academia – industry barrier, including partners from industry (a condition set out by the funding call). For another, it had the more robust (if more amorphous) task of setting the foundations for a European synthetic biology community. These broader aims were reflected in the size of the consortium – a consortium largely made up of a European synthetic biology *core set* (Collins, 1985). Moreover, EMERGENCE included a steering committee made up of the project leads of the other NEST synthetic biology projects; and held a remit of placing a European synthetic biology in articulation with American and Asian researchers / parallel initiatives. With this topology, EMERGENCE can be productively interpreted as a *forum* :

> "In "forum" type networks, [researchers] are only involved in traditional activities: colloquia and meetings between researchers. [...]. These networks organize the exchange of ideas and the constitution of a community of interest. They lead to the emergence of bilateral cooperation and the structuring of a collective problematic." (Vinck, 1999, p. 394 translated from French)

Indeed, the remit of the EMERGENCE project is that of structuring of European synthetic biology. The project is, by design, a transient actor in the trajectory of synthetic biology. Moving to the future, in the context of FP7[32], the ERASynBio project can also be interpreted as a forum. In this iteration, the actors moved to the realm of funding agencies, though their remit and their attempts to make European synthetic biology by looking beyond the geographic borders of Europe remain.

These projects were entangled in their aims, participants, and (in the case of EMERGENCE and SYNBIOCOMM) temporalities; in the following sections, I will address them together in outlining how they contributed towards making a European synthetic biology community.

5.2.1 Making of community by enrolling novices:

The narratives around the development of synthetic biology in Europe afford novices a prominent role, as I showed in the previous section. Still, the current system for training novices was framed as inadequate for producing researchers with an appropriate epistemic arsenal. Instead, both projects devoted considerable resources to ensure the participation of European students in the international genetically engineered machine competition (iGEM). SYNBIOCOMM provided €10.000 in financial support for (each of the) European teams entering the competition in 2006 and 2007 (a total of 20 teams). Later, EMERGENCE was one of the top tier funders if the competition in 2010. After this project finished, ERASynBio picked up the baton, funding two of the European, regional stages in the years the competition was split, and the iGEM competition itself when it returned to a one stage affair; and it funded either the teams progressing to the second-stage of the competition, or contributed to the entrance fee of a number of European teams. Taken together, the attention and resources these projects devoted to the iGEM competition suggest not just a commitment to novices, but a commitment to training novices via iGEM.

This competition, organised (at the time of NEST) out of MIT, was a key emerging forum for the enrolment of novices into the budding field. Modelled after pop-

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[32] In the interest of brevity, I omit the discussion of the TARPOL project; this project was very closely linked to EMERGENCE (to the extent that several of the activities were joint), and provides little analytical novelty.

ular undergraduate engineering competitions, iGEM encompassed teams of students (ostensibly with a mix of biology and engineering training) who attempted to manipulate DNA fragments in a way that was systematised, and which yielded novel functions. The competition was (and continues to be) a key forum for the promotion of parts-based synthetic biology – a (synthetic) biology driven by an engineering ethos[33]. iGEM quickly became institutionalised as an important site for creating the novel and hybrid *breed* of researchers argued as key for enabling (the promise of) synthetic biology. Still, creating hybridity posed challenges. As noted in an EMERGENCE project meeting:

> "Depending on their view of SB, they [iGEM participants] all have the same problems:
> - The biologists have hardly an idea about modelling
> - The engineers have hardly an idea about the complexity of biology" (EMERGENCE, 2007a)

The chasm between biologists and engineers is framed as both evident and severe; their epistemic cultures (Knorr-Cetina, 1999) remote. This was a problem that EMERGENCE set out to address, and did so by the creation of summer schools. In these summer schools, the students would be exposed to a robust curriculum in (parts-based) synthetic biology. Engineers would learn the basics of molecular biology; biologists the basics of modelling. In addition, they would all gain practical experience in laboratory work, by replicating seminal (and established) synthetic biology work – like (Elowitz & Leibler's (2000) repressilator. These were skills which were important for participating in iGEM. Indeed, at their core, the summer schools were designed "to prepare the[students] for the iGEM competition" (EMERGENCE, 2007b, p. 1). Such a purpose, however, impacted on participation. While the summer schools were open to students from all EU (and associated) countries, attendance was only permitted to students who would also enter the iGEM competition. That firm attachment of the summer schools to iGEM, however, was lost as the *forum* changed from EMERGENCE to ERASynBio. The latter organised summer schools as

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[33] I explore the evolving structure and role of the iGEM competition in the development of synthetic biology in chapter 9.

well, and did so with a wider focus than the previous projects – e.g. the second summer school was dedicated to the synthetic biology of plants, in a decision which went against the hegemony of E. coli as the de facto model organism of synthetic biology.

Beyond these short pedagogic initiatives, EMERGENCE also set out to create more conventional avenues for training novices into the community by planning a masters-level qualification in synthetic biology. This was not a straightforward task at a time where synthetic biology modules were only still appearing in Europe. By the researchers' own admission, at that point there were "most probably not enough teachers at any single one school" (EMERGENCE, 2007a, p. 34). The solution came in the form of aiming for a *European* Master programme[34]. In the envisioned programme, students would attend École Polytechnique for the taught portion of the course and spend the second year conducting a research project in a different institution (in a different country). The curriculum for the taught portion of the course was imagined as pliable – both to respond to the emergence of new objects of interest in synthetic biology and to the needs of industry (to the extent industry was imagined as having a role in shaping the ongoing curriculum). Still, the programme was to encompass training in the cornerstones of parts-based synthetic biology: wet lab biology, computational approaches, and the theoretical underpinnings of this engineering-driven approach[35]. A last component of the course – and one which straddled the line between desirable and essential – was the participation in the iGEM competition. While not mandatory, iGEM participation was expected and rewarded; when it came to grading the students' masters project, the programme organisers would "consider[...] favorably the participation of the student in that institution's iGEM project"(EMERGENCE, 2009, p. 16).

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[34] This programme would take the form of an Erasmus Mundus Master Course. The Erasmus Mundus programme provides another window into the European Integration process, particularly as it runs in tandem with the development of the ERA. However, in the interest of brevity, discussion of Erasmus Mundus is ommitted in this thesis.

[35] The curriculum was also planned to include a number of optional modules which addressed ethical and societal issues. This institutionalisation of synthetic biology training which encompasses these themes is a likely reflection of the embeddedness of social scientists in the community. For a reflection of the role of social scientists in synthetic biology, see Calvert & Martin (2009).

These three projects devoted considerable effort and resources towards training novices. This is indicative of a strategy of making community from the ground up – the making of an epistemic community by outright creating its epistemic subjects. These students were also to become part of the *new breed of researchers* versed in biology and engineering. All three – the iGEM competition, summer schools and the European MSc – were designed towards promoting the *individual interdisciplinarity* (Calvert, 2010) which characterises these (imagined) researchers. It is also remarkable the extent to which the iGEM competition – at this point, ostensibly an American event – was mobilised in the drive to make European synthetic biology. EU funds were made available for supporting entry of European teams into the competition, the running of a European competition stage, and designing a masters programme which heavily promoted participation. By having the budding generation so closely entangled with iGEM, these projects tether (to a considerable extent) the future of European synthetic biology to both parts-based synthetic biology and iGEM alumni.

The establishment of the MSc programme as a European masters is also interesting. Participating students would be required to attend at least two institutions in at least two different EU countries. This contributed towards the goal of creating a "European dimension" (European Parliament Decision no 1720/2006/EC, 2006) to the student's training, and constituted a prelude to the mobility of researchers envisaged by the ERA. It also further cemented the transnational character of European synthetic biology.

5.2.2 Making of community by enrolling (established) researchers

The second key element in the strategy of all three projects revolved around events. One of the two aims of SYNBIOCOMM was to organise a "European Conference in Synthetic Biology as a quasi-inaugural event for the future community" (SYNBIOCOMM, n.d.). This took the form of SB3.0 – the third iteration of international synthetic biology conferences; participation in this conference broke the trend from the other two, in that the first two were overwhelmingly attended by researchers based in American institutions, while SB3.0 encompassed a majority of attendees based in European institutions. EMERGENCE also devoted considerable effort towards events – both as a (co-)organiser and as a (co-)sponsor. Unlike SYNBIOCOMM, however, those events were not planned a priori. Instead, the project was expected to organise events in response to issues/needs which manifested in (European) synthetic biology; and to provide resources for (European) researchers willing to do the same. This led to events ranging from a workshop in the UK to discuss the potential usefulness of microfluidics for synthetic biology; to a workshop in Germany, organised to bring industry closer to synthetic biology; or a meeting in Spain, aiming to bring together experts in systems and synthetic biology from southern Europe.

Besides these deliberate attempts to bring researchers together, the making of community among established researchers was an ancillary benefit to the activities targeting novices. The organisation of the MSc hinged on the enrolment of researchers from multiple institutions from multiple countries. These researchers then formed a small network around their various roles in the programme; as both external (and temporary) teachers for the modules taught during the first year, and as hosts for the students as they progressed towards their research year. The summer schools ran in the lead up to the iGEM competition were aiming to "attract[…] good/eminent teachers" (EMERGENCE, 2007a, p. 33); and at the same time, hoped to "become a focal point for the exchange of synthetic biology faculty from all over the world" (EMERGENCE, 2009, p. 15)[36].

Further, EMERGENCE produced periodic newsletters, which publicised these calls for events, as well as the ensuing supported events (and often reports on those)[37]. This was a strategy replicated and expanded on by ERASynBio. In its news-

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[36] I explore the dual purpose of pedagogic activities in greater detail in Chapter 7 (in the context of the CyanoBioFoundry project).

[37] Events were not, however, the sole remit of the newsletters. They relayed events news relevant to European synthetic biology(ists); listed recent synthetic biology publications; publicised upcoming synthetic biology events; and listed open positions. There is relatively little work on newslet-

letters, the project publicised events, but these were but a part of the long newsletter. Events were not only listed, but it offered a brief description of past/present events. ERASynBio also publicised its calls for proposals, as well as ancillary, relevant ones. In the lead up to the iGEM competition, it would describe it and add vignettes of the experience of previous participants. Indeed, a multitude of vignettes were presented, on topics ranging from relevant synthetic biology (European) projects, themes at the interface between science and society (including a vignette by Maja Horst), and outlines of the development of synthetic biology in a number of (changing) European countries.

In the context of ERASynBio, one of its activities is worth outlining further, in that it departs from the activities from the previous projects – the *twinning* programme. One of the guiding objectives of the projects was to "overcome extant fragmentation in European research landscape and strengthen the scientific community" (ERASynBio periodic report, 27th Febryary 2015). The twinning programme was designed for (partial) fulfiment of that objective. The programme encompassed the support of small-scale, scoping / preparatory activities between researchers across Europe. Specifically, it invited proposals with the aim to "start up a research programme or to prepare a joint proposal in the field of Synthetic Biology"(ERASynBio, 2014b). At a minimum, this would require the participation of two senior researchers from two countries, although ERASynBio encouraged the involvement of more participants. The twinning programme can thus be said to have promoted the making of explicitly transnational (European) community, and to have done so through the promotion of assemblages which can be interpreted as *micro*-forums; small assemblages which were transient, but which left the door open to the creation of stronger structures as they dissolved.

In sum, the role of this plethora of activities, events (and the newsletters) in the trajectory of synthetic biology can be productively explored by interpreting them as

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ters as focal points in community (Kelty (2012) and Hogan (2013) being notable exceptions), but their potential role is far from insignificant. Unfortunately, for reasons of space, I am unable to delve into that detail.

community-making devices (Molyneux-Hodgson & Meyer, 2009). Whether in a global stage or in a local workshop, these events enabled the researchers to articulate the need for community and negotiate (within their bounds) what a synthetic biology community could look like. They enabled the *movement* of actors towards (a still budding) synthetic biology, as in the case of participation of EU researchers in SB3.0, or that of industrial actors in a synthetic biology workshop; and they also built community by promoting *stickiness* (ibid.) (between and) among those actors, as in the distribution of a newsletter on synthetic biology to interested actors, or the promotion of a sense of shared enterprise among researchers based in southern Europe.

Besides the question of *how* these events make community, it is also important to note *who* was being enrolled into the community. Most of the relevant events were organised for an audience which was both academic and based in EU institutions. Some, however, deliberately included a global academic audience (I address these in the following section); a small number aimed at industrial actors based in the EU; and another small number explicitly brought together European and Asian academic researchers (which I will address shortly). The didactic framing of the workshops specifically catering to European industry (e.g., their aim was described in the project deliverable as "teach[ing] the industry in synthetic biology concepts and tools"(EMERGENCE, 2008, p. 80)) indicates there was still a clear *boundary* (Gieryn, 1983) between academic synthetic biology research and the relevant industrial actors. Still, the sustained engagement with the latter can be attributed to the (performative character of the) expectation that synthetic biology was to be one of the contributors to the European knowledge economy, and this transition would necessarily involve industry.

The link between participation in workshops with Asian researchers and the making of European synthetic biology, however, is less obvious[38]. Indeed, the ties to Asian researchers go beyond (co-)participation in workshops. They extend to the in-

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[38] EMERGENCE was not restricted to nurturing links with Asia; instead, the push was ostensibly global. However, (a broadly defined) Asia was the sole geopolitical target for formal interactions.

clusion of such researchers in the development of the EMERGENCE project, as well as the inclusion of European researchers in similar local projects, as well as exchange visits. The interaction between the two groups culminated in the signing (by relevant EU and Asian institutions) of a document outlining common interests in synthetic biology and ways to advance them. The (largely) concurrent global emergence of synthetic biology occasioned its use as an instrument of *science diplomacy* (Royal Society, 2010). This was, once more, a path which ERASynBio followed and built upon. In the case of the latter, the funding bodies that managed the project carried out several exchanges / visits with their American (NSF) counterparts. Moreover, American researchers were eligible for participation in the calls for proposals and the twinning programme. In this way, the intersection between the making of an epistemic community of European synthetic biology and the making of a particular European Union (as a geopolitical entity) is rendered salient. I now move to an examination of the making of the European synthetic biology community in the course of *doing* research.

5.3 DOING SYNTHETIC BIOLOGY

Over this section I explore the building of community in the context of the technical synthetic biology projects. I start with an examination of the openness of the NEST programme. I then problematise the transition from FP6 to FP7, and what that meant for the performance of research. I finish with an examination of research in FP7 – largely in the context of collaborative projects, although with a brief allusion to single-researcher projects.

5.3.1 NEST synthetic biology (technical) projects

The focus of the synthetic biology NEST pathfinder was, unquestionably, on technical projects. The bulk of the funding was allocated to 14 STREP projects, split over three calls. Moreover, in the spirit of the NEST programme, this was funding awarded without restrictions as to the areas of research or predetermined material outcomes. The range of projects reflected this thematic flexibility. Researchers employed many different (model) organisms – from cyanobacteria to yeast – or even attempted to create novel ones. They used different approaches to the modification of those organisms, ranging from wholesale changes to the genome to the disregard of the existing genetic machinery; from the attempt to integrate new (mostly) modularised snippets of genetic material (more or less integrated to complete a given function), to introducing genetic material which conformed to a different genetic code to be kept in parallel, to the search for the smallest genome required for a cell to operate (from both directions – by deleting existing genetic material and by adding a collection of genes from scratch); or the researchers eschewed the use of organisms altogether and focused on creating / modifying relevant protein (building blocks), from antibodies to motor proteins. The ultimate aims of the projects were similarly diverse, encompassing goals like the biological production of fuel and (other) complex molecules, the development of medical treatments, or the establishment of cells with a genetic make up useful for industrial applications.

This large variety of focus, strategies and outputs was not only expected, but explicitly desired by the EC. The programme was expected to support "ambitious "beacon projects" which [...] expand the knowledge base in significant ways" (NEST Programme, 2003). As such, these technical projects were expected to build capacity in synthetic biology. However, their purpose went beyond that of capacity-building. These projects were also expected to "develop and demonstrate the technologies for synthetic biology"(ibid.), and their abstracts were compiled by the EC into a publication which has been distributed (and cited) far and wide (DG Research, 2007). In this way, they were to become *exemplars* (Kuhn, 2012 [1970]) of synthetic biology. Thus, the technical projects were to contribute in this two-fold way to a (thus far particularly bare) *repertoire (Leonelli & Ankeny, 2015)* of synthetic biology. They were to build community by building the methods, the artefacts, the infrastructures (and, to some extent, the identities) which a synthetic biology community would come to use.

While the programme offered considerable thematic freedom, it also ensured the synthetic biology practised was one which fit under the (developing) imaginary for the field and the restrictions of the NEST programme. This meant there were some substantial curbs on flexibility regarding methodology and ethos, which grew stricter with each call. Funding requirements played a balancing act between enabling the materialisation of the vision for European synthetic biology that was coalescing around the NEST synthetic biology programme (including the HLEG contribution I address in the following section) and the legalistic restrictions to the NEST programme in general.

Perhaps the most salient framing of synthetic biology is that of the technological counterpart to the (science of) systems biology. So, under this imaginary, "synthetic biology is not primarily a "discovery science" (that is, concerned with investigating how nature works), but is ultimately about a new way of making things" (NEST Programme, 2005). As noted in the previous section, it is also about making things in a specific way, with an expectation that it will follow a rigorous engineering approach, underpinned by design of and control over the biological machines. This imaginary was weaved into the funding call(s), which "made clear that the focus of the research w[ould] be the practical demonstration of the "generic functionality" of components and systems ("proof-of-principle")" (NEST Programme, 2004). Research which focused on *understanding* (be that via computational or wet lab approaches) was explicitly excluded by the calls. These approaches were valued, but only as components of a (larger) synthetic biology that *makes*.

Besides looking at what synthetic biology under NEST could be, it is worth examining what it could *not*. For one, it could not be research "of limited interdisciplinary nature, or of limited long-term scientific impact" (NEST Programme, 2005). For another, it could also not be research which could be reasonably expected to have a place under the thematic priorities of FP6. These specific exclusions are due to the mandate of the NEST programme; thus, the synthetic biology funded under the scheme would explicitly have to be interdisciplinary, (potentially) revolutionary and methodologically novel. Hence, by design, no amount of *window dressing* (Laudel, 2006) would enable classical approaches to the genetic modification of organisms to be funded.

Lastly, it would also have to be a synthetic biology which was transnational, collaborative and interdisciplinary in a particular way. Once again, the first two points relate to the remit of the NEST programme. Research funded would have to be collaborative, and projects could only be considered if they included at least three participants based in three participating countries (EU member states and associated countries). Interdisciplinarity was evaluated on the consortium as a whole, which meant it enabled the coming together in a consortium of a heterogeneous range of experts. Interdisciplinarity was also presented differently over time. It was first presented as a desirable meeting of biology and allied fields, with a generic indication of the need to recruit all relevant expertise; but it gradually became institutionalised as the meeting of biology and engineering, with explicit requirements of recruiting engineering experts into the consortium.

5.3.2 Synthetic biology after NEST – research in FP7 (and ESF) projects

As 2006 came to a close, so did the Framework programme 6. A new iteration – Framework Programme 7 (FP7) – was then put into place to support (European) research in the period of 2007 – 2013. In this programme, the emphasis grew on the funding of research driven by a societal *need*, as noted in Chapter 4. Such a funding environment presented a challenge to synthetic biology. In this section, I will address how (community in) synthetic biology was made under the new framework programme. I will start by charting where synthetic biology featured in FP7 (and an instance where it went beyond the programme). I will then explore how how changes to the funding environment impacted on the trajectory of the epistemic community – in the context of the (bottom up) Ideas programme; and of the (top down) Cooperation programme. In particular, I will address the interplay of the second theme of the Cooperation programme (Food, agriculture and fisheries, and biotechnology) and the KBBE agenda with the drive towards making synthetic biology (community) thrive, putting particular emphasis on development and delivery of the synthetic biology ERA-NET Project ERASynBio.

Synthetic biology was by no means excluded from FP7 – in fact, it boomed, as illustrated in Figure 8. The number of participants (not unique) in synthetic biology projects almost tripled when compared with FP6. The bulk of participants engaged in projects funded under the Cooperation programme, as had been the focus in previous FPs. However, there was also considerable funding for single researchers –under the scope of the promotion of mobility (the Marie Skłodowska Curie programme); but mostly under the scope of promotion of excellence (ERC grants). Indeed, the volume of funding allocated to synthetic biology projects by the ERC alone was close to double that of the entire synthetic biology NEST programme of FP6.

The geographic scope of participants in synthetic biology projects also widened considerably in the new FP. Researchers were drawn from 13 countries for the FP6 NEST programme, albeit from a limited number of institutions. Under FP7, participants were based in institutions from a wider range of cities / regions. Moreover, projects under the framework programme encompassed researchers based at institutions in an additional nine (European) countries. Still, the number of participants from new countries was timid. Funding remained concentrated in a small number of hands, which roughly match the countries with developed national funding streams for synthetic biology.

This cursory glance at the funding under the new FP yielded a number of insights into the development of synthetic biology and the community on which it is rooted: synthetic biology grew under FP7, as did the number of European countries from which researchers were involved; there was considerable funding made available for single researcher projects, but the majority of participants engaged in collaborative research; and the geographic distribution of researchers was asymmetric, between north and south, and also east and west (I return to this theme in Chapter

7). I now move to explore the aesthetic of synthetic biology under the different FP7 funding schemes.

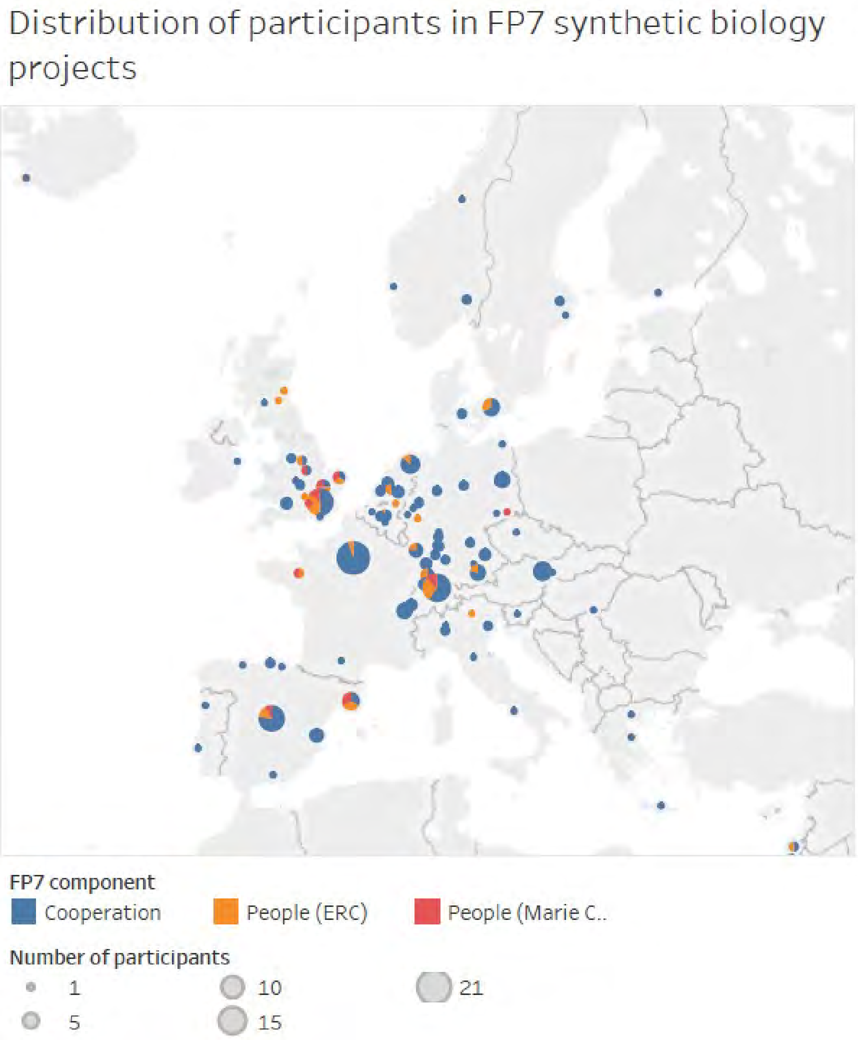

Figure 4: Distribution of participants in synthetic biology projects supported by the Framework Programme 7. Participants in projects funded under the "Cooperation" programme are shown in blue; participants in projects funded under the "Ideas" programme are shown in orange (ERC) and red (Marie Skłodowska Curie). The size of the circles is proportional to the number of projects funded in a given city / region. In locations where there were participants in multiple programmes, the size of the circle refers to the total number of projects.

3.3.3 Single-researcher projects

In FP6 only a single Marie Skłodowska-Curie postdoctoral fellowship was funded to address synthetic biology. Over the course of FP7, single-researcher synthetic biology projects were funded to the tune of tens of millions of Euros. Projects were funded under the “People” pillar of the framework programme, encompassing Marie Skłodowska-Curie fellowships, grants for “career integration”, and initial training networks; and under the “Ideas” pillar of the framework programme, encompassing all three levels of ERC grants. A detailed analysis of the projects funded is beyond the scope of this thesis, but it is nevertheless noteworthy that while the majority of projects focused on DNA-based device construction, other approaches operating under the banner of synthetic biology made up a sizeable (and diverse) minority. In these projects, synthetic biology emerges as a broader church; not as an inevitable (and indissociable) marriage of biology and engineering, but a more dissonant mix, where an engineering ethos varies between prominent and backgrounded absent. In particular, there is a substantial minor genre of approaches predicated on *understanding* (synthetic) biology, be that in the form of learning about them by replicating biological components / functions in proto and minimal cells. However, even projects which are, in some meaningful ways, textbook parts-based synthetic biology, deviate from the budding engineering-driven canon. A useful example is the ERC project SYNTHECYCLE. This project explicitly aimed to bypass the cell cycle of cells, instead creating “the most synthetic and artificially modulable cell cycle control network to date” (SYNTHECYCLE, n.d.). This synthetic circuit was predicated on the use of modular parts and designed / refined with the help of a mathematical model. However, it does not promise an output beyond the understanding of the cell cycle; and the genetic circuits for the (minimal system capable of) control of the cell cycle. Where tangible outputs are alluded to, they are framed as beyond the scope of the current project. It is closer to what Bensaude Vincent (2013) argued was a synthetic biology modelled on (the discipline of) chemistry, rather than driven by engineering; the focus is on synthesis for analysis, rather than synthesis for production. This is a departure from the NEST programme and the Cooperation programme of FP7 (as I will show in the following section). Unlike either of those programmes, however, “People” and “Ideas” operated without thematic restrictions. Instead, the programmes pursued bottom-up funding strategies; the programmes were open to proposals in any given area, and were overwhelmingly judged with *excellence* as the main criterion.

The increase in Marie -Curie funded projects and the funding of several ERC projects provides a useful window into the progressive institutionalisation of the community. There were now established researchers working under the umbrella of synthetic biology – several conscious and explicitly doing so – and there was a stream of young researchers being welcomed into the community. However, these were both elite programmes, which means the volume of participation was limited; as such, they alone would be unable to support the development of an EU-wide community.

5.3.4 ESF EUROCORES

A second response to the perceived absence of relevant funding streams which would support the development of synthetic biology came in the form a synthetic biology initiative under the ESF[39] EUROCORES programme. The ESF was a member of the TESSY (FP6) project, which meant the institution was acutely aware of European researchers' plight over the coming funding shortfall due to the disappearance of the NEST programme in FP7 (having been exposed to this view in engagement with the researchers from the EMERGENCE project). Conversely, it was through the ESF's participation in that project that some of the key European synthetic biology researchers came to know of the existence / appropriateness of its EUROCORES programme to pick up where NEST had left (or would leave) off. The potential opportunity was then discussed in the context of the EMERGENCE project consortium, who started to work on a project proposal; a final proposal, involving a subset of the EMERGENCE consortium PIs and some other (mostly prominent)

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[39] ESF stands for European Science Foundation. It was (while not defunct, its remit has radically changed) an organisation propelled by several European countries with the aim of coordinating European research. In that context, it performed a role relatively similar to what the European Commission performs now.

names of EU synthetic biology was submitted in 2007 and the EuroSYNBIO programme approved in 2008.

EuroSYNBIO published a single call for proposals, which was predicated on the funding of collaborative projects with the broad purpose of supporting the development of synthetic biology. It was a programme which resembled the synthetic biology NEST pathfinder of FP6 in both style and substance; unlike NEST, however, participation was restricted to researchers based on countries whose funding agencies had agreed to collaborate in EuroSYNBIO, as there was no central funding source (funding was disbursed according to the nationality principle[40]). This meant only researchers based in in 12 EU countries (plus Norway, Switzerland and Turkey) were eligible for funding. Beyond the nationality restrictions, the call involved modest volumes of funding, and only a total of five full proposals had a positive outcome. Thus, this was an initiative which involved 23 research groups, based in 7 countries. So while EuroSYNBIO undoubtedly made a contribution for the expansion and refinement of a European synthetic biology *repertoire* (Leonelli & Ankeny, 2015), continuing on the path set out in FP6, it provided no long-term support for the development of a community.

5.3.5 FP7 Cooperation programme

The majority of participants in European synthetic biology projects did so as part of projects within the FP7 cooperation programme. However, synthetic biology did not fit the established themes of the cooperation programme. The research envisaged was more applied and relied on more mature approaches than synthetic biology could reasonably deliver over the course FP7. This incongruence was resolved in two key ways: by creative use of available funding instruments; and by outright changing the funding instruments that were made available.

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[40] In the interest of brevity, the EuroSYNBIO is only very superficially described; the programme shares considerable similarities with the ERA-NET initiatives, so readers might find useful insights into how EuroSYNBIO was structured / how participation was organised in the description of the ERASynBio ERA-NET, in section .

In the context of FP7, the majority of projects (and participants) were concentrated under the food, agriculture and fisheries, and biotechnology theme of the cooperation programme; the remainder being funded under the ICT and Energy themes. The gathering of projects under the food, agriculture and fisheries, and biotechnology theme is a key juncture for the trajectory (and the history) of European synthetic biology. It was made possible solely because the theme deviated substantially from the rules established for the FP7 cooperation programme and created funding calls specific to synthetic biology, as I note in section 5.2. I address that theme last.

In the cases of the Energy and ICT, however, there were no changes which were to the specific benefit or support of synthetic biology. In these cases, synthetic biology projects made creative use of existing funding instruments. As it had been the stated purpose of the bulk of research in FP7, the majority of calls in both themes addressed specific problems / points of potential economic and/or societal benefit. In many cases, the calls prescribed the desired outcomes and/or the desired approach; concurrently, they would ask for mature approaches to a given problem, or the creation of mature technologies, which would not be far from the point where they could be commercialised. At this point, synthetic biology provided poor competition to other approaches. However, several researchers were able to find a niche for their (multiple) synthetic biology approaches at the edges of two themes, on calls for *future and emerging technologies* (FET).

As noted in Chapter 4, FET projects had *fewer* demands on the ways of working and the outputs of the projects. Nevertheless, they did not provide a space for conducting *basic* or *blue skies* research[41]. An Energy project would, invariably, be expected to produce outputs related to energy. Thus, the funding of synthetic biology projects under such umbrellas nevertheless impacted on its trajectory for they guided

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[41] I am conscious that the definition of basic research is problematic (e.g. that the concept is understood differently by different actors (Calvert, 2004) and deployed with different purposes in different contexts (Calvert, 2006)). It is not my intent to insert myself into these debates, but my allusion to basic science is motivated by an attempt to make a hermeneutic distinction between *basic* and *applied* research.

the development of synthetic biology towards particular objects of study and particular outputs – with concomitant impact on the resulting *repertoire*. Moreover, in the case of ICT in particular, these restrictions so much as prescribed the practice of synthetic biology in the modular, PBSB tradition. All projects funded under this theme operated under that imaginary; indeed, it is difficult to imagine any approach to synthetic biology fitting under the ICT theme other than the one whose epistemic inspiration stemmed in no small part from ICT. As before, the support of this *way of working* over others is of consequence for the shared repertoire of European synthetic biology.

I now turn to projects funded by KBBE. The funding calls presented here somewhere between those of the NEST pathfinder programme and those described above. As in NEST, there were few thematic restrictions, and project were required to be collaborative and transnational. However, as KBBE progressed, the expected size of the projects grew; by 2013, the indicative budget for synthetic biology projects had grown to €9M, and the EC made clear it would fund multiple projects. In tandem with growth, the range of actors also expanded – the participation of SMEs was, in later calls, no longer encouraged, but mandatory. Further, the absence of thematic restriction was not synonymous with the absence of restrictions in the ways of working. Very briefly, an illustrative example comes in the 2011 KBBE work programme, which included a call for "Applying Synthetic Biology principles towards the cell factory notion in biotechnology" (European Commission, 2011, p. 73). The aim of working towards cellular factories is more attuned to some synthetic biology approaches than others. It is thus not an open field as it had been the case in NEST. Moreover, the choice of the *cell factory* metaphor is interesting. That had been a metaphor which had gained currency in the context of KBBE-NET. Thus, the KBBE calls were still a site of considerable scripting of synthetic biology – as a(n increasingly) large-scale endeavour, increasingly prescribing synthetic biology as *big biology*; and as an endeavour to be undertaken with the private sector, crossing the academic-industry boundary. In this way, the KBBE contributed to the further steering of the synthetic biology *repertoire* (Leonelli and Ankeny 2015). I now move to a final context of the conduct of synthetic biology – that of ERASynBio.

5.3.6 ERASynBio

Over the course of the project, ERASynBio published two calls for technical projects in synthetic biology. These calls were imagined as a "powerful tool to encourage interdisciplinary collaborations and to establish and strengthen the scientific community in Synthetic Biology" (ERASynBio, 2013). The funding of such projects was thus explicitly framed as a way to make community in synthetic biology, and a community bound in particular ways (of working) and with a particular trajectory. The evaluation criteria for proposals provide a useful window into which synthetic biology (and which community) was to be developed; (a subset of) the evaluation criteria for the first call reads as follows:

> "(1) Relevance of the application to the aims and scope defined in the call
> a) Opportunity to embed and develop the principles and methodologies of Synthetic Biology
> b) Opportunity to add value from collaborative transnational projects and build a European (and global) Synthetic Biology community
> […]
> (3) Impact
> a) Opportunities for economic impact and advancement of the Knowledge-Based Bio-Economy (KBBE)
> b) Opportunities for public good and to address global grand challenges
> […]
> (4) Implementation
> a) Balance of the partnership, transnational added value and quality of the consortium as a whole" (ERASynBio, 2013, pp. 10–11)

The first criterium links the funding calls with one of the major aims of the ERASynBio project – to *build* synthetic biology; to create projects to (as in the NEST programme) serve as exemplars of synthetic biology, while at the same time continuing to build capacity and develop its epistemic practice. To continue to build the synthetic biology *repertoire*. It is nevertheless important to note the calls made explicit restriction to funding solely synthetic biology which fit the definition put forward by ERASynBio. This was to be synthetic biology aiming at development for *useful purposes* – an expectation clearly articulated in section 3, which once again links the development of synthetic biology and the development of the KBBE; and rewards (only) synthetic biology which provides solutions to societal problems. Furthermore, in the definition offered, synthetic biology is portrayed as inexorably interdisciplinary. The call acknowledges this and includes as an additional criteria the aim to "establish a true interdisciplinary research" (ibid.). The proposals were thus expected to "clearly demonstrate a biology-chemistry/or -informatics/ or-mathematics/ or-physics/ or-engineering interface" (ibid.). Projects were also to be judged on their ability to build a European synthetic biology community, predicated on transnational, networked collaboration. The eligibility criteria made clear that for projects to be considered, they would have to include a minimum of three researchers based in three different European (participating) countries. Still, this criterium is not addressing the unification of research across Europe, as promoted under the ERA agenda – that is referenced in point 4-a, in the reference to transnational added value. Added value in 1-b refers back to one of the key dimensions of EAV over time – that of scale. Synthetic biology was framed in ERASynBio as having great potential, but a potential which "can only be realised through strategic international cooperation" (ibid.). Thus, proposals would be judged on their ability to bring about the potential of synthetic biology which was only available by moving from the national to the transnational scale.

The second call was launched in 2014, after the vision white paper had been completed. While both calls shared the aims and restrictions for synthetic biology detailed above, the second one was also to "be used to enact the recommendations of the newly published ERASynBio Strategic Vision" (ERASynBio, 2014c). This expectation was formalised as the mandatory inclusion of one of four "strategic elements" [ibid], which were linked to the recommendations made in the white paper. So, beyond all the other requirements, proposals for the second call were to explicitly address themes in responsible research and innovation; community-building; training and education; or data and (infrastructure) technologies. The projects awarded funding under this call were then to further build community and repertoire as a response to this clear and forceful funding requirement.

* * *

Over the course of this section, I mapped out the contexts in which synthetic biology was practised, and the restrictions with which the researchers were forced to contend. Indeed, the thematic and epistemic freedom afforded to the *bottom-up* funded ERC/MSC projects provides a stark contrast to that of the *top down* funded collaborative projects. This suggests there is scope for a more plural vision for European synthetic biology, but that plurality is negated through the exertion of authority via the funding instruments.

There is some whimsy to the fact that, from the FP6 start in the NEST programme, to (almost) the FP7 finish, in the context of the ERASynBio ERA-NET, the funding conditions for European synthetic biology have come full circle. These programmes were not subject to particularly onerous requirements, other than those of the classic dimensions of EAV: collaboration and transnationality; and *alignment* (Fujimura, 1987) with the vision for a European economy driven by (bio) knowledge. As all other collaborative projects included these requirements as well, these ways of working and locus became a cornerstone of a European community.

The messy shift from FP6 to FP7 brings to the fore the role of funding in the trajectory of the epistemic community in two important ways. For one, it indicates the fragility of the extant field as it fell through the cracks of a funding programme. Indeed, this is illustrative of the impact generic governance mechanisms can have on emerging fields (Gläser, Laudel, & Lettkemann, 2016); it constitutes a particularly poignant articulation of the way in which governance mechanisms are able to (inadvertently) block the development of fields, leaving the epistemic community in limbo. For another, the fact that the epistemic community travelled through projects which were steered to varying degrees, with demands on practice, outputs and constellations of actors is not inconsequent for the trajectory of the field. While these projects may have ended, they are unlikely to have dissolved without leaving *residue* (Rip, 2000) – a theme which I articulate in Chapter 7 and explore further in Chapter 9.

As noted above, the funding calls were thus far more than an arm's length means of allocating resources to synthetic biology. In this section I argued that they were devised as a key instrument to build synthetic biology. They were to enable a particular repertoire to flourish – one which supported a synthetic biology developed for useful purposes. Thus, funding impacted on the trajectory of synthetic biology by constricting what was *fund-able* synthetic biology, and thus what was a *do-able* (Fujimura, 1987) synthetic biology problem with concomitant impact on the repertoire of the epistemic community and its membership.

5.4 CONCLUSION

In this chapter, I have detailed the complex interplay of changes to institutional arrangements and the articulation of visions in promoting a particular, European, synthetic biology. I have argued that the promises made prompted the mobilisation of resources towards making both a synthetic biology community and doing synthetic biology. Further, I have traced the role of funding mechanisms in articulating the requirement portion of the promise-requirement cycle, and argued that funding served as a means for enacting governance (by proxy) over synthetic biology. I also note the ways in which major community-making attempts took place, and link those to resources made available through the funding streams. Lastly, I argue that these arrangements promoted the development of a particular repertoire for European synthetic biology – one which is grounded on big biology ways of working and an engineering ethos – and of a community which is deliberately transnational in nature.

The visions for a particular EU were closely entangled with the visions put forth for European synthetic biology. Indeed, in the formal futuring exercises, synthetic biology was consistently cast as contributing towards enabling the EU to transition towards a knowledge economy and an area where research transcended national silos. This was a synthetic biology driven by an engineering ethos, and thus inherently interdisciplinary; one which was interested in *making*, rather than *understanding*. And a synthetic biology which was explicitly European, but whose community yet did not exist. Unlocking the potential of European synthetic biology would thus require the building of such a community. European synthetic biology was leveraged through an institutional push – firstly, a generic push towards promoting the creation of cutting-edge, economically relevant knowledge; and then through the specific support of synthetic biology under that same agenda. In both cases, this institutional push meant the availability of dedicated funding for *making community in* synthetic biology and for *doing* synthetic biology.

Community-making is an arena where the institutional push was made very visible. The NEST programme made clear there was an expectation of community-building, and that expectation was translated into dedicated funding for the establishment of *fora*. The two forums created served as bases for researchers (including industrial partners) to negotiate and institutionalise synthetic biology, and for the enactment of community-making devices. The latter took the form of (funding for) events spread out across Europe, in a bid to enrol senior researchers; and the combination of a formal education programme, summer schools and entry into the iGEM competition, in a bid to enrol novices. In turn, the ERASynBio ERA-NET provided dedicated funding to enable senior researchers from different European countries to produce grant proposals for collaborative synthetic biology projects; and continued to support the running of summer schools and the iGEM competition, aimed at novices. Community-making was thus an aim which followed the visions set out for synthetic biology – it encompassed activities run across the continent (and, in some cases, explicitly transnational); it went to great lengths towards the creating community from the bottom up; enshrined new generation of interdisciplinary epistemic subjects; and it emphasised the engineering ethos of synthetic biology, particularly in the enrolment of novices. The iGEM competition was thus a key site for community-making, and I explore it in greater detail in chapter 9.

If far from invisible elsewhere, the hand of funding was felt particularly acutely when it came to *doing* synthetic biology. If visions set out promises, funding was a key site for the articulation of requirements. For one, in the case of dedicated streams, funding performed considerable boundary work. From a negative standpoint, it made explicit what European synthetic biology could not be; and from a positive one, it ensured it would be an interdisciplinary endeavour – and one where an engineering ethos featured prominently. For another, collaborative projects supported outside dedicated streams restricted the development of synthetic biology in detriment of the creation of outputs; and suggested the coalescing of different approaches around the different application areas. Yet, single-researcher projects, which were judged solely on their excellence, yielded a far broader and plural set of approaches to synthetic biology; in particular, they enabled the support of a synthetic biology modelled after chemistry, rather than engineering.

The bulk of synthetic biology, however, was collaborative (by design). The funding calls embodied the legalistic requirements of EU research, and ensured that European synthetic biology operated through consortia, in a big (or at least *meso*) biology model. That is, as networks of research groups working together towards a large, common goal; and funding also ensured these networks were explicitly spread across Europe. By restricting what was *fundable* research, these mechanisms impacted on the trajectory of European synthetic biology in meaningful ways, thus providing some empirical basis for Braun's (1998) argument for the expected role of funding in what he called the cognitive development of the sciences.

PART III

SYNTHETIC BIOLOGY AT THE COALFACE

In this section, I progress further along the path of exploring the making of European synthetic biology, albeit from a different perspective. Part II was concerned with the broad strokes of the emergence of synthetic biology in Europe. Here, I eschew the macro lens in favour of a focus on the processes and aesthetics of community-making at a more micro level, though I retain the emphasis on the role of funding instruments in guiding/driving community. As such, Part III is rooted on a case study of a long-term endeavour in synthetic biology, aiming to produce large quantities of hydrogen (for ultimate use throughout the economy) through the modification of a bioorganism.

The central pillar of this case study is a large-scale, distributed, EU-funded research project. However, considering the longitudinal nature of community-making, my gaze extended to the past – to an earlier EU project which kick-started this long-term effort; and into the future – to preparations for the next (multiple) iteration(s). As noted in Chapter 3, this is an account based on a multi-sited ethnography. It includes insight from (participant) observation in project meetings, research exchanges and routine lab work; from semi-structured interviews of junior, middling and senior project participants; and from analysis of documents produced by the participants in both projects.

The first EU project in this endeavour of (synthetic) biological production of hydrogen – CyanoH2Modules – was one of the projects funded under the synthetic biology Framework Programme 6 (FP6) New Emerging Science and Technology (NEST) Pathfinder programme. It brought together six research groups from across Europe with the aim of using a synthetic biology approach to modifying cyanobacteria (a type of particularly simple unicellular organisms capable of photosynthesis) with a view to enhancing the organism's ability to produce hydrogen. CyanoH2Modules was (consciously) only the first step in a long journey towards a robust, well characterised system; in this project, the focus was on the reinterpretation of the organism and the hydrogen metabolism through the lens of (parts-based) synthetic biology: through modularisation of key portions of genetic material, mathematical modelling of the organism's metabolism, and efforts to make the organism more amenable to manipulation and industrial production.

Despite the longitudinal nature of this combined effort, a (successor) project which advanced the research agenda started only after a gap of over two years. The process of moving forward was complicated somewhat by a loss of interest in the specific research topic by some members (which was entangled with different commitments towards synthetic biology); but it was mostly complicated by the (perceived) expectations and demands of EU funding mechanisms. Thus, the exercise of assembling a new successful proposal was also an exercise in (re)imagining the coalitions of actors which would work towards synthetic biology, as well as what synthetic biology could be under the FP7 programme.

The second EU project – CyanoBioFoundry – built on the work started in CyanoH2Modules, while at the same time diverging focus from the development of synthetic biology to the development of the technologies which would enable the industrial production of hydrogen. In this project, the focus went beyond that of using synthetic biology to create modules, but it promised to create variations of the cyanobacteria with modifications in the direction of higher yields of hydrogen production; and the development of synthetic biology shared the spotlight with the development of lab and industrial reactors for specific use with these cyanobacteria.

The members of this second project were also acutely aware that this was only another step in the direction of a mature system, and that several more iterations would be required. This prompted the researchers to plan for the future after CyanoBioFoundry from the very beginning, which the researchers accomplished by a strategy of looking in (to the group) and out (to potential new members). Much like in the aftermath of CyanoH2Modules, the efforts towards charting further work blended with finding support for synthetic biology in the subsequent framework programme.

This section is structured around these four moments. I chart the making of community through the twists and turns of the execution of the projects and the preparation of (and for) new ones in the two chapters which make up the section. Chapter 6 addresses the two research projects – CyanoH2Modules and CyanoBioFoundry. I sketch out how the projects were structured and imagined to work, as well as their link to the vision for a particular (European) synthetic biology. I note how a synthetic biology community was built in these projects through the contribution towards the synthetic biology "repertoire" (Leonelli & Ankeny, 2015) – through the creation of artefacts, identities and ways of working which ground community. In tandem, I also explore the different extent and different ways in which issues of governance, interpreted through the lens of funding – bled into the architecture of the projects, their aims and, ultimately, into the projects' contribution to the synthetic biology repertoire.

Chapter 7 focuses on the undertaking of (re-)assembling coalition of actors towards the continuation of synthetic biology work in the European arena. It is temporally anchored in the period between CyanoH2Modules and CyanoBioFoundry, where the latter was imagined and prepared; and in the period of the execution of CyanoBioFoundry, where multiple, overlapping potential futures were imagined and (to different extents) prepared. Analytically, this chapter provides a negative of the preceding, with the foregrounding of the articulation of the vision for synthetic biology with several of the (changing and overlapping) visions for Europe and European research; and backgrounding of community-building through the lens of the repertoire. Here, I trace the ways in which the synthetic biology in preparation was forced to contend with the visions for European synthetic biology and European research more broadly, the ways in which these constraints were handled and what that means for European synthetic biology.

As suggested in their description, the two chapters navigate overlapping themes. The separation into two chapters is motivated by the drive for analytic clarity, and is intended to provide a snapshot of the community-making process through two different lenses. The entanglements between building the synthetic biology repertoire and the struggle over what repertoire is (possible) to be built are woven throughout both chapters. I turn now to the start of that exploration, with Chapter 6.

6 DOING EUROPEAN SYNTHETIC BIOLOGY

This chapter is tasked with the exploration of the ways in which community in synthetic biology was made through the execution of epistemic labour. As such, it focuses on the two research projects funded as part of the long-term endeavour to use synthetic biology for the modify cyanobacteria to enhance the output of hydrogen gas. I address each project independently, with CyanoH2Modules being the object of section 6.1; and CyanoBioFoundry the object of section 6.2. In each project, I will trace community-building with particular emphasis on the building of a synthetic biology *repertoire (Leonelli & Ankeny, 2015)* as an analytic tool.

The chapter starts with section 6.1. Here, I introduce the CyanoH2Modules project and analyse the ways in which the project was imagined and structured with a view to devising/providing an exemplar of synthetic biology ways of working, with concomitant creation of artefacts on which to ground community and (to a varying degree) the creation of epistemic subjects. I further argue that the combination of these aims and the funding guidelines can be traced down to the outcomes / legacy of the project – the artefacts, the identities, the ways of working.

Section 6.2 revolves around the (FP7) funded CyanoBioFoundry project. It details the ways in which this project progressed along the synthetic biology imaginary set out in CyanoH2Modules, while navigating a focus shifted away from the development of synthetic biology and towards the production of materials with potential economic relevance. The section describes the ways in which the aim of (building and) doing synthetic biology required consistent negotiation against the (perceived) demands on the project by the funding body – negotiations made visible in the day-to-day working and key decisions during the project. This negotiation was not only important for the delivery of the project, but it also impacted on what synthetic biology became within the project – how it worked, who performed it and the range of artefacts produced.

Lastly, I bring the chapter to a close with a discussion as section 6.3. Here, I reflect on the ways in which the projects contributed towards community in synthetic biology by populating and sharpening the repertoire which grounds it. In particular, I note the creation of artefacts and the development of ways of working towards including their cyanobacterial organism in the expanding the range of organisms amenable to synthetic biology manipulation; and the enrolment (Callon, 1984) and concomitant creation of (mostly) weak identities as practitioners of (cyanobacterial) synthetic biology. However, I also remark that, despite even the apparent continuity in the projects as part of a long-term trajectory, there was considerable difference in the repertoires built in CyanoH2Modules and CyanoBioFoundry. I link the difference to two confounding factors: the shift in membership which moved the projects from being driven by the "committed engineers" community within synthetic biology to that of the "sceptical constructors"; and the changing demands placed on the projects by the funding environment, with the move towards FP7 having exacerbated the extent to which the European Commission (EC) exerted authority over the process and outcomes of research in the projects, through a mechanism of *governance by funding* (Gläser & Laudel, 2016).

6.1 A FIRST ITERATION OF WORKING TOGETHER: CYANOH2MODULES

CyanoH2Modules was a research project funded under the FP6 synthetic biology NEST Pathfinder initiative. It ran for three years, between 2007 and 2010 and involved 6 research groups based in institutions throughout (and arguably beyond) Europe. It is thus of little surprise this was a project explicitly centred around synthetic biology. This was a project that trod the line between suggesting the application of synthetic biology towards *useful purposes* and developing and building capacity in synthetic biology. This was, in some ways, a double mission; and in others a unitary aim. In how the project was framed, fulfilling the latter goal was, to a considerable extent, predicated on the successful completion of the former. More specifically, the project was framed around the production of hydrogen to serve as a fuel and synthetic biology.

The project was spearheaded and led by Hernando – a physicist turned synthetic biologist, who was a member of the "core set" (Collins, 1985) of researchers working towards the parts-based synthetic biology emerging out of MIT[42]. Only one other group leader was aligned with synthetic biology at the start of the project – Ignacio. The latter, also an engineer turned (proto) synthetic biologist, had been enrolled by Hernando. Alongside this commitment towards synthetic biology, sat three groups with expressed commitments towards the type of organism – the cyanobacteria. Olga and Oscar had long-standing research interests in the molecular biology of cyanobacteria, and hydrogen production; and Oliver's research interests had started moving to encompass the use of microorganisms (and cyanobacteria in particular) for the production of particular products. Lastly, there was a sixth group, which was focused on directed evolution / manipulation of genes via classical approaches[43]. Thus, at the start, the project encompassed researchers from broadly different epistemic communities, with minimal overlap. I now move on to the exploration of how these two words collided in the CyanoH2Modules project.

6.1.1 Constructing the organism, imagining synthetic biology

The organisation and narrative of the project were closely aligned with the imagination of synthetic biology embedded in the funding call. Reflecting the drive towards *useful purposes*, the researchers proposed to design modifications to a photosyn-

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[42] Hernando was deeply entangled with the development of parts-based synthetic biology, being one of the original participants of the international synthetic biology competition which would become iGEM (the focus of Chapter 8); and a co-leader of the synthetic biology theme of the EU-US Task Force on Biotechnology Research, which aimed to harmonise the development and goals of synthetic biology across both sides of the Atlantic.

[43] This group was peripheral to the project and is peripheral to the tale of synthetic biology in this chapter. As such, it will feature only sporadically over the course of the chapter.

thetic microorganism so as to increase the amount of hydrogen it produced when exposed to light[44]. The microorganism chosen to host the required modifications was a cyanobacteria – specifically, Synechocystis sp. PCC6803. This strain of the Synechocystis genus has been sequenced in the 1990s and its sequence is the most heavily annotated in the cyanobacterial world. The combination of the readily available genetic information and the relative simplicity of cyanobacterial organisms made Synechocystis sp. PCC6803 an excellent candidate for *modelling* – a key component of this synthetic biology imaginary. The choice of hydrogen as the product followed a similar logic. Hydrogen production has been a long-standing research topic. The metabolism of hydrogen within the cells is simple and peripheral to the general metabolism; and the resulting product is also the simplest a product can be. The combination of these features rendered hydrogen production an excellent candidate for what was a project meant as an "exemplar" (Kuhn, 2012 [1962]), but which was navigating uncharted waters.

Indeed, when CyanoH2Modules was designed in 2006, synthetic biology was still in the early stages of (epistemic) development. While the project was predicated on the use of "reusable, standardised molecular building blocks", most of these did not yet exist; and it was not overly clear what the modules would look like. This vacuum was one the researchers recognised and pledged to address by explicitly advancing the theoretical development of synthetic biology. The project was to contribute to "establish[ing] a systematic hierarchical engineering methodology (parts, devices and systems)" (CyanoH2Modules project description), emerging out of the work *in actu*. The allusion to the abstraction hierarchy, which is a defining characteristic of the engineering ethos of parts-based synthetic biology, is close to the point of paraphrase of the articulation of the MIT / iGEM "core set" (Collins, 1985). CyanoH2Modules was then a project firmly rooted in the fledgling parts-based synthetic biology imaginary, and a project which makes an explicit commitment to building

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[44] At no point did the researchers suggest they would deliver an organism capable of producing high(er) amounts of hydrogen, but this very material difference was craftily downplayed in the way the project was framed. This enabled the researchers to draw on the imaginaries of hydrogen futures while devoting their energy to an aim which was tangential.

(on) the synthetic biology repertoire (Leonelli & Ankeny, 2015) by developing this key *way of working*.

The CyanoH2Modules aim was further aligned with the parts-based synthetic biology (PBSB) imaginary in the schematic representations of the cell and the modifications planned. Such images were prominently displayed in project materials and were relied upon as visual metaphors of the application of the “systematic hierarchical engineering methodology” (Figure 9). In such representations, the biological complexity is downplayed and the metabolic cascades of interest in the project are displayed prominently. The majority of the cell metabolism is subsumed within a *system* within a total of four displayed. A *switch* in a diamond shape links the (gen-

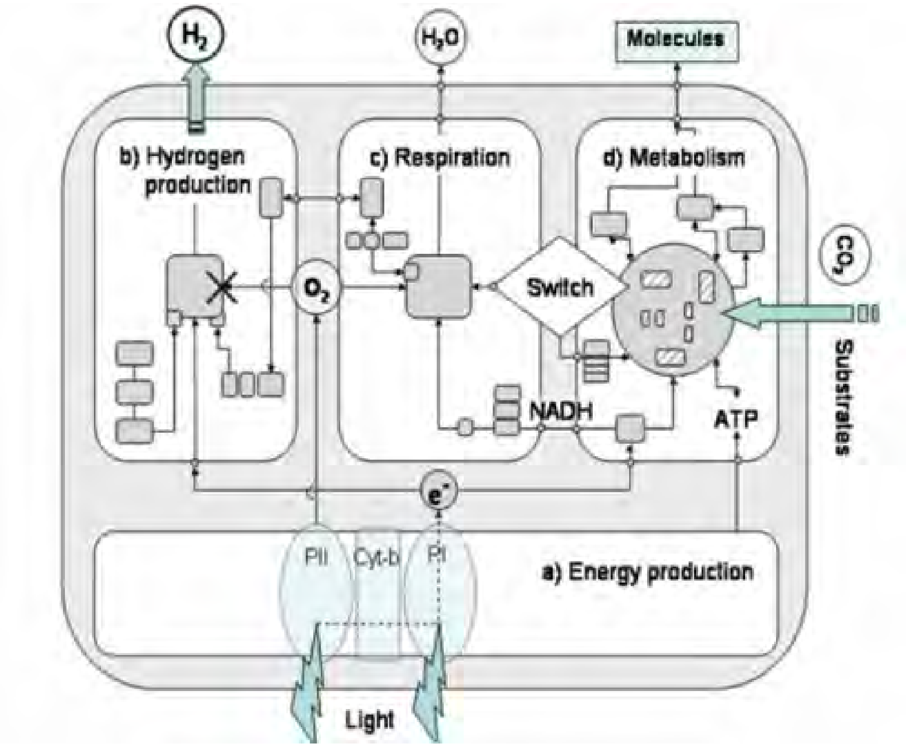

Figure 9: Schematic representation of the cyanobacterial cell in CyanoH2Modules. This representation is a hybrid between classical metabolic maps and circuit diagrams. The metabolism is presented in a simplified form, and conceptually separated into four systems (white rectangles); each system encompasses a number of parts and devices (grey rectangles), whose combined action delivers on the system function. Note, in particular, the diamond labelled switch - a staple of designed circuits, but absent from biological representations. (CyanoH2Modules project materials)

eral) metabolism and the respiration systems; this term and shape have no meaning in conventional metabolic maps (in such a system one would expect an array of metabolites and arrows), but they are commonplace in circuit diagrams. Furthermore, the (synthetic) circuits are displayed in a clear hierarchy of boxes of different sizes. These constitute a visual representation of the abstraction hierarchy of parts (smaller squares and rectangles), devices (larger gray squares and circle) and systems (white rectangles). Such representations are both emblematic of and common in PBSB, which further suggests a project which draws on the budding synthetic biology *repertoire*.

Successfully implementing the methodology proposed in CyanoH2Modules would result in moving a step further in the development of synthetic biology by building capacity. This was another core goal of the project, to be accomplished by assembling a *toolbox* – a hybrid of a repository and a catalogue of the modules of genetic material designed within the project. By packaging the genetic material (and the modified cellular host) in well-understood and controllable units, the purpose for which they had been initially created was no longer prescriptive. Instead, these were portions of DNA which could be used for any other application in the future. Thus, alongside building the synthetic biology repertoire by building its *ways of working*, CyanoH2Modules was imagined as contributing to the budding repertoire by creating *artefacts* to be shared across the nascent community. In the following section, I move from the broad imagination of the project to the ways synthetic biology was built through how the project was imagined to operate.

6.1.2 Building synthetic biology *in actu*

Figure 10 provides a bird's eye view of the organisation of the project, to serve as a starting point for unpicking the collaborations and themes in CyanoH2Modules. The six research groups which undertook the work are presented on the left, while the eight work packages which made up the project are presented on the right. Re-

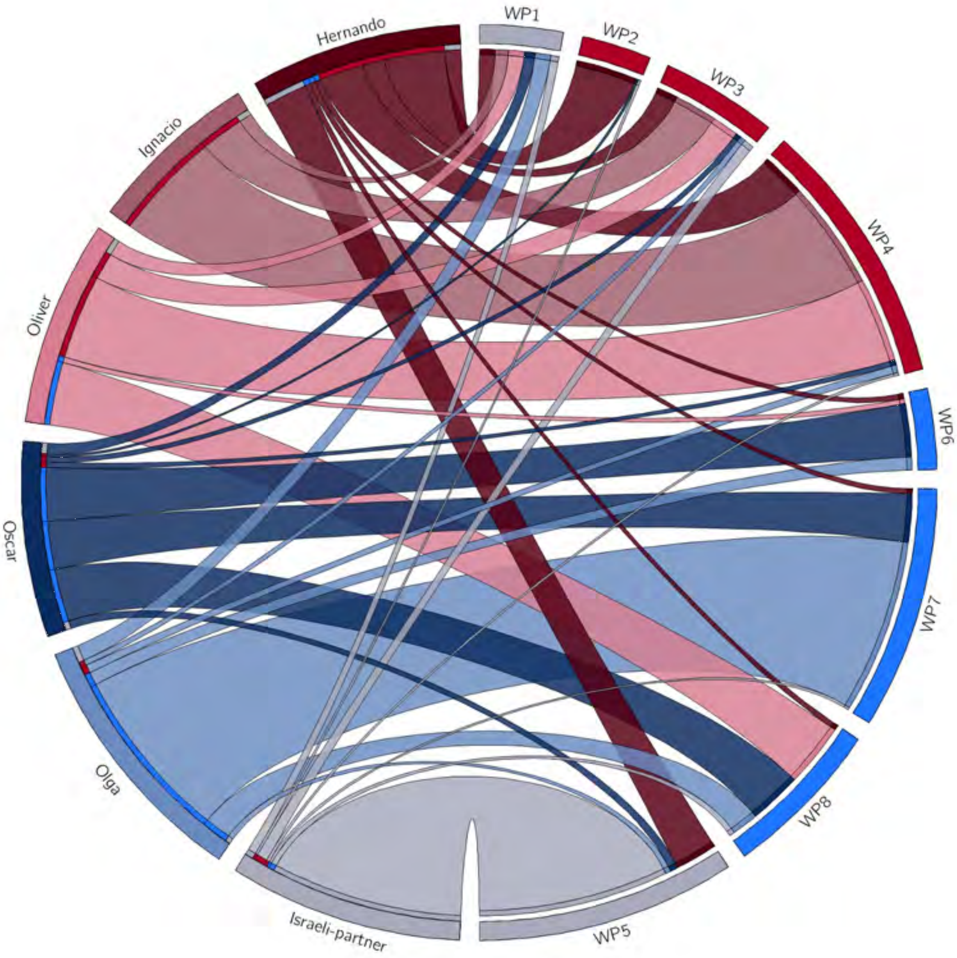

Figure 10: Visual depiction of collaborative links in the CyanoH2Modules project. Matching of research (on the left) to the work packages in the project (on the right). Research groups led by engineers, and work packages with an engineering focus are displayed in shades of red. Research groups led by biologists and focusing on the biology of the cyanobacteria are displayed in shades of blue. First work package addressed scoping / planning activities of the project and is presented neutrally. Width of bars proportional to the number of person-months allocated to each research group and work package.

search groups led by engineers, and work packages with an engineering focus (and ethos) are displayed in shades of red; research groups led by biologists and focusing on the biology of the cyanobacteria are displayed in shades of blue. The first work package is presented neutrally, for it addressed scoping / planning activities of the project, and thus muddled the biology – engineering boundary. Lines connecting a project member to a work package (WP) indicate formal participation in that work package. The width of connecting lines and nodes is proportional to the volume of work allocated (i.e. the thicker the bars / labels, the greater the number of hours). Visualised in this way, the project emerges as a highly collaborative enterprise, hinging on interdependence between biologists and between engineers; but also between biologists and engineers, in a complex web of links.

In the way that the project is presented, the cyanobacteria is a minor player. The focus is squarely on synthetic biology. The distribution of work in the project, however, paints a different picture. The volume of work dedicated to preparing the cyanobacterial system to *enable* the synthetic biology approach on which the project is predicated outshines the volume of work dedicated to *building* that synthetic biology approach. The responsibility of producing the material outputs relating to cyanobacteria also fell squarely on the three groups which had existing expertise with those organisms – those led by Olga, Oliver and Oscar. On the other hand, Olga and Oscar held few formal commitments to the theoretical development of synthetic biology. That task was emphatically to be spearheaded by Hernando and Ignacio, with Oliver also contributing with over half of the time his group was to dedicate to the project. Mirroring the ambitions expressed in the project goals, building synthetic biology was split into three work packages: one dedicated to engineered *parts*, another to engineered *devices*, and a third to engineered *systems*. Indeed, an engineering ethos was pervasive in this undertaking. The parts were to be *optimised* to fit devices; the devices were to be *rationally designed*[45]; and the systems to be the result of extensive

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[45] Rational design is jargon in (at least) chemical and biological engineering. It refers to a method of changing the structure of molecules – or building them altogether – to perform an intended function. It is often rooted on predictive methods, such as modelling.

modelling and *simulation*. Altogether an engineering approach, led by three (different types of) engineers. Once again, CyanoH2Modules proves to be an approach overwhelmingly guided by the PBSB imaginary.

Another key insight gained from such a visual representation is the extent to which the completion of work was predicated on a strong (and thus visually messy) pattern of collaboration between the project members. Each work package was designed around tasks which required input from multiple research groups. The outputs of work packages would feed into each other, both in the work specific to cyanobacteria, the work specific to synthetic biology, and across both. One example of this interdependence is the construction of a standardised hydrogen device specific for the Synechocystis sp. PCC6803 cyanobacteria. A device was to be designed out of a number of parts; the assembled device was then to be inserted into the cell; and its function characterised. The insights gained from this characterisation were then to be fed to the budding models; the models used for the basis of simulations; and as a result of the simulations a new part/device design suggested, which would kickstart a new iteration in the cycle[46]. Thus, while two main tasks compose the project, its imagined ways of working bring us full circle to an ideal type of parts-based synthetic biology.

Lastly, through examination of the practicalities of delivering on the project, two trends are foregrounded: the importance of collaboration for accomplishing (work in) synthetic biology; and the rise in prominence of the organism, which was somewhat subsumed under the overall aim of pushing synthetic biology forward. The first point provides yet another glimpse of the PBSB ethos in the project; while the second provides a glimpse into the relevance of dedicated expertise in the model organism for making synthetic biology work. As such, a synthetic biology epistemic community was emerging at a crossroads with an existing "model organism community" (Leonelli & Ankeny, 2012).

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[46] Such an iterative cycle would also be accompanied by an analogous one aiming to both increase the robustness and increase the efficiency of hydrogen production by making changes to the cellular *chassis*.

The imagination of working according to a synthetic biology approach differed considerably from the practice in the project[47]. In particular, the *in silico* methods which would serve as the linchpin for the iterative cycles of work struggled to perform the desired function. Nevertheless, organising and attempting to perform the project in such a way was also not without consequence. Its impact on research trajectories and (material) outputs warrants a modicum of scrutiny.

6.1.3 CyanoH2Modules' legacy

Two groups with non-overlapping commitments to research objects and cultures entered CyanoH2Modules, but over the course of the project that boundary grew fuzzy. The experimentalists adopted synthetic biology language (e.g. the cell became a *chassi*s) and practice (e.g. in the modularisation of the regulatory sequences). The dry lab groups gained insights into the biological complexity of Synechocystis sp. PCC6803 (e.g. the metabolic network of hydrogen production). As a result of working together, the research groups developed hybrid and partial expertise in the multiple components of molecular biology of cyanobacteria, solar fuels and/or synthetic biology.

Such hybridisation manifested differently across the career ladder. As noted in the previous section, the bulk of the groups' research efforts was directed towards work which did not constitute a major epistemic departure from previous and ongoing research. Thus, it is not surprising to note that (most) PIs did not display major changes in research interests; and changes to research approaches were subdued. Hernando and Ignacio remained part of what Schyfter & Calvert (2015) dubbed the community of "committed engineers" of synthetic biology. The experimentalists, however, moved towards the fold, and could arguably be placed under the community of "sceptical constructors" (ibid.). That is, they were acceptive and supportive

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[47] This is a common observation in STS work on synthetic biology; see O'Malley et al. (2008) for an argument of the role of *kludge* in making synthetic biology work.

of *a* synthetic biology, but did not imagine that synthetic biology as inherently driven by an engineering ethos.

Moving to the other end of the career ladder, there is the case of PhD students. Working together required considerable exchange – of data, materials and people. In most cases, those people were PhD students. This group was particularly susceptible to hybridisation / considerable enlargement of its epistemic arsenal. Indeed, this was by design – in another articulation of CyanoH2Modules as an epistemic project, the supervision of PhD students within the project was deliberately split between their home group and a PI with an explicitly dissimilar expertise. Their research projects sat across the realms of expertise of both supervisors. They spent month-long periods in the institution of their second supervisor (both completing PhD and project relevant work). In the end, the PhD students were budding experts in narrow features of both the *in vivo* and the *in silico* worlds. Thus, the project contributed towards a synthetic biology repertoire by cultivating new *identities* in the participants (albeit weakly), and through wholesale production of synthetic biology's epistemic subjects – epistemic subjects who would be "the next generation of synthetic biology engineers" (CyanoH2Modules project description); and who conformed to the ideal of "individual interdisciplinarity" (Calvert, 2010) associated with the PBSB imaginary (and the vision for EU synthetic biology circulated as part of NEST, referenced in Chapter 5).

The project also yielded a number of noteworthy (material) outputs. The combined work led to a more refined strategy for increased hydrogen production in cyanobacteria – and one whose success was predicated on synthetic biology. Some synthetic constructs were successfully designed for implementing that strategy, a portion of which were specific to the cyanobacterial host. The work also enabled the construction of a metabolic model of the Synechocystis sp. PCC6803 cyanobacterial strain, albeit a rough, early version. Lastly, dedicated work on the *chassis* yielded a number of Synechocystis sp. PCC6803 mutants, each which were more resistant to a different type of stress. Thus, the project made a clear contribution to synthetic biology repertoire through the creation of *artefacts* which supported the research approach.

In summary, CyanoH2Modules provided important contributions to building (community in) synthetic biology. It did so in three main ways: by advancing the theoretical agenda of synthetic biology; by expanding the range of practitioners, both by drawing in existing experts in allied fields and by training altogether new ones; and by expanding the range of available tools for practicing synthetic biology (despite having fallen short of providing a coherent *toolbox*) – in particular, by taking steps to enable the use of a synthetic biology approach with the Synechocystis sp. PCC6803 (model) organism. This project, however, was only the first one in (what can be) a long line of successors. In the following section, I outline the work and the hurdles associated with assembling a second iteration of work.

6.2 A SECOND ITERATION IN THE CYCLE: CYANOBIOFOUNDRY

After a successful funding application, CyanoBioFoundry jumped out of paper in late 2012. It ran for three years, until late 2015. This new project was made up by a total of 10 member institutions spread throughout Europe, who shared a total a budget of roughly 4 million euros. In this project, the work on the synthetic biology of cyanobacteria was to go beyond the creation of key modules, to the creation of multiple variations of the organism, all of which incorporated a different range of deliberate, systematic modifications. While suggested by the project materials, however, there was no promise to deliver a single organism which encompassed the full range of modifications. Alongside this aim, there was the foregrounding of the increase of hydrogen production, as well as the design and construction of the (photo)bioreactors where the organism was to be held.

In this section, I will explore how the different epistemic (and non-epistemic) commitments were negotiated in the project. I will start by noting how work was imagined in the project and where (and which) synthetic biology was located; then move to explore how the spectre of the funding body remained over the project, manifesting in the execution of planned work and, above all, in the changes to the project plan; and I finish by examining the outputs of the project, with an emphasis on the ways in which synthetic biology was built over the course of the project.

6.2.1 *Working together – imagining and building synthetic biology*

The project was split into 10 research work packages, with (roughly) each project member leading one. Nine of the work packages were split into three themes, with the last one extending across all themes, as depicted in Figure 11. The "chassis and parts framework" theme encompassed the work towards creating / improving the DNA *parts* and improving the cyanobacteria's ability to convert light and survive in the bioreactors. It was a theme which relied heavily on wet lab research. The "systems biology & 'omics" category (predictably) mostly revolved around computational approaches. Both work packages here relied heavily on *in silico* approaches to

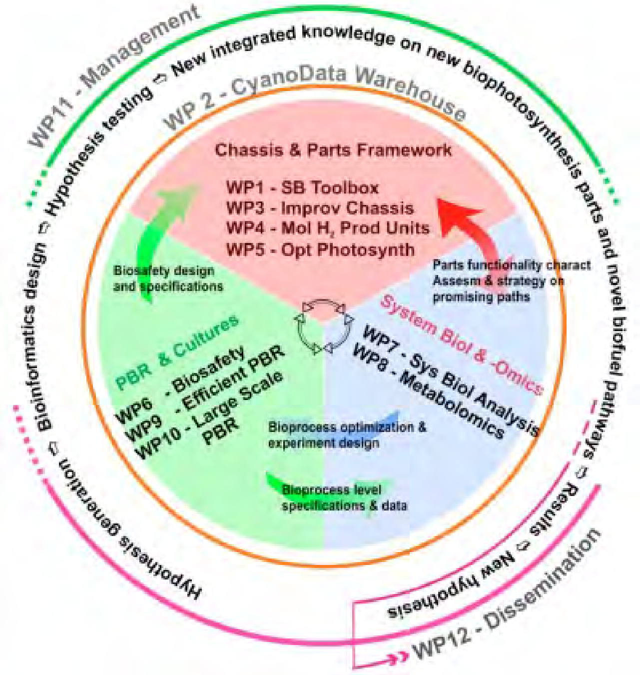

Figure 11: Schematic representation of the domains / links between work packages in the project. (CyanoBioFoundry project grant agreement)

understand and model the phenomena occurring within the cyanobacterial cells. The third category, "PBR & cultures" revolved around the scale-up of research. This included the development of the bioreactors where to place the cells and concomitant process engineering, and the development of strategies to ensure biosafety by preventing the cells from being able to survive outside the reactors. Lastly, WP2 is drawn as encircling all others, suggestive of a panoptic role within the project. Indeed, this work package dealt with the development of knowledge infrastructures which were imagined as an "obligatory passage point" (Callon, 1984) (OPP) in the consortium; the data would flow from the producers to the "data warehouse", where it could be retrieved by relevant consortium members.

While presenting the three categories as separate, the diagram also alludes to flows of data and materials across the three categories. This suggestion of mutual reliance is further compounded by the diagrammatic illustration of the division of labour provided in Figure 12. So, along flows of data and materials, there were flows of labour spanning the categories and the work packages within each category. As was the case in CyanoH2Modules, no work package was to be the responsibility of a sole research group. As such, collaboration was once again designed into the project. In stark difference to CyanoH2Modules, however, collaboration was not an end in itself; the project was constructed in a way that attempted to minimise the scope of collaboration. This can be seen by the organisation of the work packages around the contribution of the project members, whose time was to be mostly dedicated to a given work package, though all work packages encompassed (at least) minor contribution from various groups. This is arguably a reflection of the change of the steering of the project from a *committed engineer* to a group led by *sceptical constructors*; while seen as essential for the project, several of the researchers articulated that collaboration was taxing. Thus, the instances of collaboration were measured against the requirements for delivering the project, rather than the drive to follow / build the PBSB epistemic practice. This suggests once again the heterogeneity of the community(ies), as well as the epistemic pluralism of synthetic biology.

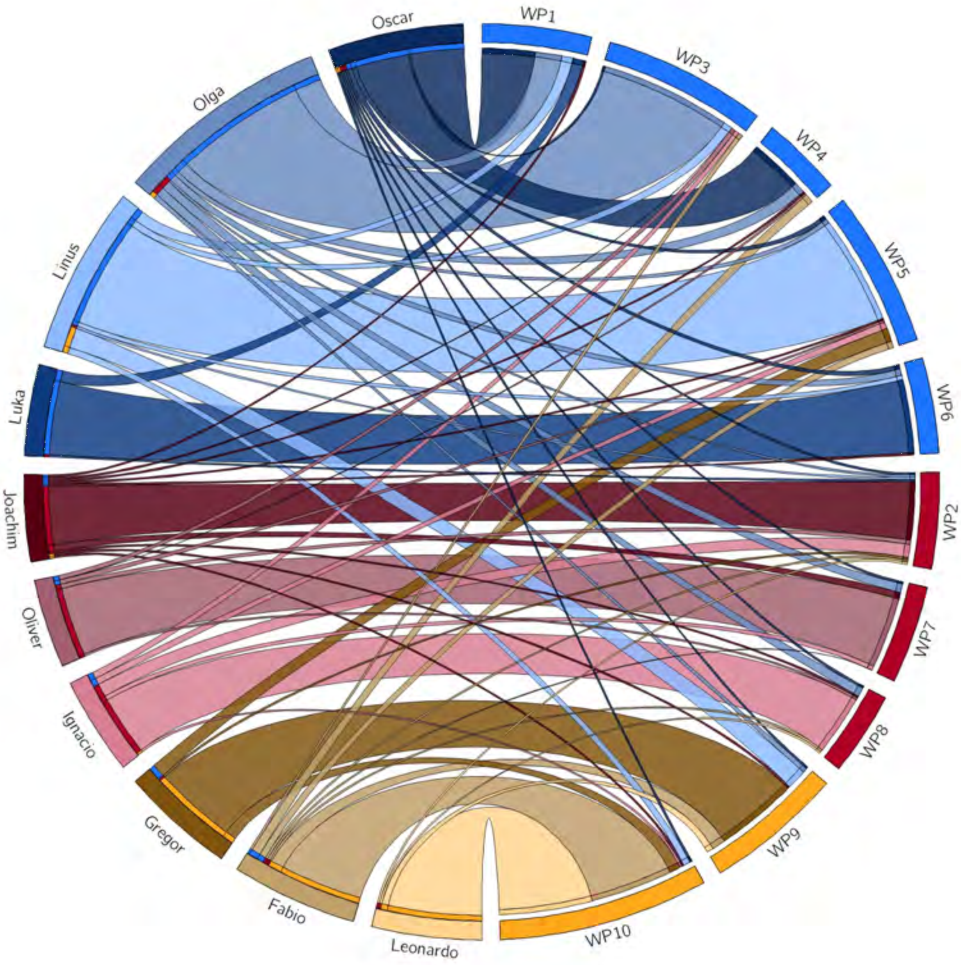

Figure 12: Visual depiction of collaborative links in the CyanoBioFoundry project. Matching of research (on the left) to the work packages in the project (on the right). Research groups and work packages with a dry lab focus are displayed in shades of red. Research groups and work packages focusing on the biology of the cyanobacteria are displayed in shades of blue. Research groups and work packages focusing on process and design of photobioreactors are displayed in shades of yellow. Width of bars proportional to the number of person-months allocated to each research group and work package.

Nevertheless, even under this imaginary for synthetic biology, not only were the work packages to be the product of collaboration, but there was also a clear pattern of interdependence between them. As the arrows in Figure 11 indicate, there flows were bidirectional. That is, accomplishing the tasks within a work package relied on insights provided by another work package; but the former would also contribute to the work in (the latter or a third) work package. In several cases, this interdependence was acknowledged in the division of labour for the work packages, as denoted by the contribution of several members for each work package in Figure 12. However, nowhere is the imagined interdependence within the project more stark than in Figure 13 – a diagram presented in the grant agreement to explain how work on the project has to be undertaken.

This framed the research endeavour as a repetition of cycles based on eight steps. It would start with the aid of *in silico* insights, with a computer-modelling driven generation of a hypothesis (1). Concomitant to this hypothesis was the suggestion of codon optimisation and of the experimental design for *in vitro* work. This would be followed by the synthesis of DNA parts specific to the cyanobacterial host which would enable the testing of the hypothesis (2). These parts would then be assembled in a vector – or other genetic vehicle – (3) and the end result inserted into the "cyanobacterial host chassis" (4). Towards enabling the growth of these cyanobacterial cultures, dedicated photobioreactors would be developed (5), where the cultures would be cultivated. The amount of hydrogen produced would then be quantified (6). The cells would then be subjected to different flavours of 'omics analysis (7). The results from these wide-reaching types of analysis would then be used to validate or reject hypothesis and perform "rational design of improved systems" (8). And the cycle would repeat (over and over) again with 1, with the generation of hypothesis based on newly identified possibilities for increasing hydrogen production.

A key insight that emerges from such a diagram is that, imagined in this way, CyanoBioFoundry fits a textbook definition of parts-based synthetic biology *ways of working*. It is an approach to research purported to be driven by hypothesis generated based on *in silico* models. One where the design and fabrication processes are decoupled. One where genetic material is framed not as a continuum (even if with different functional zones are recognised), but as amenable to be split into a number of well defined categories of modules. One where the modules are subjected to deli-

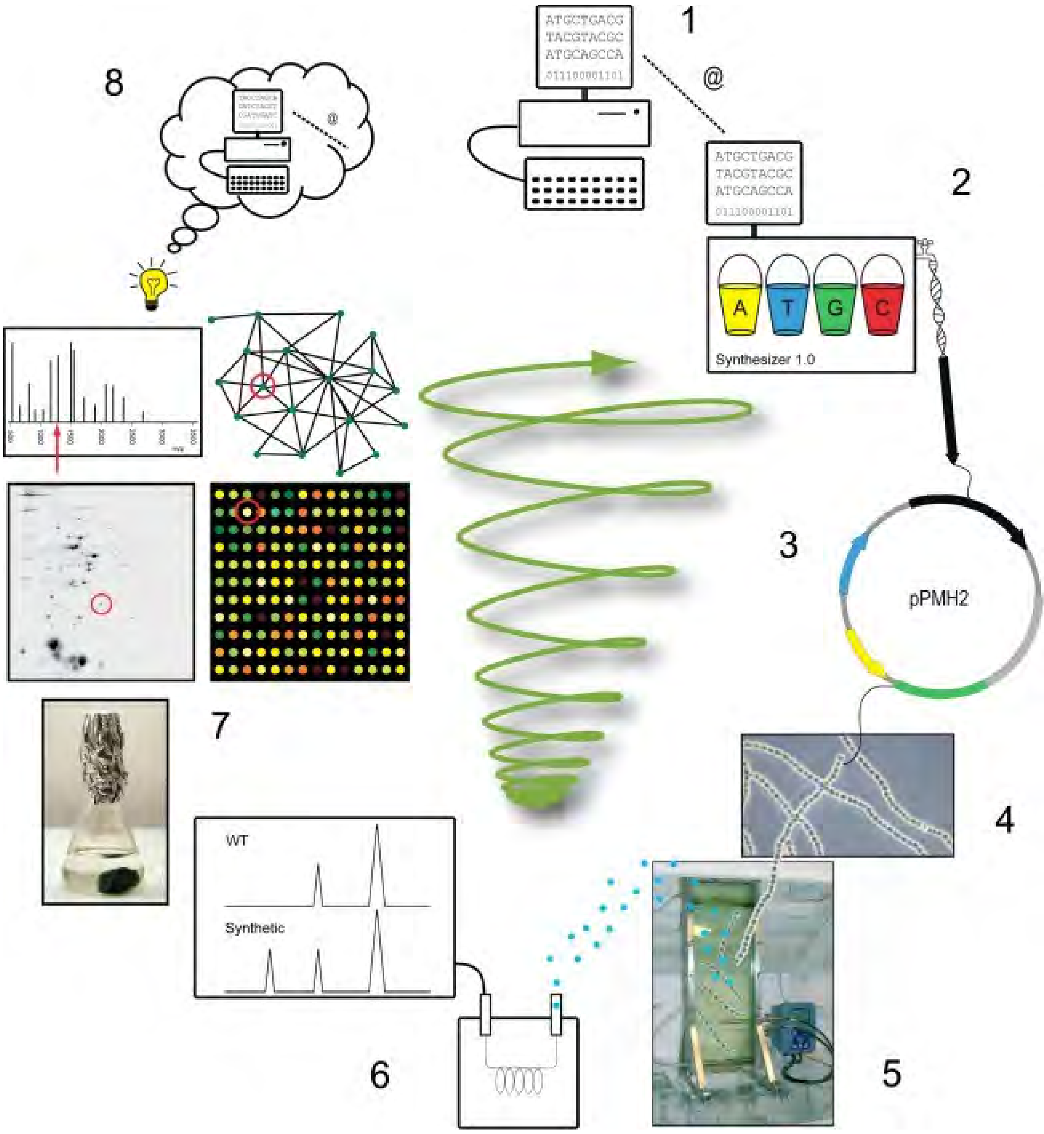

Figure 13: Diagram of the proposed epistemic practice under the project, framing epistemic labour as an iterative cycle of practices integrating modelling, wet lab work, bioreactor development and 'omics analysis (CyanoBioFroundry project grant agreement).

beberate and purposeful manipulation, both in terms of their genetic sequences and in their combinations within genetic constructs. One where the resulting genetic constructs are tested for their ability to perform the (useful) function for which they were intended and the results of such tests are used to feed the *in silico* models. And, lastly, one where this (iterative) cycle is repeated an indefinite number of times. Throughout this process, the biology is also subsumed under a language of engineering. Cells become *chassis*; the functional zones of genes become modular *parts*; and those *parts* were to be catalogued and assembled into a *toolbox*, which researchers could access to construct *devices* which performed a given function.

Yet even in this imagination of textbook synthetic biology it is useful to return to the impact of funding on the project. This is particularly visible in the placement in equal footing of the cultivation of the cells and the development of the bioreactors in number 5. This activity, considered at best peripheral by several partners, was embraced as part of what it meant to do synthetic biology in the project. In CyanoH2-Modules, the modelling efforts had been focused exclusively on the (intra) cellular level. In CyanoBioFoundry, the scope of modelling for Ignacio's group grew to include a model of light penetration and cell behaviour within the small-scale bioreactors. This meant that this became a new research line for Ignacio; a postdoc was now to manage/contribute to the development of that model, alongside the cellular one; and, most strikingly, a PhD student's work was to revolve solely around the creation of that model. In this way, a top-level decision of *accommodation* of the restrictions presented by funding led to the re-imagination of how synthetic biology was performed, with concomitant impact on the epistemic arsenal of a given research group; impact which was considerably greater at the bottom than at the top of the career ladder. I address this point in greater detail in the following section.

While such a conception of working together is far from complete (to the extent one group is entirely written out of it), some important themes shine through. Accomplishing the goals of CyanoBioFoundry is framed as predicated on the consortium working together as components of a well oiled machine. In this framing, research groups are highly interdependent on one another. E.g. refining the cellular model relies on the results from the ‘omics work; the ‘omics work relied on the existence of cells with *improved* machinery; some decisions on the strategies for how to *improve* the cellular machinery were guided by the cellular model. Thus, this interdependence draws from the existing synthetic biology repertoire, by drawing on its ways of working; and it builds the repertoire by expanding the *ways of working* through the inclusion of the development of the photobioreactors (PBRs).

6.2.2 Practising synthetic biology – interplay of (non-)epistemic criteria

Delivering on the promises set out in the grant agreement was, as noted in the previous section, predicated on the collaborative ways of work which enabled the multiple, interdependent parts of the project to be successfully accomplished. This meant there were constant flows of data, materials and people throughout the project. In this section, I provide an overview of those flows and a number of vignettes to illustrate the ways in which such flows serve as a marker of interdependence, as well a brief allusion to how funding continued to impact on the trajectory of the project *in actu*.

The exchanges which were to be key for the project started even before the project formally began. The epistemic drive for standardisation (another defining mark of PBSB) led to the dissemination of a specific strain (and stock) of the cyanobacteria from a freezer in Oscar's laboratory to all the academic groups in the project (the companies [SMEs] accessed the biological material through their closely linked academic partners). Once the project began, so did the data flows. For example, Olga's group shared experimental results with relevance to the development of the small scale PBR with Gregor's group; all four wet lab groups started a coordinated programme of work towards improving the introduction of genetic *circuits*, which required sharing experimental plans and outcomes; Oliver's group ran proteomics assays, which were distributed across the consortium and mostly taken up by Ignacio's group, for the refinement of the cellular model. These early examples of data flows only grew – particularly as the exchanges of materials and people also ramped up.

The movement of materials was also a key feature of working together. These took many forms, from bringing agar plates to a project meeting so that a group had access to a particular mutant; to mailing (freeze) dried cells to Oscar's group to run experiments on; to driving prototype PBRs for testing; to bringing live cells in tubes on ice over (a cross-border) train. Data and material flows were essential for the iterative epistemic practice imagined (and depicted in Figure 13). A useful PBR (and concomitant process) could not be designed without insight into how (well) cells survived to different types of stress; the ‘omics experiments could not be accomplished without the (modified) cells grown by the wet lab group; nor could the model be meaningfully refined without the broad picture of what was taking place within the cells from ‘omics and dedicated wet lab experiments. Thus, these exchanges were also essential for *performing* synthetic biology.

A last type of flow which was also a core component of the epistemic practice of the consortium is that of people. Working together required constant articulation work (Fujimura, 1987). On the one hand, this meant the (physical) convergence of researchers in formal meetings, organised at 6 month intervals and virtual gatherings through videoconferencing software. Such meetings were useful formal monitoring points, but they were much more than that. They were also sites where epistemic cultures were made visible and often collided, with outcomes which influenced the trajectory of the work; where shared problems were articulated and troubleshooting (or at least a plan for subsequent troubleshooting) took place; and, in particular, sites where personal commitments were developed towards other researchers. As Bran remarked:

> “You have to go to these places to make lasting connections. Somebody sent me […] I never met this person in real life. They were just a person I sent a couple of emails to and then, eventually, received a hard drive in the post from. And the data was interesting, but I never physically met the person. And as a result of that, then...you know, I didn't care that much that I was letting them down in some ways. I couldn't see the face.” (Bran interview, 17th November 2015)

Thus, at a time where there were multiple tasks competing for Bran’s time, this instance of collaboration fell through the cracks because he had not developed commitments towards that person. Indeed, the value of a personal connection in the success of collaborative epistemic labour was a strikingly prevalent theme in interviews, suggesting these instances provided important focal points in the conduct of the work – and, by extension, in the building of synthetic biology.

On the other hand, the flows of people also took the form of bi and multi-lateral physical exchanges and video calls, spanning different periods (from a few days to multiple months). Unlike the previous meetings, these instances were organised around a specific task or a specific goal. For example, Oliver and Oscar's groups coordinated work over the creation/analysis of strains producing hydrogen in biweekly or monthly videoconference meetings spanning a period of months; Joachim and Ignacio's groups had weekly videoconference meetings over most of the project, to align work on the mathematical model, computational interface and data formats. However, not all problems/tasks were amenable to being handled at a distance, which called for physical exchanges. These were, once again, guided by a specific task or goal, and were programmed / prepared months in advance. Unlike the videoconference model of collaboration, the physical exchanges were driven by the absence of expertise to perform a given task; as such, they were used to acquire expertise (often "tacit knowledge" (Collins, 1974)) in a given domain, or to use a researcher's epistemic arsenal to complement a given task elsewhere. These exchanges were also performed exclusively by junior researchers – mostly PhD students.

Such exchanges were framed as not essential for subsets of the project, but desirable nonetheless. The most salient example is likely to be the multiple exchanges of Natalia and Henrik, who spent several multi-week periods working embedded in Joachim and Ignacio's group, respectively. This co-presence enabled the researchers to showcase their work in depth to the group for whom it was most relevant, and these periods were key moments where decisions of the design of the computational interface and the model were taken.

The exchange of junior members is also a key site where the non-epistemic criteria took a prominent role in the decision-making process. Chief among those was funding, which impacted on exchanges in weak and strong ways. An example of impact in a weak way is the exchange which led Natalia and Henrik to spend a 2-week period with Oliver's group. The idea for this exchange was born out of interaction between the three PhD students (including Bran). However, from the point of view of the project outcomes, some of the PIs expressed doubts that this would be a fruitful exchange, which created a deadlock. The deadlock was broken only by one of those PIs putting forth the argument that there was value in the exchange on the basis that it was an activity which would curry favour with the EC. So, this was an exchange which (ostensibly) took place due to the performative nature of expectations (Brown & Michael, 2003).

An example of impact in a strong way is linked to an exchange which stemmed from the need to run a given experiment, the outcome of which had been proposed as a deliverable[48]. As work on the project progressed and differed from the expectations at the start, it became clear there was little value in conducting an experiment led by Oliver's group and a different experiment was proposed. However, since the outcome of this experiment was a key component of a project deliverable, any deviation from the plan would require the EC's consent. That consent, however, was not forthcoming, which led to another instance of "accommodation" (Fowler, Lindahl, & Sköld, 2015): the original experiment was run, but with an extended version (designed in collaboration with Natalia) which could be of some (epistemic) value (thus, alongside the (partial) accommodation, there was also resistance (ibid.)). This meant that Bran still travelled to Linus' group (where the revised experiment was run), where he spent a full month – becoming familiar with the experimental apparatus and waiting for the cells to grow, besides conducting the experiment.

In both cases, the actions detailed were not justified on epistemic criteria (alone). However, in both cases, there was also a clear epistemic upside for the students. The benefit was similar to Natalia and Henrik, the latter of whom noted:

> "[I] got mass spectrometry data already, half a year ago, at least, from [Oliver's group]. But until now I had no real idea how to interpret this data. So...this was now the idea of this meeting here. To get the hang of the data. Because, when I don't at least understand a bit what the purpose of the data is, I can also not integrate it in any useful way. [...] practically, I don't need to know this, but I think it is very useful to get a glance at the experiments, because...that you not only get this: here, these are some raw numbers with peaks. Yeah, good luck. But then you can also know how that was obtained. So, why was it done." (Henrik interview, 18th December 2014)

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[48] In the project (and in the EC's funding programmes more generally), deliverables are formal outputs from the project.

From a personal, epistemic, point of view, the visit was a resounding success for these junior researchers. Taking Henrik's example, his immersion in the work from Oliver's group nudged the PhD student in the direction of developing "interactional expertise" (Collins & Evans, 2009) in the types of 'omics work undertaken in the group. This, in turn, enabled the researcher to increase the scope of his "contributory expertise" (ibid.) in a direction that bridged his existing computational expertise with the 'omics work he was exposed to. Similarly, Bran's period of exchange was fruitful at a personal (if not so much as the project) level. He placed the key benefit to his expertise as deriving from going to the sites where

> "you learn the skills as if that was the main thing. [...] Everything they do they'll probably scale up and they'll either go onto like...light harvesting machinery, and do the technical stuff. Or they'll go into the bioreactors. Because that was their expertise. [...] Seeing people with the well established knowledge, probably helped with the: this is a new thing, but I have seen the way that is different, fundamentally. There...and here. So I can see the parts I can wiggle around, because I can see which bits change when you go different places." (Bran interview, 17th November 2015)

In Bran's case, it is noteworthy that his existing (personal) repertoire overlapped with the domain of expertise of Linus' group (unlike the case with Henrik). Here, he places the value of the co-presence in his ability to draw on the long-standing expertise of the host group. This embeddedness (along with the duration of the exchange) enabled the PhD student to develop to a meaningful understanding of the group's key areas of work, to the point where he felt confident he understood the work at such a fundamental level he was able to deconstruct it. Thus, the exchange mostly paid off in the development of contributory expertise.

These two brief vignettes provide poignant articulations of the high degree of interdependence in the project and the actors on whose shoulders the instances of collaboration ultimately fell. Indeed, if it was the case that collaboration was agreed at the PI level in all cases (regardless of the drive being epistemic or not), the standing hierarchy of labour in research meant that the execution of agreed work was taken up by (PhD) students or, in a minority of cases, postdocs. This led to different engagement with the practice of (the components of) synthetic biology along the career ladder and, consequently, to the stacking of epistemic hybridity to researchers at the lower rungs of the career ladder. This pattern of segregation along career progression mirrors the generational gap Bartlett, Lewis, & Williams (2016) have identified for bioinformatics.

Furthermore, in this section I argued that the interdependence and collaboration which characterised the imagination of CyanoBioFoundry led to a project heavily reliant on the flow of data, materials and people. I note that the two former were key for the practice of working together, and that the latter was key in ensuring working together was practised. Lastly, funding emerges again as a relevant theme for work *in actu*. It does so through a combination of the performative character of expectations and through the exertion of authority, resulting in both cases in the overriding epistemic criteria as the basis for the decisions over epistemic labour.

6.2.3 Project outcomes

Similarly to what has been described for other synthetic biology projects, the execution of the project fell short of its imagination; *kludge* (O'Malley et al., 2008)[49] continued to be a defining feature of doing synthetic biology. Nevertheless, it is undeniable that the project produced a range of outcomes which advanced the researchers' original agenda of hydrogen production while both performing and building synthetic biology. In this section, I provide a bird's-eye view of artefacts and ways of working built, as well as the development of commitments to synthetic biology (and the temporary assemblage where it was performed); and I trace the impact of funding criteria on the outcomes of the project.

The most conspicuous outcome of the work conducted as part of the project stands in the form of the artefacts produced. These span (and go beyond) the differ-

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[49] Regrettably, a discussion of the ways in which the project depended on kludge must be omitted due to space limitations. I will note, however briefly, that kludge was a defining feature of the work of / reliant on the creation of the data warehouse and the mathematical models, as well as the creation of genetically stable cyanobacterial mutants.

ent domains of expertise within synthetic biology. These address some of the fundamental biological, computational and infrastructural components which can enable further researchers to conduct synthetic biology *of cyanobacteria*. They include a modified, stripped down version of the cyanobacteria with improved efficiency in hydrogen production; the many individual components which were modified to construct this organism and further ranges of genetic material in the form of of a *toolbox* of *parts*; the genetic code for a biosecurity measure, developed with scaling up in mind; a refined mathematical model of the cellular metabolism, as well as a novel model of light diffusion inside the bioreactors where the cells would be grown; those very bioreactors, in sizes ranging from the lab-friendly to (designs for) industrial production units; or a repository for the data produced as part of the project, which was made public.

Alongside artefacts such as these, the project also contributed with novel ways of working in synthetic biology, with an emphasis on the synthetic biology of cyanobacteria. From the range of contributions, the solution of a notorious (and widely recognised) issue with genetic stability through the development of a strategy of "bicistronic design" for promoters is particularly noteworthy. It is, however, by no means the sole important contribution; there was also the development of promoters specific for cyanobacteria, to eliminate the intractable pitfalls with the use of E. coli promoters with the organism; the design and creation of PBRs specific for use in cyanobacterial research, for which a standard was missing; and the assembly of a central data repository for creation of the PBR/cell models, which was also novel. Through contributions to these two categories, the project made very clear contributions to building synthetic biology by building its *repertoire* (Leonelli & Ankeny, 2015).

Another key dimension of relevance for exploring project outcomes is that of the development of epistemic subjects. With the exclusion of the SMEs and Fabio's group, there was a clear trend towards the development of / strengthening commitments towards synthetic biology. The development of such commitments can be illustrated by the change in Linus' stance, who had little regard towards synthetic biology before the start of the project, but came to see the use of synthetic biology as "very important, because this is the only way to make progress with these systems" (Linus interview, 10th December 2014). Despite this framing, the project appeared to drive little, if any, meaningful change to the researchers' identities – similarly to what Bensaude-Vincent (2016) has identified, the researchers appeared still grounded in their referent disciplines, though they recognised synthetic biology as something they *practised*. What *practising* synthetic biology entailed, however, looked different across the career ladder.

As noted in the previous section, there was an increasing distance to the epistemic demands of working together as one moved further away from the coalface. Thus, and even though they displayed varying commitments towards synthetic biology, PhD students (and postdocs involved in the day to day work) grew towards its epistemic subjects. Through the practice of collaboration with groups which were epistemically distant on which the project was predicated, these researchers developed expertise in a way which was tantamount to the internalisation of interdisciplinarity – a phenomenon which Calvert (2010) has labelled the development of individual interdisciplinarity. These were, then, epistemic subjects which fit the model of the "new breed of researchers" (NEST High-Level Expert Group, 2005) which was deemed as needed for sustaining synthetic biology in the EU.

Further EU imaginaries can also be traced to the outcomes of the project. As noted in section 5.2, the inclusion of SMEs and concomitant development of PBRs was deemed by most researchers as beyond the scope of a synthetic biology project. Yet, the inclusion of this work in the imagination for the operation of CyanoBioFoundry led to the development of a synthetic biology which integrated the design and process engineering tasks into its imaginary of (synthetic biology) practice. As such, a key outcome of the project was an enlargement of the ways of working within the synthetic biology repertoire mediated by the funding pressure. Funding pressures – through the exertion of authority of via expectations – also steered the project in the direction of more collaboration with the intent (and/or consequence) of enlarging the epistemic arsenal of (junior) researchers. Thus, from a community(-making) point of view, the project provided important outcomes in the form of building (European) synthetic biology through the making of its repertoire and apt epistemic subjects, and doing so in a trajectory set out by the interplay of epistemic criteria and funding pressures.

6.3 CONCLUSION

Looking to reflect on the making of a synthetic biology epistemic community, I will first look to what grounds community – its *repertoire* (Leonelli & Ankeny, 2015). CyanoH2Modules was, in itself, an explicit attempt to build this synthetic biology repertoire. This was an effort which yielded a plethora of artefacts that enable work in synthetic biology (of cyanobacteria). In all cases, the artefacts still required considerable work, and were refined as part of the subsequent CyanoBioFoundry project. While these artefacts are, arguably, still a work in progress, their absence negates the possibility of applying synthetic biology ways of working to the Synechocystis sp. PCC6803 cyanobacteria. Thus, the creation of such artefacts is a key step in creating community – as the latter will rely on the former in its epistemic endeavours.

The artefacts produced as part of the projects are also closely intertwined with the *ways of working* which were adopted and developed as part of the two projects. Since these projects provide two steps in what was imagined as a long road towards cyanobacterial biohydrogen production driven by synthetic biology, the overlap and coherence between the ways of working in the CyanoH2Modules and CyanoBioFoundry is expected. In both cases, the projects were predicated on big, collaborative ways of working, with interdependence between participants who covered a range of expertise from wet lab biology, to *in silico* approaches and (varying guises) of engineering. Both projects were also characterised by synthetic biology's what Schyfter (2013) dubbed a "drive to make" (albeit different artefacts.). As such, both projects drew on the ways of working which have come to characterise the synthetic biology repertoire.

However, the projects also contributed to the epistemic development of synthetic biology. They did so with particular emphasis on the extension of the existing ways of working to research based on the Synechocystis sp. PCC6803 cyanobacteria – the model organism chosen. This was far from trivial; since most synthetic biology tools were predicated on the use of E. coli, extending to the cyanobacteria was tantamount to building a specific *synthetic biology of cyanobacteria* – leveraged through the E. coli canon, but for which the canon fell short. As such, it required the creation of specific parts, devices and systems, alongside the re-imagination of what these abstractions looked like in the case of cyanobacteria. Thus, these projects drew upon the existing synthetic biology repertoire as a basis for work, and built upon those resources through the population of the repertoire with new artefacts and ways of working. In this way, CyanoH2Modules and CyanoBioFoundry built community in synthetic biology by building (on) its repertoire.

Despite the considerable overlap between the projects, it is nonetheless noteworthy that there were also differences in their *ways of working*. In the case of CyanoH2Modules, it shines through that *building* synthetic biology was a goal in itself: e.g., the work packages were organised around the contribution to the development of the field; and the supervision of PhD students was deliberately shared between PIs with different expertise. In this way, the participating groups in general, and the PhD students in particular, were forced to engage with the different domains of synthetic biology in a meaningful way. In contrast, in CyanoBioFoundry, the focus was on building synthetic biology *towards* a particular goal. Collaboration and interdependence were valued and accepted, but not reified; junior researchers were exposed to the different domains of expertise where required, not as a general rule. While some of these differences can be attributed to the changing demands by the funding body, to attribute full explanatory power to funding would negate the different ethos of the project leaders. CyanoH2Modules was led by Hernando – a prominent European "committed engineer", as per Schyfter & Calvert's (2015) classification. By contrast, CyanoBioFoundry was spearheaded by a group of mostly "sceptical constructors" (ibid.). The different ethos of the leadership of the projects (concomitant to belonging to different communities within synthetic biology) contributed to the development of synthetic biology along closely related, but different trajectories.

Another key dimension of community-making relates to the creation of its epistemic subjects. In this chapter, I have described how that happens, in both weak and strong ways. Weakly aligned epistemic subjects are those aligned with the ethos of parts-based synthetic biology, but who kept "grounded in their referent disciplines" (Bensaude-Vincent, 2016). These individuals conserve their disciplinary identities, though they also support synthetic biology ways of working. For them, the work is to be interdisciplinary. On the other hand, strongly aligned epistemic subjects are those with an epistemic arsenal which extends across in vivo – in silico – omics divides. These are individuals which internalise expertise from different domains, and are thus characterised by what Calvert (2010) dubbed *individual* interdisciplinarity. The latter are framed by proponents of the field (from the academic and the policy arenas) as having the desirable epistemic breadth necessary for synthetic biology in the long-term.

In the case of the two projects, the different types of epistemic subjects were distributed along a pattern across the career ladder. The most senior researchers (if not already aligned) only became weakly aligned epistemic subjects, while the strongest alignment was visible in the case of the most junior researchers. Bartlett, Lewis, & Williams (2016) have described a similar pattern of engagement in the case of bioinformatics, where they framed the difference in stance as stemming from a generational divide. Indeed, a generational divide is likely at play in this case, due to the distribution of labour. While in both projects there was a strong drive for collaborative enterprise, work at the front-line was mostly accomplished by junior researchers. In this way, the drive towards the enlargement of the researchers' epistemic arsenal (and the development of individual interdisciplinarity) was mostly felt by the junior researchers. As such, work in the projects built community in synthetic biology by creating its epistemic subjects – from subjects amenable to / supportive of the epistemic enterprise to those with the epistemic arsenal to make that enterprise come to fruition.

Having explored the trajectory of the practices, artefacts and identities which underpinned synthetic biology in these projects, in the following chapter I turn my attention to them again, but with a different focus. In Chapter 7, I address the ways in which the imagination and trajectory of the projects (and, consequently, the trajectory of EU synthetic biology as practices within them) was intertwined with issues of governance, with particular salience to issues of funding.

7 IMAGINING (AND ORGANISING) EUROPEAN SYNTHETIC BIOLOGY

With this chapter, I bring to a close my exploration of the making of European synthetic biology. This chapter is closely related to Chapter 6. Nevertheless, if the former explored the aesthetic of community and the process of community-making within the projects themselves, this chapter brings a different analytic focus. The spotlight is still on the string of projects which anchored the aim to modify cyanobacteria through synthetic biology for the production of hydrogen; however, Chapter 7 is concerned with the imagination and preparation of future work which took place in the periods between the projects and even in parallel with their execution. Here, the focus is on the processes through which (the need for) community is articulated and bonds cultivated; and the multiple and overlapping roles funding played in the imagination and the organisation of future work – which may or may not have come to fruition.

The chapter is organised around two moments where the role of funding is particularly salient: the period after the end of the CyanoH2Modules project, where a new grant proposal for what would become the CyanoBioFoundry was negotiated; and the preparations that took place within the CyanoBioFoundry project in an attempt to ensure the research programme would endure. Thus, section 7.1 addresses the period after CyanoH2Modules had ended and before CyanoBioFoundry began. In particular, it provides an account of the challenge that the higher degree of control over the content of research exerted by the funding body posed to continuing the research avenue; and the process of packaging research in a way that was amenable to receive funding under the EU research programmes. Through these accounts, it foregrounds the importance of the combination of imaginaries of EU research and practical funding constraints, and the way these constrained the potential trajectory of (this iteration of) synthetic biology.

Section 7.2 outlines the many ways in which the future was already being prepared during the course of the CyanoBioFoundry project. Here, I describe how the temporality of the project and the high degree of dependence on external funding prompted the researchers to continuously explore ways in which to support the next iteration of this long-term research avenue. I provide an account of how a breakup of the existing group was framed as inevitable because of funding constraints – constraints which subordinated the continuation of this research line (and concomitant development of synthetic biology) to the existence and amount of relevant calls for funding. I show that the group looked in when deciding on where to move next, but the new proposals invariably encompass the inclusion of new members. I then describe how the search for new members was integrated into CyanoBioFoundry through the running of events with hand-picked participants where the need for community in the synthetic biology of cyanobacteria was made explicit; and I note the cultivation of a relationship with one of the participants with a view to creating a new, common project – a relationship which was explicitly propelled by the perceived availability of funding.

Lastly, section 7.3 provides a discussion of the themes identified in 7.1 and 7.2. From the point of view of process, I argue community-making took place through the combination of *movement* and (the creation of) *stickiness*, which were induced by and crystallised in what Molyneux-Hodgson & Meyer (2009) dubbed *community-making devices*. Different visions for Europe and synthetic biology, however, led to competing pressures as to where to move towards and what / whom to stick to. I note the forcefulness of particular visions for Europe(an research), institutionalised as a process of *governance by funding*; and the mobilising role of less institutionalised *expectations* made demands on the synthetic biology to be practised. These demands were addressed through overlapping processes of resistance and accommodation – but which invariably impacted on what was a *do-able* synthetic biology project and, consequently, on the possible repertoire and concomitant trajectory of synthetic biology.

In sum, this chapter outlines a multivalent process of walking the tightrope of feeding off and into a (stabilising) parts based imaginary of synthetic biology, and an imaginary of what was desirable and/or permissible under the umbrella of European research. I will now start the exploration of these themes, with an examination of the period between CyanoH2Modules and CyanoBioFoundry in section 7.1.

7.1 IMAGINING AND PREPARING A SUCCESSOR TO CYANOH2MODULES

While the researchers were conscious that the work pushed forward in CyanoH2Modules was far from complete, the project finished without moves towards a successor. After its conclusion, Ignacio, Olga, Oliver and Oscar came together to discuss the possibility of reassembling a consortium to carry out a new (and explicitly not final) iteration of the work. The group agreed to work together once more, and extended the same invitation to the two remaining PIs. Both declined. The refusal of the Israeli partner was expected and little mourned – the distance between them was not just geographic, but epistemic too. The absence of the former consortium leader – Hernando – however, was somewhat puzzling. Some of the PIs continued publishing (synthetic biology papers) with the latter, although that had slowed down to a trickle as CyanoBioFoundry finished. The PIs also spoke of Hernando fondly, noting encounters at synthetic biology (relevant) events. Yet, when mulling over why Hernando was absent from CyanoBioFondry, a surprising boundary presented itself. This was most acutely articulated in a casual conversation I had with a senior PI during a project meeting; in their interpretation, Hernando was still doing synthetic biology, but a completely different synthetic biology. The researcher went further to frame the distance from the two different synthetic biologies by drawing on differences on the approach to research, and also on differences on the organism on which that research was conducted. In this way, the PI performed *boundary work* (Gieryn,

1983) between *their* synthetic biology and *Hernando's* synthetic biology. This erection of boundaries within synthetic biology echoes the assertion by Schyfter & Calvert (2015) that synthetic biology remains a loose community, where *epistemic pluralism* (Chang, 2012) is a defining feature[50].

Four PIs then remained aligned with the research programme started with CyanoH2Modules. These four PIs constituted a kernel around which a new project was assembled. This was to be, once again, a collaborative, European project. By then, however, the FP6 had concluded, which meant that so had the NEST synthetic biology pathfinder programme. A new project was to be organised and funded under the EU's new framework programme – FP7. However, as noted in Chapter 4, the NEST programme had been discontinued in FP7 and no other programme put in place to support the development of synthetic biology; and demands on research in FP7 had changed to emphasise research which addressed *societal problems*. As such, what was a *do-able* (Fujimura, 1987) synthetic biology project also changed. In this section, I chart the ways in which the researchers navigated this landscape, with a particular emphasis on how the expectations (or explicit requirements) associated with the funding programmes can be traced in the resulting project (proposal).

7.1.1 New project, new opportunities and new constraints

Moving towards a new project offered the possibility for the researchers to address some of the shortcomings they identified in CyanoH2Modules. Chief among these was the low number of groups with wet lab expertise. Unsurprisingly, the decision to include another such group was one made early in the project planning. This re-imagining of the practice of synthetic biology with the increase in prominence of wet lab

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[50] There is one point of caution to be made, however, in that one is at peril of reifying the boundaries of these communities by locating in them full explanatory power of the divergence between the researchers. To do so is to obscure the importance of the objects of research which, as I argued was the case in CyanoH2Modules and will argue is the case in CyanoBioFoundry, play an important role in the making of community.

biology was the sole key decision made on epistemic criteria alone. The decisions that followed were forced to contend with considerations on funding.

The group then started the process of exploring the potential range of funding calls which would enable them to "do more and continue what [they] were doing in the FP6 project" (Olga interview, 28th November 2013, translated). At this stage, however, the potential ideas for new projects were as vague as the quote suggests; the firm commitment was to continue work started in CyanoH2Modules. With this kernel in place, the following step was to find funding calls which would enable this idea to come to fruition. The researchers were acutely aware that work in FP7 was subject to a higher degree of thematic and epistemic control by the EC. This manifested in both the framing of the work as solutions to problems the EC had identified; and in the importance of matching the requirements put forth by the funding call. Thus, assembling a new project was nothing short of a balancing act – one which satisfied the researchers' interests (of both the core group and those of as yet unidentified additions) and the EC's stated needs, while also being of an appropriate size, cost and feasible in the available time-frame.

The range of funding calls available to the researchers was considerably different to those of FP6, as I note in Chapter 5. The absence of a successor to the NEST programme meant there was no option to continue *just* developing synthetic biology. Now, they were beckoned to help the EC solve one of the *societal problems* it had identified and for which it put forth calls. With such calls, however, came clear restrictions. Restrictions which often outright negated the budding consortium plans, or demanded fundamental changes to those plans. Thus, finding a new funding call to support the emerging project also became a task of finding a funding call which imposed restrictions which could be managed and/or resisted.

7.1.2 Fitting a FET Energy call

After a long period of consideration, the group set its sights on a Future and Emerging Technologies (FET) call under the Energy work programme[51]. Perhaps the best quality of this call was that "this FET doesn't have that many restrictions" (Oscar interview, 10th December 2014). Not many, however, still implies restrictions exist. In this section, I detail the main ones and how they impacted on the project aims, the consortium composition and its ways of working.

One important dimension where the funders were prescriptive was in the aims of the projects. The call set out as the ultimate goal for the projects themes to devise

> "New paths leading to highly innovative technologies for energy applications, and contribution to the establishment of a strong scientific and technical base for European science and technology in emerging areas in the energy field. The potential impact on the energy system has to be clearly demonstrated, already at stage 1." (Call for proposals under which the project was funded, 2011)

This articulation betrays a combination of the aims of creating the European Research Area (ERA) and that of using the FP as means for reshaping the energy landscape[52]. It also provides a clear articulation of the attempt by the funding body to direct the trajectory of research through the funding mechanism – a well described model of what Gläser & Laudel (2016) have dubbed "governance by funding". These high policy aims, combined with a tightening of the grip on funding research which contributed towards those policy aims, made clear to researchers what the EC expected would be outputs of the projects funded under this call. This, in turn, impacted on how the researchers framed their project and what it aimed (or appeared to aim) to deliver.

The framing of the projects changed from the development of synthetic biology, with hydrogen being produced as a marker of the development of synthetic biology

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[51] As I note in Chapter 5, FET calls in the later stages of FP7 became the closest thing to a successor of the FP6 NEST programme.

[52] These aims went all the way to the highest levels of EU policy, with the energy work programme being the means for furthering the "implementation of the [EU's] Strategic Energy Technology Plan (SET-Plan)" (European Commission, 2010).

(as it had been in CyanoH2Modules); instead, the new project was constructed around an aim of "design, construction and demonstration of solar biofuel production using novel (photo)synthetic cell factories" (CyanoBioFoundry project grant agreement). Synthetic biology was, in this framing, (the best) means to that end. Yet, no more than five minutes had gone by in the first consortium meeting I attended, when one PI proclaimed: "This [project] is not about [producing] energy. This is about tools and fundamental science" (field notes, 12 month CyanoBioFoundry project meeting, 18th November 2013). This authoritative statement suggests the difference in framing constituted little more than *window dressing* (Laudel, 2006). That the trajectory of the work did not change, but only the way it was presented to the EC and the world at large. Indeed, this statement provides a pointed example of *resistance* (Fowler, Lindahl, & Sköld, 2015) to the epistemic demands of the funding body. This is not to say that energy production was irrelevant, but it was clear it was not the ultimate aim of this project in the eyes of the researchers. As Clara noted:

> "Anyone who works in this area knows that from where we are to producing hydrogen goes...once we were in a meeting where a student asked: oh, but isn't the goal of the project to produce hydrogen? And someone told him: yes, but that is CyanoBioFoundry 7" (Clara interview, 26th November 2013, translated)

This placement of the project as an iteration in a longer continuum is interesting in two key ways. On the one hand, it give useful context as to why think about CyanoBioFoundry being about "tools and fundamental science". This project is a second iteration of work towards an ultimate aim which is far flung in the future. At this stage, rather than producing energy, the project is rather more focused on laying the groundwork for future research. On the other hand, placing the project as part of a long continuum of projects which build towards a unitary aim hints that the work is imagined as a projectified form of big science (Vermeulen, 2010).

Still, it is undeniable funding did impact on the aims of the project and the trajectory of work. It bound researchers to work towards tangible outputs. If there could be any doubts as to whether such impositions also applied to projects under the FET theme, the call further states

> "this topic is "purpose driven" and not "blue-sky" research. "Increased understanding" alone would not be considered sufficiently tangible. Projects should try reaching clearly defined scientific goals and/or creating a new basic technology." (Call for proposals under which the project was funded, 2011)

In this way, the call is prescriptive as to what should be the outcomes of the projects. They must be tangible and they must advance technology. "Tools and fundamental science" would not be enough. Thus, the consortium found itself in the position of being able to move on their agendas of synthetic biology / H2 research only if they developed outputs which made a tangible contribution towards a societal / economic goal. As such, *accommodation* (Hackett, 1987) – the process of incorporating particular demands on research on the basis of reward by the actor which controls resources, when that choice is made outside or against of epistemic criteria – in the context of research aims constituted another key avenue for the securing of resources.

Beyond the aims, the funding call also had considerable impact (through accommodation) on the composition of the consortium – both in terms of the range of expertise to be made available and in geographic terms. It noted:

> "Projects shall involve multinational partnerships, often from different scientific disciplines and/or different technological sectors, in order to cross traditional boundaries. High-tech SMEs participation is encouraged." (Call for proposals under which the project was funded, 2011)

The allusion to SMEs in this text provided a particular interesting insight. Two SMEs made it into the consortium. They were largely involved with the design and production of the reactors where the energy producing organism were to be placed. When I probed why these SMEs had come to take part in the project, respondents consistently referred back to this portion of the call. In Joachim's view, the companies became involved

> “because it was demanded. Or, at least...I'm not 100% sure whether it was demanded, or whether it was just clear that it would increase the possibility of acceptance. Yeah, maybe something fuzzy like that” (Joachim interview, 29th September 2015)

The encouragement in the call text translated as an imperative to the participants. It was clear to Joachim that it was in their best interest to submit a grant proposal which included SMEs. When asked about whether their participation as members of the consortium was important, however, he noted:

> “it was important from the European Union's perspective. Yeah. [...] But from the project point of view it was not necessary to have a company in. [...] Because what they are doing we could also have bought as a service from the company. To develop a bioreactor.” (Joachim interview, 29th September 2015)

The inclusion of SMEs as full members of the consortium is framed as superfluous. While Joachim saw a role for the companies in enabling the project to come to fruition, it was a role which could be performed at arm’s length. Having companies in the project was not to the benefit of the project itself or of synthetic biology more broadly, but perceived as purely to the benefit of the EU. The inclusion of SMEs, then, constitutes another clear example of accommodation. In this case, however, accommodation is not a response to explicit requirements. Instead, it took place because the researchers perceived the absence of such participants as detracting from the likelihood of success. Thus, inclusion of SMEs provides a textbook example of the performative character of expectations (Brown & Michael, 2003).

Concomitant to the acceptance that the inclusion of companies was a key design component of a grant proposal submitted under this call came the question of which companies to include and what duties they were to perform. On that subject, Olga noted

> “the companies were picked because it was required to have companies, and something we desperately needed was for all of us to have identical bioreactors” (Olga interview, 28th November 2013, translated)

Alongside acknowledging the imposition from the funding call, she signals how the consortium handled that requirement. The difficulties posed by the different designs of bioreactors were acknowledged in the FP6 project. Of particular interest to this thesis was the issue of comparability of results between different labs – an issue which standardising the experimental apparatus would solve outright. While I am agnostic as to whether the inclusion of this set of companies and the role they were to play constituted an act of subversion or whether this was the intended outcome of the *encouragement* to include SMEs, there is little doubt that it constitutes another instance of resistance. The funding requirements impacted on the composition of the consortium and on the trajectory of community(-making), insofar as they foregrounded addressing themes which could be tackled with/by SMEs. At the same time, the consortium managed those requirements in a way that enabled them to strengthen a shared *repertoire* (Leonelli & Ankeny, 2015) by coming to share experimental instruments, and one which supports (a) synthetic biology community.

While the inclusion of SMEs was the more forceful constraint as to the expertise to be made available and the ways of working, it was not the only one. Referring back to the funding call quote two pages behind, there is a clear portrayal of interdisciplinary modes of research and international collaboration as inherently desirable[53]. Meeting the criteria on interdisciplinarity proved no challenge to a project which built on an earlier project in the NEST synthetic biology pathfinder programme. Synthetic biology as imagined in the programme was interdisciplinary *by design*. Meeting the multinationality criteria was less straightforward. Beyond that general statement, the call made clear dispositions on the geographic distribution of this network. As is the case for most collaborative projects, it required the consortium to be composed by

> "At least 3 independent legal entities, each of which is established in a M[ember]S[tate ...], and no two of which are established in the same MS" (Call for proposals under which the project was funded, 2011)

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[53] This links back to the contemporary EU policy thinking I addressed in Chapter 5, where interdisciplinarity is framed as inherently better.

The baseline for one such project is thus set at the inclusion of participants in three different states. This is a standard requirement in FP7 collaborative projects [REF?]. However, besides the explicit restrictions there appear to be more opaque rules about what would be an acceptable geographic distribution of partners. Reflection on how to assemble consortia to take part in FP projects, the consortium leader created the hypothetical scenario of putting together a consortium made up of partners based on institutions in northern European countries. In this scenario, the EC was an antagonist; one which he predicted would react by pointing out: "oh, is that all the partners are from northern Europe? Maybe you should have some from the south" (Oscar interview, 10th December 2014). This predicted reaction from the EC instilled in Oscar the need to "start having this kind of thinking" (ibid.). In CyanoBioFoundry, there is a 5-5 split between consortium members based in institutions across the north – south axis of Europe. Once again, the expectations set out by the EC – in this case, regarding the creation of the ERA – were *performative* (Brown & Michael, 2003). The geographic balancing of participants was not an accident, but a response to those expectations; it belies another dimension where considerations of funding had material impact on CyanoBioFoundry.

Despite the framing of the energy FET call as desirable due to the low onus of *restrictions*, the multitude of ways in which it constricts / guides potential research is striking. At the most basic level, implied in the explicit backing of interdisciplinary arrangements, the 3 million euro budget ceiling for projects, and the multinational character of projects is the expectation that the projects will operate as *networked* big science (Vermeulen, 2010). It was also a call heavily guided by tangible outputs, rather than process (or any support for given research avenues). All these were *sine qua non* conditions made explicit in the call text. Alongside these requirements, the call included an allusion to the *encouragement* of the inclusion of non-academic participants. While not a demand, this set out a clear *expectation* of the EC; beyond the confines of the call, the researchers articulated further *expectations* by the EC regarding the appropriateness of geographic distribution of participants. In both these cases, the expectations drove action in the (budding) consortium; i.e. they were *per-*

formative. These restrictions and expectations were addressed in different ways by the CyanoBioFoundry project – ranging from *window dressing*, to complete *accommodation*, the result of which I described in Chapter 6. This represented a clear departure from the CyanoH2Modules project; for this iteration, *governance by funding* played a far greater role in establishing *which* synthetic biology was possible and *who* was to perform it. I now move to explore this balancing act in the composition of the new consortium.

7.1.3 Finding appropriate collaborators

A final dimension to consider in the making of this consortium is that of its composition. I now explore how this specific consortium was assembled. I argue personal networks played a key role in negotiating membership and, in parallel, that here too the impact of funding requirements is plain. It is to the latter that I turn first.

Through the participation in CyanoH2Modules and in the initial stages of assembling a new consortium two domains of expertise were established as pivotal: that on cyanobacteria (– biohydrogen nexus) and that on (components of) synthetic biology. The new project was being imagined a continuation of previous efforts, and that expertise remained central. As I argue throughout this chapter, continuing the same line of research (or at least giving the impression of doing so) was framed as a key dimension of *fund-ability*. The point on the importance of having a proven track record on a given theme was less often articulated, but no less important. As Oscar noted:

> "if you have done evaluation at the European level, you know that: step 1, you need to fit to the call. Otherwise you 're out [...] and, the way I see it, you need to show activity and competence within the field of the call." (Oscar interview, 10th December 2014)

The first theme is another example of the deference to the funding call. Matching the requirements set out therein was the difference between being a contender or being eliminated. However, and of particular interest to the investigation of consortium membership, fitting the call was also governed by the ability to demonstrate the appropriateness of the fit via one's track record. This sentiment was echoed by Linus, who argued

> "if you start from scratch you have no chance. And if you have experience and you can prove this by publications then...then you might have a better chance of getting a grant." (Linus interview, 10th December 2014)

Thus, fitting the call was not just a matter of addressing the themes outlined in the call and picking a range of epistemic tools which fit the agenda. Such efforts would be in vain if not anchored in the ability to evidence expertise in the relevant areas. Consequently, participation in FP7 collaborative projects was explicitly geared towards enabling researchers to continue pursuing established lines of research, while deterring change[54]. For CyanoBioFoundry, this meant there was a clear incentive to include new members who had a proven track record of research in cyanobacteria (–biohydrogen nexus), synthetic biology and / or bioreactors.

The resulting consortium fit those membership criteria exactly. It did so by design. The group of researchers which participated in CyanoH2Modules sketched out the main features of the emerging project, and with it the areas of expertise required. Moving from that outline to identifying new members, however, became a task for the individual who proposed himself as consortium leader – Oscar. This left an imprint on the project design and membership in the shape of his personal network of (former or current) collaborators. Linus' group, identified early on as the additional group of experimentalists, was a participant alongside Oscar in another (string of) EU project(s) addressing the production of hydrogen from microorganisms (or bio-mimetic means). Joachim had been a postdoctoral researcher under

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[54] A knock on effect of such a policy is a bias towards a nexus of seniority and previous participation in EU projects. Regrettably, it is a theme which I am unable to explore in detail in this thesis, but I will note there was the sense that once one makes it to a first EU project, then "[EU] money makes money" (Clara interview, 26th November 2013, translated). While that was not always the case, it was enough of a perceived trend that repeated participation in such projects would soon make researchers members of a "community of researchers funded by the EU" (Joachim interview, 29th September 2015).

Oscar, and the two had kept in touch even as Joachim veered towards bioinformatics. A last, and weak, connection is the one with Fabio. He and Oscar were country representatives in an International Energy Agency project dedicated to the microbial production of hydrogen. Thus, out of the six new project members, three were, in one way or another, connected to Oscar.

Selecting the SMEs proved less straightforward than most other new members, largely because those were beyond the reach of Oscar's personal network. Yet, the same logic of searching through personal networks prevailed, even if one step removed. As he argued:

> "You don't send out an e-mail or post in the internet: would any company like to work with me? Either you know some company, or you have some friends that know some company." (Oscar interview, 10th December 2014)

Personal networks were still in the spotlight. In this case, the friends *in the know* were Linus and Fabio. Each had a working relationship with one of the SMEs which made it into the consortium. Nevertheless, the inclusion of these specific companies was only viable because of the companies' proven record of research in the specific areas of (process) engineering they were ultimately to be involved in.

Lastly, there was the case of Luka. There was no link between Luka and any other of the consortium members prior to the start of CyanoBioFoundry. His inclusion into the consortium followed a literature search. The search identified Luka as an expert in synthetic biology, though mostly as a result of his participation in multiple iGEM competitions. This points to the centrality of iGEM as a *community-making device* (Molyneux-Hodgson & Meyer, 2009) in synthetic biology: not only as a "maker", but also as a "marker" of community (I discuss iGEM in detail in the following chapter).

Thus, all these groups / SMEs had a track record in the domain they were to contribute to in CyanoBioFoundry (and which I describe in greater detail in the following section) and all this expertise fell into the broad domains of cyanobacteria (/hydrogen production), synthetic biology and bioreactors. The expectation that success was contingent on each participant being able to prove expertise in their tasked area, however, meant that there was considerable segregation of expertise in the three domains. The performance of this expectation provides a further indication of a mechanisms through which the funding mechanisms impacted on the trajectory of the nascent community. In addition, the process of finding adequate members to fit in the new consortium also provides interesting insight into the centrality of personal networks as a first port of call. It was only when the networks were exhausted that more open-ended strategies to identify potential new participants were taken up.

7.1.4 The finished proposal

The researchers came to a finished grant proposal by late 2011. The resulting project was a veritable balancing act of epistemic and non-epistemic criteria. Above all, the finished proposal reflects the tightening grip of the EC over the research supported under FP7. This control was manifested in forceful ways and through the performative character of expectations, with changes to funding constraints which reflected a different social contract for science, as noted in Chapter 4. In particular, the conditionality of funding on the production of tangible outputs and the push towards the inclusion of SMEs in the fabric of the research community point to the incorporation of the knowledge economy imaginary into the funding schemes; and the demand for collaborative ways of working, with particular geographic distributions, points to the embeddedness of the ERA agenda (alongside the knowledge economy) into the funding scheme. In enacting these imaginaries (in the wider FP), the EC changed what could be a *do-able* (European) synthetic biology project by impacting on what was a *fund-able* project.

The resulting project reflects these non-epistemic demands on the researchers' epistemic endeavour. These are, to some extent, resisted. They are brushed off with the suggestion that any changes to ensure *fund-ability* are to be merely discursive, leading to no epistemic fallout. However, the rhetoric of *window dressing* and other avenues of resistance is problematised by the concomitant presence of a process of *accommodation*. Accommodation can be traced to the goals of the project; the epistemic breadth of the consortium; and the inclusion of researchers with proven track records in a given speciality.

The combination of the latter with a recruitment process driven by personal networks led to a peculiar situation where only one of the new members had any meaningful commitments to synthetic biology. Unsurprisingly, that was Luka – who identified as a *practitioner* of synthetic biology[55]. The other researchers varied between agnosticism, doubt over the novelty of / justification for synthetic biology (a trend commonly reported; e.g. Bensaude-Vincent (2016) and Schyfter & Calvert (2015)) and outright indifference. In the following section, I explore how this group of researchers worked together to deliver a synthetic biology project – and developed some commitment to the epistemic project as part of the process.

7.2 PREPARING FOR THE FUTURE AFTER CYANOBIOFOUNDRY

CyanoBioFoundry was a project funded for three years. Any subsequent work would require a new funding stream. Thus, further work required the researchers to embark on new iterations of the process of submitting grant proposals. This (wider trend[56]) *projectification* of research was something the PIs were acutely aware of, and for which they actively prepared. In this section I address the continuous preparation for a range of (often overlapping) potential futures. I describe how this preparation took place within the CyanoBioFoundry consortium; how the project was concurrent and heavy-handedly used to draw potential new collaborators (while shed-

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[55] Luka conserved a self-identity of a biochemist, which was the discipline of his initial training. This follows a well-described pattern of self-identification along the lines of initial academic training, while maintaining the new epistemic commitments at arm's length. It is a phenomenon which has been linked to commitments to emerging fields, including in the specific case of synthetic biology (Bensaude-Vincent, 2016).

[56] See Vermeulen (2010) for an analysis of the trend of projectification of research.

ding some of the current ones); and I delve deeper into how one potential new project emerged over time. In all cases, I argue that funding played a key role in mediating which imagined futures were opened up and those which were closed down.

7.2.1 Continuously preparing for what might come next

The future post-CyanoBioFoundry started being prepared before the project started. The grant agreement proposed that the large, yearly project meetings would incorporate an open day. This open day was formally described as an event to the benefit of students from within the consortium. In practice, however, these served as *community-making devices*, where the need for community was articulated to carefully picked guest researchers. A more detailed exploration of the role of the strategic choices of invited speakers and the futures imagined together follows in section 7.2.3.

This explicit preparation for the next iteration of projects also took place within the consortium, both in formal and informal settings. An important formal setting for such discussions was the steering committee meeting. These meetings took place yearly, as a component of the project gatherings. The agenda for the meetings was made up by a varying set of practical issues for the committee to decide upon, but the discussion would invariably find its way to potential new work opportunities. Likely possibilities for further work were raised without detailed plans – in many cases the PIs had no previous knowledge of what was being proposed. As such, these discussions were overtly speculative, and came across as arenas for gauging interest. Any substantive work was dependent on how successfully they appeared to draw in project partners and was pushed for more informal (and more intimate) settings.

A key feature of these discussions lies what they were centred around. They were consistently tied to funding schemes which had recently been announced / materialised, or that were predicted to be in the pipeline. At the time of the 12M meeting, draft work programmes under the new Horizon 2020 framework programme were starting to surface. Those drafts, combined with insider knowledge from PIs which were well known to the Brussels bureaucracy, was what was driving the discussions. The content of those documents made it difficult to predict the specific funding calls, but the PIs nevertheless attempted to find niches which would be accommodating of the combined research interests of synthetic biology, solar fuels and cyanobacterial organisms. Come the 24M meeting, the (lack of clear) opportunities for a similar project were examined against the backdrop of the now finalised work programmes for Horizon 2020, as well as a parallel ERA-NET programme.

As the project deadline was coming to an end, the settings for intra-consortium discussions of future projects grew. During the 29M meeting, the formal deliberation of potential new avenues of research took place in a dedicated session. In addition, the scope for involvement in imagining a future together also grew to encompass the more junior participants. As the PIs held a steering committee meeting, the remaining consortium members held a future planning meeting of their own, which would be fed back to the PIs.

The amount of time and effort dedicated to finding new common projects culminated in the last – 35M – meeting. There, the most substantial attempt to come to a new iteration of the project took place over two sessions. Together, they were allocated roughly a third of all time available for the closed portion of the consortium meeting. PIs were no longer discussing the future in segregated settings; it was then a key component of the meeting in how it was designed and run.

While this string of formal discussions with the entire consortium leadership was undoubtedly important in planting the seeds of new iterations of collaboration, they were not used as sites for developing concrete plans or grant applications. That role was largely played by informal discussions in smaller / different groups. These took place over the days of the consortium meetings, over coffee breaks, meals and late nights in the hotel lounge; they were started or continued over email chains; over periods when PIs visited each other; or even at the margins of conferences. These settings – elusive for those not included – were key in moving from intentions to attempts to generate new projects. A (partial) account of these negotiations, as well as the resulting groupings, follows in the subsequent sections.

7.2.2 Playing the numbers (or funders) game

A striking outcome of the discussions of future projects over the first two years of the project was the acknowledgement that no funding call appeared to be an adequate choice for an attempt to conserve the consortium together. Over the course of the 12M meeting the consortium leader first articulated something which would be repeated during most other instances of imagining future projects: that it would be difficult for the consortium to find another call which would be a good fit for all. Instead, they should search for projects together, but then break into a smaller, more informal groups to discuss the possibility of embarking on specific projects.

By the time the project hit the two year mark, potential fault lines started to emerge. Two small subsets of the consortium had been working together, and two Horizon 2020 grant applications for projects framed as the successors of CyanoBioFoundry had been submitted. Each of the applications was led by a current consortium member, who had included two other groups from the current project. The rest of the consortium was made up by new members[57]. An interesting feature of these applications is that they were not direct continuations of work being undertaken in CyanoBioFoundry. Instead, they were in the direction of

> "more synthetic biology. More developing synthetic biology. And not hydrogen, but maybe other products. But then the other partners doing the other products." (Oscar interview, 10th December 2014)

On the table were then two applications which maintained the focus on cyanobacteria and the production of useful metabolites, albeit different ones, and increased the emphasis on the cellular machinery once again. Yet, neither the return to focusing *more* on synthetic biology nor the scrapping of hydrogen as a product is a symptom of dissatisfaction with the current focus on either. Instead, it can be understood as a change in the direction the funding winds were blowing. Oscar also expressed

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[57] One of these applications included an American partner. When probed, the rationale offered for seeking members from the other side of the Atlantic was the same as in section 7.1.3 – it was encouraged by the funding call. Mediated funding calls, governance actors are thus impacting on the *(geographic) placement* (Livingstone, 2003) of scientific communities.

doubts that both projects would be successful in acquiring EU funding. One was likely to be supported, but not both. In this way, funding decisions were also placed in the role of ultimate arbiter over which line of research would be enabled and which would be (at least temporarily) halted.

The outcome of both bids, however, was negative. That, combined with the successive delays in even being able to submit proposals with the Japanese project which can be loosely characterised as its double (I examine the character and importance of this connection shortly), meant the project reached its final meeting with no successor in place. This state of affairs prompted an emphatic effort to scrutinise the range of options available to subsets of the consortium in the last meeting. Here too the framing of funding as a numbers game was a core feature of how the consortium approached the possibility of new projects. The discussion had barely started when the consortium leader proclaimed:

> "I think we should as a group go in with multiple different applications with different coordinators, if we are serious about getting money" (field notes, 35 month Cyano-BioFoundry project meeting, 30th September 2015)

So, in the lead up to the meeting, 6 of the PIs volunteered to dissect recently published Horizon 2020 work programmes in search for appropriate forthcoming calls. Exploring the FET, Food, Energy, Transport, Climate, and Marie Skłodowska-Curie programmes, the consortium cast a wide net. In the setting of the meeting, each of the 6 PIs presented their impressions of where the consortium – or a subset of the consortium – might *fit*. Out of the range of calls examined, one merits brief outlining. The researchers had placed hope that their research would be *fund-able* in the context of the Food programme's biotechnology calls. However, the funding requirements seemed mostly incompatible with a potential continuation of Cyano-BioFoundry. There was, however, one notable exception: the use of "neutral sites"[58] - a research outcome from the two projects, which was envisaged as having potential

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[58] "Neutral sites" correspond to specific sites in the organism's where DNA sequences could be inserted without impacting on the cyanobacteria's metabolism. This is a non-trivial discovery, which emerged out of CyanoH2Modules and CyanoBioFoundry.

for advancing the (very much PBSB) imaginary of the cyanobacteria as a production platform. This was a suggestion made by Olga, who noted she was in the final stages of preparation of a grant proposal to submit to a national funding council; still, these plans were amenable to change were the consortium interested in exploring the idea further. Another large, collaborative project struck Olga as more productive than a single-researcher one; even if, to meet the requirements of the call, that would mean reframing the grant proposal to a synthetic biology led by *in silico* approaches. Reframing was imagined as a task of window dressing (Laudel, 2006) to the greatest possible extent, but accommodation (Hackett, 1987) would be unavoidable; the research questions and the relative weight of each portion of the project would change, even if only slightly. Olga's stance foregrounds once again the collaborative, interdisciplinary *ways of working* which characterise the synthetic biology repertoire. Nevertheless, and while attempting to conserve the consortium (Olga's suggestion was the one which enabled the largest portion of the consortium to continue a shared research avenue), a new configuration would have to be found to meet the demands of the call. Only the PIs with expertise in 'omics or wet lab biology of cyanobacterial hydrogen production would be retained; and those with expertise in the (cyanobacterial) production of another metabolite would be recruited – all to meet the demands made by the funding call.

While of primary relevance, the explicit demands by the funding call were not the sole basis for assessing suitability for potential submission of proposals. As the six researchers moved fastidiously through the calls of the Horizon 2020 programme they had examined, it was striking the that they voiced an imagination of what the EC was looking for based on the text of each specific call. This can be succinctly (though pointedly) illustrated by Luka's remark before guiding the consortium through the potential suitability of the calls in the Transport programme, who asserted that "the EU does not want cyanobacteria in its transport" (field notes, 35 month CyanoBioFoundry project meeting, 1st October 2015). So, while there were two calls whose text could, in principle, encompass a *solution* driven by the synthetic biology of cyanobacteria, Luka's reading of the work programme was that it was slanted to the benefit of other model organisms – a reading which was corroborated by senior PIs in the consortium. Accordingly, the Transport programme was summarily dismissed from further discussions.

In this section, I foreground the way funding was constituted as a key consideration for further work; I note the importance the researchers attributed to funding and the strategies they adopted to attempt to ensure a continuation of patronage. In particular, I showed how considerations of *fund-ability* pre-empted most other considerations of *do-ability*. *Fund-ability*, then, guided the epistemic development of the project, both through explicit, forceful requirements; but also through (the performative role of) expectations of what was *fund-able* research across the different programmes. Above all, it was clear to the researchers that the forcefulness of funding requirements would involve some degree of reorganisation of labour; the constraints associated with new projects would necessitate dropping existing members and recruiting new ones. I now turn to describe a key venue for finding and recruiting such new members.

7.2.3 Expanding the community: open days of project meetings

The yearly, large, project meetings were events which span several days. Matters of project management (and preparation for new projects within the consortium, as noted above) were addressed at the start of the meetings. The last day, however, was formally referred to as an *open* day, and had an altogether different purpose. Unlike the first portion of the meeting, the open days were ostensibly accessible to the public; they were written into the grant agreement as an opportunity for training, mainly geared towards junior members of CyanoBioFoundry, but open to attendance by other researchers (in training). This training was to be provided in the format of lectures, delivered by researchers with expertise which complimented the consortium's.

In public settings, a successful open day was measured by the "education and training" (CyanoBioFoundry project grant agreement) provided for the junior participants. In private, however, the educational aims of the open days were downplayed.

In lieu, these open days were described as opportunities for expanding the community and finding new partners for future projects. The structure for the open days as delivered laid bare that tension between the two roles, insofar as lectures by invited speakers made up only a portion of the programme; a programme which also included a similarly long presentation of CyanoBioFoundry by the consortium leader, as well as sessions spanning a considerable amount of time devoted to discussion of where they (and the field) might go (together).

The content of the presentations also exposed a similar tension between a pedagogic and a community-making role. The invited speakers made up a combination of junior and senior researchers. The former mostly delivered technical presentations in themes which were closely related to the interests of (some members of) the consortium. The latter, however, delivered lectures with little technical depth. Instead, senior researchers presented a broad overview of their current research projects, with occasional focusing on technical detail. Similarly, the CyanoBioFoundry consortium leader also used a lecture slot to present an overview of their own project. In these presentations, the educational value was low; instead, they came across as senior PIs showcasing their current research interests and attempting to find common ground.

The open days were finished by a pair of long sessions devoted to the trajectory of the field(s). The discussions were open-ended, but returned consistently to four major themes: the availability of relevant funding streams; the need for the establishment of a dedicated synthetic biology of cyanobacteria; the need for digital and biological infrastructures to support the community; and the importance of attracting students into the field. These were also events where the seed for potential new collaborative arrangements was planted (I discuss one such example in the following section). As such, the open days were thus events where the *need* for community in synthetic biology was articulated and which provided the "'glue' to capture and begin to sustain emerging links." (Molyneux-Hodgson & Meyer, 2009, p. 140). They acted, in other words, as community-making devices (ibid.).

It is, however, noteworthy that while the priorities were consensual, the (range of) actions seen as needed was not. There were conflicting understandings of what the field *was*, which knowledge infrastructures were relevant, and what were good methods for enrolling students[59]. Arguably, this is to be expected in a field whose heterogeneity has prompted Schyfter & Calvert (2015) to split synthetic biology into three communities; and it also indicates that a repertoire (Leonelli & Ankeny, 2015) is still to be stabilised. Nevertheless, it begs the question of who was invited as a guest speaker and the criteria on which these speakers were chosen. Here, too, funding emerges as a key consideration. I now move to explore this dimension in the imagination of future work.

7.2.4 Choosing (potential) new members – interplay of epistemic and funding criteria

The planning for the invitation of relevant speakers evidences the intertwining of epistemic and funding criteria. The consortium aimed to "invite "global leaders" for the workshop day that did largely the same as the consortium members" (field notes, 12 month CyanoBioFoundry project meeting, 19th November 2013). So alongside epistemic overlap, there was a targeting of "global leaders" – which, in this context, refers to individuals with privileged access to funding resources. These researchers were broadly imagined as belonging to a core group of "scientists that are funded by the European Union" (Linus interview, 10th December 2014), which would enable them to access resources not made available to those on the periphery. The reference to the European Union is not accidental – the funding requirements associated with the EU's framework programmes restricted the potential pool of researchers to one which was very much *placed* (Livingstone, 2003) in the European Union. In this way,

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[59] It is important to note that, despite the lack of consensus, there was consistent reference to iGEM by researchers at all meetings as an important avenue for both recruiting novices into the field and ensuring the supply of novices with an adequate epistemic arsenal. The disagreement regarding iGEM sat mostly along the lines of organisms – some researchers argued iGEM bred a *model organism community* (Leonelli & Ankeny, 2012) around E. coli, which was not compatible with the model organisms of the synthetic biology of cyanobacteria. Unfortunately, this is a point that may not be discussed at length in this thesis, in the interest of brevity.

the broader policies towards making Europe through the research programme (which I explore in Chapter 4) can be shown to restrict the potential trajectories of the European synthetic biology community at the micro level.

However, with the EU's FP7 finishing and Horizon 2020 (the eight FP) materialising, what *making Europe* entailed also changed. While a detailed exploration of these differences is beyond the scope of the thesis, I must still note that a key difference between the two FPs stands in the extent to which *making Europe* was confined to the geographic borders of the bloc. In Horizon 2020, the dimensions of EAV expanded again, and now included *science diplomacy* (Royal Society, 2010) with developed nations, as well as the use of experts based in third countries to facilitate the quest for European *excellence*. Thus, the inclusion of partners from outside the EU in collaborative research projects was to be increased. Such (high) policy changes led to changes at the coalface of Horizon 2020, mainly with the (promise of) creation and expansion of the range of funding calls for collaborative projects between the EU and given a third country.

So, while the majority of the invited speakers was based in institutions in the EU, two sets of researchers were not: an American researcher was also invited to the second year meeting; and Japanese researchers were invited to all three meetings. The inclusion of both sets of researchers as speakers – and the corollary of their consideration as potential collaborators – was explicitly linked to the perceived availability of funding. This became clear as a PI introduced Jiro (the Japanese speaker / project leader), noting that "the main reason why Jiro was invited was the potential EU – Japan collaboration within Horizon 2020" (field notes, 12 month CyanoBioFoundry project meeting, 18th November 2013). Similarly, the American researcher was invited because of a call for collaborative proposals between the EU and the USA, which was published around the second year meeting. This researcher came to be involved in one of the grant proposals led by a CyanoBioFoundry member which was submitted at the time. As noted in section 7.2.2, however, the proposal was unsuccessful. To my knowledge, no further attempts have been made to resubmit a proposal including the American researcher; and the researcher was not invited back to the final project meeting.

This is in sharp contrast to the relationship cultivated with the Japanese researcher (and his group). He was first invited based on the expectation of funding availability (based on the personal networks of senior PIs, which included EU policymakers), despite no funding call being spelled out in the available Horizon 2020 work programme drafts. Jiro and junior and mid-career stage researchers under his supervision were invited once more to the second year meeting; no dedicated call had materialised (although calls for collaborations with other countries had), but this was portrayed as nothing other than a temporary setback – the word from contacts within the EC was that a call was bound to materialise soon. By the last meeting, as the project ended, the optimism had waned somewhat. As the group discussed the viability of potential calls within Horizon 2020,

> “the discussion turned to collaborations including groups from outside the EU. Oscar frowned and remarked in a grave tone: “Haven't seen mentions of having to work with a partner from another country, like Brazil, India or Japan. (…) “and I was looking for Japan”. (field notes, 35 month CyanoBioFoundry project meeting, 30th September 2015)

Yet, Jiro had been invited again, and the two groups continued strengthening the link. In fact, in this last meeting the CyanoBioFoundry consortium expressed the ultimate aim of merging with the Japanese project. The difference in outcomes of the two attempts at working together can be productively explored through the examination of existing boundaries within the synthetic biology of cyanobacteria. A key boundary presented in the organisms used. As a senior researcher noted:

> “some Americans will swear by ’coccus, others by pcc. 78XX, others by, PCC7002. Things are different in Asia, where many groups use 6803. Also argued that groups are “usually only good at working with one strain”. (field notes, 35 month CyanoBioFoundry project meeting, 30th September 2015)

Such characterisation points to the segregation regarding the choice of organism. It suggests that researchers will rally around and develop expertise (at least predominantly) in a single organism. In doing so, it highlights the importance of the organism in enabling or hindering working together; the *boundary work* (Gieryn, 1983) implicit in this statement foregrounds the relevance of *model organism communities* (Leonelli & Ankeny, 2012) even within the synthetic biology of cyanobacteria. Since the latter leverages membership of such communities (which predate even the genesis of synthetic biology) and there are clear boundaries between them, it follows that local articulations of the synthetic biology repertoire will reproduce those boundaries. As such (and despite the concurrent development / efforts towards globalisation), the reproduction of patterns of geographic distribution of expertise with different organisms means that synthetic biology remains science which is *placed*. Expertise with Synechococcus strains remains concentrated within North America; and expertise with Synechocystis as concentrated in Asia and Europe. While researchers may belong to multiple model organism communities, they appear to mostly concentrate around a single organism, to the extent that there is a *path dependence* (Arthur, 1989) effect – the investment required to move towards a different organism is great enough that researchers refrain from doing so.

In the case at hand, the very inclusion of an American guest speaker (one whose expertise did, in effect, revolve around the Synechococcus genus) is telling of the potential weight of the availability of funding in the trajectory of (the European) synthetic biology. The availability of such resources provided a stimulus which was of enough magnitude that it proved greater than the cost associated with deviating from the existing path; and stands as an empirical example of the ways in which funding can draw epistemic change, hypothesised by Braun (1998). The removal of the stimulus (in the form of the absence of new dedicated funding calls) led to the abandonment of plans to work together, for the case for collaboration was hard to make on epistemic criteria alone. Nevertheless, epistemic proximity cannot, on its own, be reasonably expected to sustain a close relationship between two groups of researchers. Thus, I explore how the European and Japanese projects converged in a final section.

7.2.5 Working towards a new iteration – a potential merger of EU and Japanese projects

In the previous section, I argued that a closely shared *repertoire* was a key factor in enabling the European and the Japanese projects to grow closer, even in the face of promises of funding which had not (yet) come to fruition. In this section, I briefly describe the Japanese project, outline how the projects grew closer, and note the paralysis induced by the absence of funding.

The Japanese project is an endeavour with an overall aim which was remarkably similar to its European counterpart. It is a project which trades on the imaginary of cyanobacteria as biological factories. In particular, it proposes to change these organisms in a way that harnesses their photosynthetic capabilities for the production of a range of biofuels (or biofuel-related products). Synthetic biology is also portrayed as the key for enabling this vision to come to fruition. This project is funded under the (Japanese) CREST scheme, and its funding is ongoing (at the time of writing, has been in place for nine years). As such, and despite the formal characterisation as a project, from an organisational standpoint it is closer to the traditional model of block grants than the contemporary project-based work model under which CyanoBioFoundry operated.

Despite the overlap between the projects, there was a palpable sense that the projects would benefit from avoiding the frame of competitors, if nothing else, because they were "doing slightly different things" (Olga interview, 28th November 2013, translated). Indeed, the European project put greater emphasis on understanding and controlling the photosynthetic system (from the most detailed phenomena inside cells to the bioreactors) than on the specific product generated; the Japanese project prioritised developing strategies for generating (and increasing yields of) a wider range of products and harvesting these products from the bioreactor systems. The European project arguably fell still under the realm of *building* synthetic biology, while the Japanese counterpart was closer to *using* synthetic biology. This difference in framing did not go unnoticed. As Natalia put it, the Japanese project was "actual synthetic biology. It's like ten iGEMs in one project. You feel the...constructions" (Natalia interview, 17th December 2015)[60]. So, while both projects shared an overall aim and their expertise overlapped greatly, the differences in project design, framing and approach left room for complementarity and, as I will now show, collaboration.

Intercalated with the European project meetings, the Japanese project also held events. These were formally described as workshops, and were organised in a similar fashion to the open days of meetings of the EU project – around talks by invited speakers who were experts in (aspects of) synthetic biology of cyanobacteria. The first workshop included the participation of three PIs from the European consortium. These were Linus, Olga and Oscar. The first two delivered talks on their specific domains of expertise and work in CyanoBioFoundry. Oscar, however, did not present his work, but the European project. The second workshop was organised around an even larger proportion of speakers from the European project. Out of a total of nine lectures, five were allotted to PIs from that project (and only one other speaker was not local), which suggests their participation was the cornerstone of the event. Linus did not return as an orator, but Olga and Oscar did. The other members were Luka, Gregor and Fabio. Thus, all the PIs of the European project working in synthetic biology from a biological angle were represented in (either or both of) these workshops. Furthermore, both leaders of the efforts towards creating novel PBRs were also brought into the fold. Still, as had been the case in the European project's open days, the lectures delivered were not the key motivation for the participation in the workshops. During the second yearly project meeting, Oscar openly shared with the consortium that the three PIs had been invited to the first Japanese workshop with the explicit aim of continuing to explore potentially working together. By the last meeting, and after a large subset of the consortium PIs had attended the second Japanese workshop, the aim had grown to one of "joining forces"

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[60] Natalia has participated in iGEM projects as both a team member and an advisor. Her first direct contact with synthetic biology was through iGEM. It is interesting to note that iGEM defines what synthetic biology is, and that other approaches are measured against an iGEM (ideal) type. Unfortunately, I am unable to devote much attention to this case in the thesis, but I address ways in which iGEM has become a key market in synthetic biology in the following chapter.

(field notes, 35 month CyanoBioFoundry project meeting, 1st October 2015) with the Japanese project.

This pattern of interaction warrants examination from two main standpoints. For one, and in the same way as the European consortium open days, it suggests the relevance of the workshops as *community-making devices* – as arenas which provided the "glue" for fostering (and/or strengthening existing) relationships. For another, the range of PIs involved in these efforts suggests the making of a synthetic biology driven by biological expertise (as opposed to engineering broadly defined). All the PIs with expertise in the (synthetic) biology of the model organism were invited, and all the PIs with *in silico* expertise were excluded. Engineering expertise was valued, but at arm's length – it was expertise in the *process* of extracting the products generated following a synthetic biology approach, rather than in the ethos of synthetic biology itself. Process engineering and the concomitant instruments designed (and created) was, nevertheless, an important point of harmonisation between the projects. This suggests that the project being imagined / negotiated was to be anchored in a vision for synthetic biology driven by wet lab biology and wet lab (synthetic) biologists, with the *in silico* work being relegated to a service role; and was thus imagined as a project which would build on synthetic biology on a more (wet lab) biology driven trajectory, and less as an engineering / in silico driven synthetic biology (as in the first CyanoH2Modules project, or the potential new project which revolved around "neutral sites" discussed in the last project meeting).

The participation of researchers in events arranged by its counterpart also drove convergence from an instrumental point of view. The interactions between the projects (be that in European or Japanese meetings) stoke up interest from researchers in the Japanese project in the small-scale photobioreactor. By the end of the European project the former had visited the company from CyanoBioFoundry responsible for its production (as well as the process engineering) and observed demonstrations of the PBR in action. The performance of the PBR (and the process) pleased the researchers, who expressed interest in purchasing multiple units as soon as the company was able to take orders. Thus, the "stickiness" developed as part of the participation in the workshops/open days also manifested in the intent to adopt the use of the same artefacts and a similar process in the work with the model organism. From a wider community-making point of view, this move provides an interesting glimpse of the making of the repertoire in synthetic biology (of cyanobacteria) – the photobioreactor started its dissemination into the community through this interaction, and the attempt / intent to standardise the use of that *artefact* with a defined protocol further built the repertoire by crystallising as a novel *way of working*.

A final salient feature of the developing propinquity between the two projects was the exchange of students. The second and third large yearly meetings made those exchanges visible, with students from the Japanese projects participating in the meetings in their entirety. They did so in the capacity of visitors to groups in the EU project – the three groups with wet lab biology expertise. The periods of exchange were short, with the students spending a period between 1-3 months in the host institution. Conversely, students from the EU project spent similar periods in Japanese institutions, over the course of the EU project and after it had finished. Formally, these exchanges were primarily presented as opportunities for the benefit of the students. In being directly exposed to the work in the group which hosted them, the students would acquire new techniques and specific insights[61]. While not explicitly articulated, it was also implied the exchanges would favour both the home and host research groups. At this level, the pay-off would be one of epistemic alignment between the two groups, as well as the concomitant expansion of the groups' epistemic arsenal, as the students acted as agents for that transmission.

However, in more informal settings both the focus and benefits of these exchanges were problematised. In at least one case, it was unclear to one of the host lab members how the student (and the lab) would benefit from the exchange; neither there appeared to be specific research goals to the exchange, nor an expectation of meaningful outcomes. Combining the vagueness of the technical goals arising out of

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[61] This constitutes another example of the making of community by nurturing the creation of researchers with a wide array of (and hybrid) expertise. I explore this theme in greater detail in the previous chapter.

the visits with the choice of host groups and the reciprocity between projects suggest these exchanges constituted a form of "gift-giving" (Hagstrom, 1965). The practice of gift-giving forges a commitment between the recipient and the donor. Gift-giving in science is thus not a one-way interaction, but the first step of an exchange – may that be in the form of recognition or some other form of reciprocity. From the lens of a gift exchange, the technical outcomes of the student visits are all but irrelevant. Instead, the students were themselves the gift, bestowed upon the EU project groups in the first instance, and (at least partially) reciprocated at a later date. The exchange served as means for strengthening the bonds between the PIs in particular, and their individual groups more generally.

Through these interactions and over time, the desire to work collaboratively grew. At the end of the CyanoBioFoundry project, and as noted earlier in the section, the two projects had grown close to the point where a merger was the desired outcome. Even early on, the Japanese PI had made clear that the Japanese funding agency which supported the project he headed would readily support the participation of Japanese-based researchers in a collaborative project with the EU researchers. Thus, the clear impediment to the materialisation of such a project was the absence of resources to support EU researchers. These resources, promised throughout the duration of CyanoBioFoundry had yet to materialise at the time of writing. Thus, the absence of dedicated funding calls for collaboration with Japan meant that this aim was, at best, on hold. Considering the high degree of dependence of the biosciences on external funding for research, the absence of such funding meant that, while there was the will, there was no (immediate) way.

In this section, I have outlined the epistemic overlap between the two endeavours and how the two groups of researchers grew closer. I argued that the workshops and open days worked as key community-making devices, providing the "glue" to (strengthen) link(s) between the two projects. In addition, relations between the project were also strengthened by the gift-giving practice of student exchanges, with novices from one region spending short periods with groups in the other; and through the (intended) adoption by the Japanese group of artefacts and ways of working developed in CyanoBioFoundry. In the forthcoming conclusion, I address how this movement has value from a community-making point of view.

7.3 CONCLUSION

This chapter put on display the extent to which, as FP6 gave way to FP7 and FP7 gave way to Horizon 2020, what was a *do-able* European synthetic biology project also changed. In this last section, I reflect on how this shift manifested, the role of funding and the extent to which the trajectory of the community is intertwined with funding pressures.

In both moments addressed in this chapter – the preparation of CyanoBioFoundry and the preparation for a future after CyanoBioFoundry – the issue of funding was not only a common theme, but it was one at the forefront of the researchers' minds. It was striking that the preparation for potential new projects started before the CyanoBioFoundry project itself started, and spanned its entire duration – and that this search was not driven by epistemic criteria, but was instead mostly propelled by the precariousness induced by a competitive, highly projectified funding model in a domain of research which was already heavily reliant on external resources to undertake (epistemic) work.

Some demands of *fund-ability* were explicit, such as the types of outputs. In the preparation of CyanoBioFoundry, these demands guided the inclusion of actors dedicated to scale-up. In the grant proposals for after CyanoBioFoundry, they guided who from the consortium would be included in each of the two proposals, as well as which types of new members should be included. Mostly, however, *fund-ability* operated through less tangible levers. Expectations of acceptable geographic distribution steered the choice of consortium members in CyanoBioFoundry; and the expectation of dedicated funding streams for collaboration with researchers from outside Europe drove the engagement with American and Japanese potential partners. In these ways, funding became a conduit for enacting prominent imaginaries. In the preparation of CyanoBioFoundry, the Knowledge Economy shines through in the demands of outputs; the European Research Area in what would constitute an *acceptable* geographic distribution of the consortium. In the preparation for after CyanoBioFoundry, the recruitment of European research towards geopolitical tussles, under the banner of a *global Europe* imaginary, directed the expansion of the radius of search for new project partners to outside the old continent.

Thus, in the European sphere, fund-ability mediated which imagined futures were opened up and which were closed down. In a process of *governance by funding* (Gläser & Laudel, 2016), only projects which were *aligned* with prevalent European imaginaries had a meaningful chance of being funded. More than that, the researchers implicitly accepted the role of funding as the arbiter of the direction of epistemic labour in their acceptance that they would need to package their research in different ways – in the hope at least one project would be successful in mobilizing resources.

In itself, the *projectification* (Vermeulen, 2010) of work was also a conduit for exerting that authority. As I argued was the case in the creation of CyanoBioFoundry and projects to succeed it, the inexorable link of resources to project based work changed the coalition of actors assembled, as well as the rhythm of labour and epistemic and material outputs. For CyanoBioFoundry, it prompted the consortium to think in a 3 year horizon, foregrounding outputs which could be produced by parallel work; it prompted the creation of outputs of dubious interest, on the basis that a project must produce outputs at the end; it guided, to some extent, the actors assembled to complete the project, by promoting a coalition which could produce such outputs; and it prevented that same group of researchers from continuing on the trajectory started in CyanoBioFoundry, despite their willingness and desire to do so. Overall, I contend governance by funding played an important role in establishing *which* synthetic biology was possible and *who* was to perform it in CyanoBioFoundry.

Nevertheless, if funding pressures played an important role in the creation of new projects, they did not completely override epistemic criteria. As I articulated over the course of the chapter, the researchers *resisted* this pressure using a multitude of strategies, with the discursive *accommodation* that constitutes *window dressing* playing the most prominent role. There was window dressing in the aims of CyanoBioFoundry, which implied the creation of an organism capable of producing a certain amount of biofuel – but which the researchers never explicitly commit to creating. There was window dressing in the reasoning for including the two SMEs, with the development of a small bioreactor being tied to the needs of the community – not the project. And there was window dressing in the open days of project meetings, with the ostensible aim of teaching being little more than subterfuge. But even through these acts of resistance, *accommodation* shines through; it shines through particularly in the case of choosing *who* to invite to the open days – i.e. who the consortium approached to discuss building new projects. The expansion of focus from European researchers to Japanese and American belies the changes in what projects were fund-able, largely in lockstep with the change from FP7 (where the focus was on EU research and funding allocated to EU researchers) to Horizon 2020 (where the drive for *making Europe* became more closely linked to *science diplomacy*, which in turn expanded the pool of viable collaborators to the USA and Japan).

These tensions with funding and fund-ability inevitably also rippled through how community was made over the course of CyanoBioFoundry and in preparation for the ensuing projects. From this standpoint, the chapter articulates the ways in which community was made through *community-making devices* (Molyneux-Hodgson & Meyer, 2009). I argue that the open days of the CyanoBioFoundry project meetings and the workshops of the Japanese project constitute such devices. These are sites where the need for community was articulated – and explicitly so, in the case of the open days – to project participants, but also to researchers external to the projects but which were members of the community (broadly defined). Sites which provided the "glue" (ibid.) to capture and sustain links between researchers; in both settings this took the form of structured dialogue in a bid to establish overlapping aims and interests, which were to provide the initial *glue* and further develop the link in a more informal environment. The first of CyanoBioFoundry's open day was, arguably, successful in creating the initial "stickiness" (ibid.) between the EU and the

Japanese project. This stickiness was then sustained by further engagement in community-making devices, in the form of subsequent open days of CyanoBioFoundry project meetings and workshops of the Japanese project; and through a practice of student exchanges without a well-defined purpose, which can be interpreted as an attempt to cement the link through the practice of gift giving (Hagstrom, 1965).

It was this stickiness which drove the adoption of the PBR and the process by the Japanese group. This, in itself, provides a window into the expansion of the synthetic biology *repertoire*, through the circulation of artefacts and the establishment of novel ways of working. Furthermore, the imagined project has the potential to, in a local articulation, move the trajectory of the community to one driven by a biological ethos (arguably, along the ethos of Schyfter & Calvert's (2015) sceptical constructors) and away from the more engineering-driven ethos of other conceptions. All this work, however, was seen to stumble upon the inability to mobilise resources. Thus, while the perceived fund-ability drove the projects together, the absence of funding prevents any planning from coming to fruition. As such, this case brings into sharp focus once again that fund-ability is a sine qua non condition of do-ability for the performance of a highly projectified synthetic biology which hinges on large, collaborative ways of working.

Over the last four chapters, I explored the co-production of synthetic biology and the European Union. In my final empirical chapter, I move away from this messy nexus and explore the making of synthetic biology through a project of epistemic purism – iGEM.

PART IV

FOSTERING SYNTHETIC BIOLOGY

8 STRUCTURING SYNTHETIC BIOLOGY VIA IGEM

It would be difficult to write a tale of synthetic biology that did not include iGEM. From its beginnings (largely) in the midst of the MIT hive mind, iGEM has risen to occupy a space of prominence within synthetic biology – driven, in no small part, by the iGEM competition. It also underlines the explicitly global character of the emergence of synthetic biology. To look at this phenomenon from a purely regional lens would be to neglect the importance of the global context in (co-)producing European synthetic biology.

iGEM is both a key driver for a *repertoire* (Leonelli & Ankeny, 2015) and a key *community-making device* (Molyneux-Hodgson & Meyer, 2009) in synthetic biology. In this chapter I introduce the different facets and trace the origins of what falls under the banner of iGEM. In the first section (8.1) I describe iGEM as starting as a small undergraduate competition based out of MIT and its rise to prominence as a focal point of synthetic biology, drawing students and researchers from across the globe, with concomitant expansion of practices and constituencies. I trace the different ways through which the competition attempted to enrol and sustain membership, in tandem with how it expanded and changed over time. In section 8.2, I then move to argue that this competition has increasingly guided participation and rewarded teams which conformed to the ethos promoted by its organisers, and trace the two main ways through how that was accomplished. As I do so, I weave through the ethos and practices associated as put forward in the competition.

Nevertheless, I note that there is more to iGEM than the competition. Closely linked to the competition, both enabling and feeding of its epistemic practice, sits a key knowledge infrastructure – the Registry of Standard Parts (the registry). I turn the spotlight to the registry in section 8.3 (although I also allude to it over the two initial sections). In broad strokes, the registry is a communal, open, but centralised physical and material database for the *parts*, *devices*, and *systems* on which the performance of parts-based synthetic biology (PBSB) relies. It is also one particularly salient articulation of the engineering ethos which pervades PBSB; I trace that imaginary over the next section. I also note the trajectory of the registry, tracing its origin and attempts to place it as an obligatory passage point (OPP) in the performance of PBSB. I explore how its aims to transcend the iGEM competition were resisted by the unwieldiness of biology, as well as the unwieldiness of its contributions, which led to the re-imagination of its place in the global repertoire. I finish with an examination of the ways iGEM organisers mobilised the iGEM competition for the benefit of the registry.

In section 8.4, I address iGEM as it aimed to go beyond the focus on novices / the competition, and attempted to enrol established researchers, under the umbrella of iGEM Labs. I outline this programme and the ways in which it attempted to replicate the ethos of the iGEM competition. I provide a bird's eye view of how the participants in iGEM labs engaged with this ethos through the ways they engaged with the production and use of parts from the registry. I argue there is a clear split between (sub-)communities in how they contributed and drew on those parts. I also note the importance of the *distribution kit* of parts in iGEM labs. I conclude with a brief reflection on how iGEM labs converged and diverged from the ethos and practice of the iGEM competition, as a programme where the norms of the latter could not be strictly enforced.

Lastly, I conclude with a reflection on the themes presented over the chapter, in 8.5. I explore the links and departures between these three prongs of iGEM in greater detail.

8.1 FROM AN MIT CLASSROOM TO A GLOBAL STAGE

The most visible face of iGEM is its competition. It is the oldest component of what now falls under the iGEM umbrella and it is often referred to as synonym with iGEM. Telling the tale of iGEM thus starts by telling the tale of the competition.

8.1.1 Before iGEM: the MIT IAP courses

The iGEM competition is credited as stemming from a MIT course ran during its 2003 independent activities period (IAP). The IAP is an optional term run over January where students are allowed the freedom (and are actively encouraged) to pursue projects of their interest, be that independently or with faculty, either in informal settings or formal courses. Faculty are also encouraged to deliver experimental courses; experimental in their educational format, their content, or both. Thus Drew Endy, Tom Knight, Randy Rettberg and Gerald Sussman – MIT faculty from the departments of electrical engineering and computer science, and biological engineering – embarked on an experiment on synthetic biology with a course designed to challenge students to produce cells that would emit bursts of light at periodic intervals (which they called "genetic blinkers" (MIT, n.d.)). This was to be accomplished by teams of students both reusing pre-packaged genetic material described in a catalogue (a primitive registry of parts), and by designing novel pieces of genetic material to be packaged and added to that same catalogue. As such, the initial course already carried many of the hallmarks of what came to be the iGEM competition. A similar course was offered over the following year's IAP, organised by three of the same faculty – Endy, Knight and Rettberg (with the addition of Radikha Nagpal and Pam Silver as instructors) – to another audience of 16 MIT undergraduate students. The students were once again given directions as to the broad theme under which they were to develop their efforts: this time, they were to design systems of cells arranged in defined patterns on a surface.

These early courses differed from the different iterations of the iGEM competition in perhaps one major way – there was no lab work involved. The engineering ethos of the courses is thus most salient in this explicit and deliberate decoupling of design and construction of biology. This is not to say the materiality of the biological systems was negated, but it was kept at arm's length. The courses encompassed a budget for DNA synthesis, which would take place over the spring (and was to be performed by others). The syllabus for the 2004 iteration allowed for the possibility of interested students working in labs, but as something additional – and which did not interfere with the course. Moving from the course designs into organisms featuring those standard parts was also challenging. The road to accomplishing the goals of the 2003 IAP had two major blocks – DNA synthesis and genetic modification – which delayed the completion of the courses for many months. Biology proved (and would continue to prove) unwieldy and resistant to deliberate (and modular) design.

8.1.2 2004: Synthetic Biology Competition (SBC04)

Such difficulties did not appear to dampen spirits and by the fall of 2003 this group of MIT faculty had successfully applied for an NSF award to allow them to run a competition of "student design of synthetic biological finite state machines" (NSF, n.d.). The grant brought this attempt to engineer biology to an audience beyond that of just MIT. It is particularly noteworthy that, in the abstract of the proposal, the proposed competition is framed as "analogous to the initial proliferation of VLSI design courses that took place in the late 1970s and early 1980s"[62] (ibid.). This positioning of the synthetic biology course is particularly interesting for two reasons: the invocation of the Mead and Conway *revolution* in integrated circuit design is telling of the ambitions of the nascent programme and suggests (or at least insinuates) a re-

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[62] VLSI stands for Very Large Scale Integration; these courses led to the establishment of the integrated circuits on which modern computer processors are based. A particularly important feature of these courses was the role they played in promoting an approach of decoupling the processes of design and manufacture of computer chips. This approach was mimicked by the IAP courses and has become a cornerstone of (the versions of) synthetic biology experimented with by teams in the iGEM competition over the years.

volution in (synthetic) biology is also possible; and the framing of such a revolution as enabled by a combination of pulling the epistemic practice from the realms of the arcane and depositing hopes on enrolling and training students from a wide(r) range of fields. As I will show, over the years students have continuously been framed as instrumental in the making of synthetic biology.

The NSF grant was used for the running of a 2004 competition. While this iteration has only retrospectively been described as iGEM 2004[63], it was in important ways also a place of further departure from the structure of the IAP in the direction of subsequent iGEM competitions. The team projects did not last for four weeks, but were run over a long period of time, starting in June and continuing over the summer; and the competition culminated in a gathering for all the teams in MIT in the following November – a gathering which was dubbed a *jamboree*. The projects were also not to be solely focused on designing the genetic circuits, but on a combination of designing and building. Biology was pulled from the sidelines and into sharing the spotlight with engineering. This imagining of synthetic biology as a task for biologists and engineers was made explicit in (succinct) competition materials (iGEM, 2004). The section detailing the "research context" includes only two short paragraphs: one aimed at scientists; the other aimed at engineers. Not surprisingly, the challenges the new field faces and aims to address are framed differently in each case: for biologists, the focus is on the dissonance between expectation and observation; and for engineers the lack of technologies that enable systematic engineering of biology. In either case, the implicit overall goal is the same: making biology predictable. As such, this competition was the first site in the trajectory of iGEM where collaborative, interdisciplinary ways of working (which brought together biology and engineering) were a core component.

This was also the first time the competition expanded outside of MIT, to include four other US universities. Participation expanded out, and the NSF grant came with the expectation that faculty from other institutions would dedicate a week planning

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[63] At the time, the competition was run under the more descriptive title of "synthetic biology competition 04".

the competition over at MIT. These new participants were hand picked. Their enrolment was largely due to the fact that they were "friends, who wouldn't complain too much if things didn't work out" (Rettberg, 2006) and, perhaps most importantly, they "were similarly optimistic" about the potential of synthetic biology. Through the creation of this competition, then, the synthetic biology epistemic community was leveraged through a local articulation of a "community of vision" (Kastenhofer, 2013).

This vision bears some scrutiny; and that can be succinctly accomplished through an examination of expected outcomes of this competition. As noted in the grant abstract:

> "This multi-school, multi-project design competition is the first multi-site test of such a Registry, and will result in the creation of an open, community-wide resource supporting research and education on synthetic biology. Also resulting from this effort will be (i) an initial set of teachers who are capable of expanding the scope and scale of educational programs that support the engineering of biological systems, (ii) a set of students who have practical experience with the current state and limitations in biological systems design, and (iii) an expanded set of standard biological parts, from which many more schools and researchers will be able to draw upon [...]" (NSF, n.d.)

In this excerpt, the community-making role envisioned for iGEM is stark. It is described as an endeavour to create the key components of a "repertoire" (Leonelli & Ankeny, 2015) for synthetic biology – the epistemic practice, the practitioners and the artefacts and infrastructures to support said practice. Central among the latter sits the registry of standard parts. It is purported as both a research and educational tool which will both enable work in synthetic biology and feed from work in synthetic biology. An ethos of openness is also entangled with such a framing, insofar as the biological parts created during the competition are to be made (freely) available in the registry for further (re)use. In such a vision of synthetic biology, the knowledge infrastructure takes the form of an "obligatory passage point" (Callon, 1984)– either as a source of knowledge, a repository of knowledge or both – for epistemic labour in synthetic biology.

In tandem, the competition aimed to enrol both sets of students and established researchers into the vision of synthetic biology promoted. Intriguingly, the role afforded to established researchers in the text is restricted to the one of educators. This again allows a parallel with the VLSI courses and the role of established academics in popularising that approach to chip design through running similar courses to the one by Mead and Conway. As in the latter case, enrolling academics appears to serve as means to an (larger) end: training generations of students in the new field. Thus, the competition is explicitly positioned as an attempt to build a community, and to do so from the bottom up.

From such a point of view, the 2004 competition was a success. The number of teams increased, as did the number of institutions, instructors and students involved. 50 more parts were added to the registry. That out of the five projects only one achieved the desired outcome appeared unproblematic. That project – UT Austin's bacterial biofilm photographs[64] – rose to prominence by being published as a brief communication in Nature and has been used in subsequent years as an example of the achievements possible in iGEM. That project was thus shared as a "success story" (Felt, 1993) – a narrative which celebrates achievement and is circulated widely, providing a common reference point in the (emerging) community, making it *stick* (Molyneux-Hodgson & Meyer, 2009).

8.1.3 2005-2010: first iGEM competition, internationalisation and institutionalisation

The following year, the competition became international. A total of thirteen teams entered, ten of which were from US institutions, one team from Canada and two from Europe – both European teams being led by researchers who also took active and prominent roles in the genesis of EU synthetic biology as described in Chapter

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[64] UT Austin modified E. coli to detect light and respond with a change in colour; they made biofilms of the modified bacteria and displayed light patterns onto them, which recorded the light pattern outlines in a similar – albeit crude – way to how photographic film records exposure to light.

5[65]. This year was also noteworthy for the introduction of the iGEM acronym, but with one major difference: the "i" stands for "intercollegiate", rather than "international". The choice of term is telling of the focus of the competition, which was still US higher education institutions.

As the numbers grew, so did the efforts to ensure the teams were aware of what was expected of their participation. 2005 was witness to the introduction of an event aimed at the researchers supervising the student teams. These events have taken different names, formats, durations and have been held at different locations over the years. In their introduction in 2005 they were tellingly named "Teach The Teachers"[66]. Such workshops encompassed a broad definition of what constitute "teachers", which went beyond the senior instructors, as the ones invited to prepare the competition the previous year, to include teaching assistants. Participation in the workshop was compulsory for all teaching assistants of participating teams: the registration fee for the competition included a contribution towards the running of the workshop, as

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[65] The European entries into the 2005 competition were from ETH Zurich and the University of Cambridge. The ETH Zurich team was led by Sven Panke, who was the lead of the SYNBIOCOMM and EMERGENCE projects and a participant in TARPOL, besides leading and participating in several FP6 and FP7 synthetic biology research projects; and the University of Cambridge team was led by Jim Haseloff (and co-led by a number of other faculty), who was a WP leader in EMERGENCE. As such, and at an early point in synthetic biology where several approaches competed under the same umbrella (Bensaude-Vincent, 2016), it is important to note that two of the prominent figures in EU synthetic biology are also prominent figures in the early iGEM competitions. This provides a strong indication of the *co-production* (Jasanoff, 2004) of the parts-based synthetic biology of iGEM and European synthetic biology, which I will continue to evidence through the chapter and address more meaningfully in Chapter 9.

[66] Such workshops encompassed a quasi-standard package of talks / lectures on the competition and synthetic biology, as well as short contributions from the instructors of each of the participating teams, in a structure that was repeated through the years. These talks would fall under the umbrella of four major themes: accounts of the history of iGEM and the visions for where iGEM was to go; the practicalities of taking part in the competition; technical content, from the basics of synthetic biology to the intricacies of biobricks; and the role of the registry of standard parts / interacting with the registry of standard parts. This quasi-standardisation also extended to the speakers for each of the themes, with Randy Rettberg, Drew Endy, Tom Knight, Meagan Lizarazo and Reshma Shetty consistently delivering the same talks. The centre stage presence of this group of individuals in all the workshops in all locations ran over several years is indicative of the enduring centrality of MIT in imagining iGEM and attempting to propagate a competition which would fit such an imaginary.

well as room and board for the instructors over the week it was run. As the workshop attendants returned home, they were expected to share the insights gained over the week – be it in terms of what was technically feasible, what projects could hope to achieve or what were valued approaches in iGEM – with members in the local institution; and to help run the projects on the ground, supporting the student teams and guiding them towards what would be considered a successful project. Through this training, and the concomitant influence over what constituted success, the iGEM core group at MIT had a remarkable level of influence over the trajectory of the competition.

In 2006, the "i" in the iGEM acronym changed from "intercollegiate" to its current formulation as "international". This change aptly reflected the changing geographic origin of the participating teams: in 2005 US teams made up two thirds of the total, but by 2010 they constituted less than a third of the total of the 128 teams signed up for the competition. Despite this change, the number of US teams in 2010 quadrupled when compared with 2005, which is indicative of the speedy growth of the competition as a whole. iGEM was no longer a competition primarily aimed at US institutions, but had an international (albeit not global) appeal. This was recognised (and promoted) by iGEM, and by universities and funding agencies around the world. From a European point of view, there was consistent support for student teams through the range of projects funded in support of an emerging synthetic biology, as described in Chapter 5.

As the competition grew, so did the expected duration of the projects and their complexity. This was mirrored by an increasing formality of participation requirements. In 2006, the organisers offered two modes for taking part in iGEM: either as part of an unstructured or a structured competition. The description of the former as unstructured was no understatement, as this mode encompassed "no rules or requirements, although you are welcome to contact the organizers if you have questions or concerns. Or not." (iGEM, 2006a). Such unbridled openness was short-lived.

By 2008 it had been dropped from the materials, which left the structured form as the de facto mode for competing[67].

The model for running the structured competition was largely defined in as early as 2006. Participation was contingent on fulfilling about a dozen conditions set out in the description of the categories of participation. These conditions have been amended and refined throughout the years, with further ones added as the competition adjusted to an evolving vision of synthetic biology and governance pressures, but the core tenets from the initial formulation endure as core features of the competition. The (increasing) prominence of these sets of conditions became visible in 2008, when they were renamed *requirements* for participation and given a standalone page on that year's competition website. Reference to these requirements was pervasive, and adequately reflect the extent to which they would come to dominate and structure iGEM work (a theme which I address in more detail in the following section). As the competition grew, these increasingly formalised sets of requirements enabled the iGEM organisers to retain broad epistemic control over the practice of synthetic biology, tacitly disciplining successive teams of novices in a synthetic biology which fit the vision of the (progressively less tightly linked) MIT core group. This was, however, not the sole means of ensuring conformity.

The sharp surge in growth taking place during this period meant that every year many (if not most) of the teams were being led by instructors who had not had previous experience in participating in the competition. Such lack of experience was problematised by the organisers as a hindrance to *successful* participation, an obstacle which they proposed to overcome in two major ways: by introducing an ambassador programme and by modifying and expanding the "teach the teachers" workshops. The ambassador programme involved matching a junior researcher who had taken part in a (or multiple) previous iGEM competition to a number of teams in a given geographical area, whose projects the ambassador would more or less closely follow. This ambassador was imagined to "maintain communications, visit,

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[67] The legacy of the unstructured competition may still be found in less structured / experimental tracks, which the iGEM has introduced and retired over the years.

and provide tutorials or assistance as required" (iGEM, 2006b) to guide the teams towards a successful project. Such efforts were explicitly aimed at teams with instructors who were new to the iGEM competition, thus promoting a vision of what constituted a successful project that was close to the ambassadors' interpretation of success and, by extension, of the organisers' interpretation of success.

In tandem with the introduction of an ambassador programme, iGEM also introduced an *alumni* programme. This programme overlapped considerably with the former – ambassadors were mostly conceived of as alumni, and alumni as key members of the ambassador constituency. The alumni programme (later renamed alumniGEM) has come in and out of focus over the years, with its most enduring articulation being a(n episodic) newsletter. Despite the modest outcome, the alumni programme provides interesting insight into an attempt by iGEM organisers' to address the temporality of the competition. Promoting an alumni association, then, can be productively interpreted as another attempt to promote *stickiness*, with the ultimate goal of keeping the participants in the competition aligned with iGEM and, by extension, (its) vision for synthetic biology. Thus, over this period, iGEM grew institutionalised as a competition which catered to teams around the world, enrolling both researchers and, one step removed, funders. The iGEM organisers retained overwhelming control over the epistemic trajectory of the competition, enforced via particular criteria for participation, but also with the creation of programmes ancillary to the latter, aimed at ensuring epistemic conformity and sustaining the epistemic project beyond the confines of the competition.

8.1.4 2011-2014: growth, division and (subsequent) convergence

iGEM went through a number of major changes in 2011, both in the structure of the competition and in the typology of participants. Ever since the early IAP courses, iGEM had kept its focus firmly on undergraduate participation. In the requirements as elaborated starting in 2008, the teams were not required to be exclusively made up by undergraduate students, although they were still to "consist primarily of undergraduate students" (iGEM, 2008a). In 2011, however, the organisers introduced a participation category for "postgraduate teams". iGEM continued to draw increasing numbers of postgraduate students and postgraduate teams and, in response, in 2013 the organisers precipitated a sharp break between undergraduate and postgraduate participation. They did so by creating an "overgraduate" category that would run alongside the existing undergraduate one, creating what were, in effect, two parallel competitions, each with their own sets of teams and identical sets of awards.

In tandem with an expansion in the direction of higher education and older participants, iGEM also grew to encompass teams with students in pre-university education. Unlike the overgraduate section, however, the high school section did not compete alongside the undergraduate, but was introduced as a largely satellite competition. The rules and requirements for participation in the high school competition were simplified; the expectations for time spent working on the project and the sophistication of the outcomes lowered; and the jamboree was shorter and took place independently from the main competition's. Still, iGEM's expansion to encompass a wider pool of novices is noteworthy[68].

The increasing size of the competition also prompted a significant change in how iGEM was run in this period. MIT held the jamborees (the gatherings at the end of the projects where teams presented their work) until 2010, but the growth of the competition now meant the number of participants greatly surpassed the capacity of the institution's venues. Jamborees where all the teams converged to MIT were no longer possible. This prompted the re-imagination of the structure of the competition, which resulted in the introduction of a two tier system. Teams were split into three to five regions, which constituted a lower tier in the competition. Each region held a jamboree, which was run in the same way as the MIT jamborees. From those jamborees, a number of the highest ranking teams advanced to a "world championship" jamboree at MIT. In this first tier the teams competed for overall prizes in the

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[68] While the high school competition is an interesting object of study in itself, in this work I will only refer to it where helpful to illustrate the workings and the development of the main competition.

same structure as the regional jamborees (though competition no further medals were attributed).

The regional competitions were not organised by the iGEM headquarters, with that task being delegated to institutions around the world. In the European case, the regional jamborees were spearheaded by different universities (which had entered a team) each year. Organising a jamboree, however, demanded the command of considerable resources. This meant that, much like the MIT jamboree, the regional competition depended on financial support from *sponsors*. This included companies, several of which already sponsored the main competition. Beyond the companies were once again EU FP6/7 projects. ERASynBio – the synthetic biology ERA-NET project described in Chapter 5 – in particular, was a major part of the financial engine and providing a sizeable portion (in one year the only major portion) of financial support, for the European regional iGEM competition, providing consistent support for the jamborees. Alongside this backing of a European competition, ERASynBio also continued the trend of providing support for the entry and work of European teams; still, in the years where regional competitions were introduced, this support was reserved for the teams which progressed from the European regional to the final jamboree in MIT.

Despite this considerable reconfiguration of the competition, which inevitably led to the inclusion of a number of actors in the organisation and delivery of iGEM, the organisers relinquished little more than logistic control to these institutions. The competition headquarters was still firmly in charge of the direction for iGEM. This was made explicit in the page where headquarters invited proposals for organising jamborees. In a section for "goals" it stated:

> "There is only one worldwide iGEM program. The Regional Jamborees and regional organizations act under the authority of iGEM Headquarters and in support of the overall iGEM program. iGEM is an open, cooperative, educational and research program to develop and apply synthetic biology based on parts for the benefit of everyone. iGEM is exciting, positive, and fun" (iGEM, 2011).

In such a statement, iGEM headquarters reiterated with sparkling clarity what they saw as essential components of the competition ethos and positioned itself as a body with the ability to ensure such an ethos would be sustained. In the development of regional jamborees, this control was visible in two ways: by drawing a number of requirements for the jamborees; and by requiring institutions interested in organising the jamborees to submit proposals to headquarters.

Requirements for the regional jamborees further articulated the expected conformity with the headquarters' vision for the competition. There, headquarters noted the regional jamborees were to follow the same rules as the ones held at MIT and that judging would take place under the rules defined by headquarters and the judging committees (whose membership was ostensibly decided by the former). By inviting proposals from interested institutions and placing the onus of the decision solely on its own shoulders, iGEM headquarters went beyond just setting out a vision and requirements for the regional jamborees to placing itself in a position where it was able to police compliance.

Still, the organisers' ability to influence the trajectory of activities is predicated upon the existence of active, distributed engagement from the budding community. This point can be usefully illustrated by the disappearance of the (teach the) teacher workshops. Between 2006 and 2012 such workshops – increasingly organised by institutions around the world – were a staple of iGEM. Attendance of one of these workshops was one of the requirements for participating in the competition. Calls for proposals were posted on the website early in the year. 2013 was no different, with a call having been posted on the website; and an entry for the workshops having been placed in the calendar of events for that year's competition. However, no workshop materialised – neither in 2013 nor in subsequent years. While the disappearance of the teacher workshops is likely to have been driven by a combination of factors, the wording for the (very short) call for workshop proposals in 2013 points to a potentially significant contributing factor. Unlike previous years, the event to organise is not described in the call as a workshop; instead, it is a call for coordinating "meet-ups" (iGEM, 2013).

Such a change is of consequence because “meet up” is the designation chosen for student-focused events. These events were held in a largely ad hoc basis in the years before 2010, but have since taken place every year and grown increasingly popular[69]. The formats for student meet ups have varied widely between regions, years and the stage at which they are held. Nevertheless, they can be loosely characterised as events run during the summer, in the lead up to the jamboree(s); events which are explicitly catered to the student teams (and often at least partially organised by the teams); and events where sharing / collaboration are explicitly encouraged. So beyond an explicit drive to promote networking among junior researchers, meet ups often include poster submissions and/or presentations by the attending teams, which are largely framed as opportunities for practising presentation skills, uncovering potential flaws / improving the projects and / or finding areas of potential collaboration. As such, the meet-ups provided arenas for articulating the (iGEM) synthetic biology ethos, while at the same time the (delegated) policing of that ethos.

A final point to be made about reconfiguration during this period is the weakening of the links between iGEM and MIT. Over a number of years the MIT core group which had driven iGEM from the beginning slowly disbanded. Drew Endy and Tom Knight gradually stopped being involved with the competition, which increasingly became run by Randy Rettberg and Meagan Lizarazo. The increasing size of the competition also meant that it was no longer logistically feasible to run the jamborees at MIT as before and prompted the organisers to consider different venues[70]. By 2012 iGEM had severed the formal link with MIT, spinning out of the university and starting the process of establishing itself as a non-profit organisation. This separation spelled the end of the regional jamborees. With the link to MIT formally severed, the logistic constraint to the running of iGEM as a sole competi-

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[69] The geographic distribution of such meet-ups has varied widely, with some locations consistently hosting events and others operating on a largely one-off basis. Their potential audience has also been varied, with some events targeting nations or even regions, while others ostensibly opened up to participants from entire continents.

[70] Rettberg referred to the difficulties and time delays of organising an event of the magnitude of a single jamboree with all the teams entering the competition as the reason for running regional jamborees over multiple years. He framed a single jamboree competition as his preferred model.

tion also disappeared. Thus, the 2014 competition returned to a single jamboree model, celebrated as a *grand* jamboree[71]. In this way, the iGEM organisers returned to a model which afforded them overarching control over the competition once again.

Over this period, iGEM grew not only in size, but to encompass wider groups of actors both in a pre-university stage, and in a post-training, early career stage. Its focus on explicitly addressing established researchers waned, but it was replaced by a drive to more firmly enrol junior researchers in the grand epistemic project. The meet-ups also constitute an example of the tension between overall control of the trajectory of the competition by iGEM organisers, and the distributed, communitarian labour which was recruited for enabling that trajectory. Meet-ups were organised by the community, but the iGEM organisers remained an OPP – the events were made official and publicised via the listing in the iGEM website. That same tension can also be identified in the running of regional competitions, where the labour was distributed, but iGEM organisers closely policed the structure, content, and aims of the events.

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Over an 11 year period, iGEM grew from an MIT classroom with 4 instructors and three handfuls of students, to an international competition with a cumulative total of over 1200 team entries and over 20,000 individual entries. Through sheer size alone, iGEM became an unavoidable reference point in synthetic biology. Still, the iGEM competition has relevance in the epistemic trajectory of the field beyond its size. Through the competition, a *core set* (Collins, 1985) of researchers in MIT, proponents of a parts-based synthetic biology, were able to disseminate that vision; and not only disseminate it, but through participation in the competition, and explicit la-

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[71] The running of a single stage competition was a key goal of the iGEM foundation from its inception in 2012. In the 2014 competition jamboree, Randy Rettberg explicitly claimed that they had originally planned to run the 2013 competition in that model, but those plans were thwarted by the logistics of booking an appropriate venue. (field notes, iGEM jamboree, 3rd November 2014).

bour towards enrolling established (and establishing) researchers which guided the participation of individual teams, iGEM became a key entity in and proponent of a "community of vision" (Kastenhofer, 2013) for a particular PBSB.

In this way, a local, American vision for synthetic biology came to global prominence. However, making the vision come to fruition relied on distributed, communitarian (epistemic and non-epistemic) labour from novices and established researchers around the world. Labour was distributed, but iGEM organisers kept firm grip over the epistemic trajectory, both at arm's length – through programmes intended to propagate and sustain their vision for synthetic biology – and directly, through engagement with the researchers which led the teams and a progressively codified and institutionalised system of rules (and rewards) for participation, which I address further in the following section.

iGEM can thus be productively identified as a key *community-making device* (Molyneux-Hodgson & Meyer, 2009) in synthetic biology. It very clearly articulated a need for community, and it provided a clear point of convergence for (the emerging) synthetic biology. In tandem with this movement, the competition was also imbued with a vision to ground that community, and went to great lengths to create *stickiness* (ibid.) through participation in the competition (and, to a lesser extent, beyond it). In particular, iGEM was a driving (and policing) force for a synthetic biology *repertoire* (Leonelli & Ankeny, 2015) defined broadly by an engineering ethos, coupled with collaborative ways of working on the engineering / biology borderland. I now turn to a brief examination of what that repertoire included and how it was promoted and policed.

8.2 INSTITUTIONALISING THE IGEM COMPETITION, BUILDING (A) SYNTHETIC BIOLOGY

In the previous section I showed how parts-based synthetic biology went from a classroom in MIT to a competition with thousands of participant over a decade, through the hand of iGEM. I also alluded to an increasing formality in the competition as time progressed, put in place to steer the practice of synthetic biology in iGEM towards an evolving vision for parts-based synthetic biology. In this section I briefly address this point further, outlining the creation and crystallisation of a practice which drew from an evolving vision for synthetic biology from the key iGEM promoters, on a trajectory that reflected the inclusion of further actors in the epistemic project.

As noted in section 8.1, the IAP and early iGEM competitions were characterised by a drive towards loosely bound experimentation. There was an absence of formal guidance, and the work was largely driven by a fairly abstract vision for the manipulation of biology following an engineering ethos, in what would crystallise as seeing biology through an (engineering) abstraction hierarchy. At the same time, the competition was also underpinned by a focus on enjoyment in participation. As the iterations progressed, this focus on enjoyment also became blended with a reward system. The 2004 competition witnessed a first step towards the introduction of such a system, with the introduction of awards. In 2005, the competition saw the making up of awards as it progressed[72], with a total of 50 created and distributed through the teams. Some of these awards rewarded different facets of technical achievement, like the “Best Model-Driven Design” or “Best Device Award”. However, most of the awards were explicitly playful. There was a “Best TAATACGACTCACTATAGG-GAGA Award”, another for “Best Use of Transmogrified Smiley Faces” and even one “George W. Bush Geography Award”. These awards also constitute a site where (what would become the) two of the major building blocks of the competition intersect: the centrality of rewarding effort and the centrality of playfulness / having fun.

As the competition grew, the playfulness of awards became downplayed. In 2006, they were relegated to honourable *mentions*[73]. In the following year, they were

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[72] This was illustrated by Endy’s later problematisation of the initial lack of awards for all the participating teams in this year’s competition, a problem which they solved by making up a number of awards as it was running.

[73] Honourable mentions included playful awards such as “most likely to appear on CSI” or “inventing a category of bacterial schoolyard games”, alongside more substantive ones, like “progress in

largely marginalised. In their place sat more conventional structure of awards. The main award of the competition was a *grand prize*, complemented by two *runner up* spots. In tandem with these, the competition also saw the introduction of special awards (such as *best part* or *best documentation*)[74]. Starting in 2007, the range of awards expanded to a more formal set, with the introduction of medals. In the Olympic tradition, these were bronze, silver and gold. The introduction of medals belies an important step in the institutionalisation of the competition via the formalisation and codification of its evaluation system.

Attached to each medal were a number of what were dubbed *judging criteria*. The judging criteria were elaborated as a number of sets of tasks / achievements split in three sequential categories. Completing all the requirements for the first set of achievements yields a bronze medal. Completing the requirements of both the first and the second categories yields a silver medal. By extension, completing all sets of requirements yields a gold medal. The list of criteria introduced in 2007 was short, stating them as

> "Bronze -- project description on iGEM wiki, oral presentation and poster at Jamboree
> Silver -- project description on iGEM wiki, oral presentation and poster at Jamboree, parts sent to Registry
> Gold -- project description on iGEM wiki, oral presentation and poster at Jamboree, parts sent to Registry, parts descriptions entered in Registry". (iGEM, 2007)

In these criteria, the focus is very clearly on the *parts*. iGEM teams were sent *distribution kits* at the start of the competition – physical compendia of (the[75]) parts available in the registry, delivered in large (and multiple) plates of biological material.

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detecting and remediating metals in soils" or "for advancing hydrogen fuels through biodetection".

[74] In subsequent competitions both the medals, overall prize and special prizes were maintained (although the latter were simplified) and a new category of track prizes was introduced. In the interest of brevity, an examination of the competition tracks (and its prizes) is omitted from this thesis.

[75] Up to 2007, the teams were sent physical samples of all the (physical) parts in the registry. However, starting in 2008, they were sent a curated set of parts – a response to both the increase in volume of the registry, but also to issues of quality of the material available. I discuss this further in the registry section, 8.3.

These artefacts were a cornerstone of the competition, as teams were expected to draw from the work of previous teams through the use of their parts (made available in the distribution kit); and they were also expected to contribute new parts, which would then be incorporate in the registry – in a process which Frow & Calvert (2013) described as the building of a moral economy in (and around) the competition. This focus on parts, and the increasing reward associated with more sophisticated contributions, is not accidental, but it is at the core of iGEM. As noted in the introductory section, the vision for PBSB in the latter was underpinned by the availability of a catalogue of components (parts, devices and systems) which would enable the mixing and matching of biological material for the rational design of new structures and functions. In linking the rewards of the competition to the production of parts, the iGEM organisers enrol the competition as whole in the development of the key OPP of PBSB.

Acceptable formats for the parts – from the vector[76] in which they were shipped, to the specific format of the part to be added to the registry (a theme I touch on the following section, in relation to biobrick standards) – were further specified. Thus, the policing of epistemic practice in the competition through specific rules of participation dovetailed with the nudging towards particular types of practice through the judging criteria. The rules for participation also became increasingly stringent in subsequent competitions. This is usefully illustrated by the increase in prominence of biosafety concerns. As those concerns grew in prominence in the vision for synthetic biology promoted under iGEM, the competition positioned iGEM headquarters as an arbiter of biosafety, banning (or discouraging) the use of particular organisms, and evaluating the DNA sequences of all parts submitted. Once again, iGEM

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[76] In this context, vectors refer to *plasmids* – DNA structures smaller than chromosomes which can replicate independently from the latter, commonly found in bacteria; in the context of wet lab biology, plasmids are manipulated to include sequences of genetic material of interest to the researchers. The incorporation of genetic material in plasmids (parts, in this case) is often accomplished for the purpose of *amplification* of the desired genetic material – the entire structure is be introduced into a bacterial cell, which will replicate the entire plasmid several fold; the plasmid is then extracted from the bacteria, the (multiplied) genetic material of interest is cut and subsequently separated and retrieved.

placed itself in the position to police the epistemic practice and outcomes in the competition.

The institutionalisation (and concomitant bureaucratisation) of biosafety concerns provides only a small window into the changes to the vision for synthetic biology under iGEM and the institutionalisation of that vision. These changes are no better illustrated than in a comparison of the 2007 awards criteria with those of the 2014 competition, (a truncated version of) which are as follows:

> "Bronze. The following 6 goals must be achieved:
> Team registration.
> Complete Judging form.
> Team Wiki.
> Present a poster and a talk at the iGEM Jamboree. See our new 2014 poster guidelines for more information.
> [...]
> Document at least one new standard BioBrick Part or Device used in your project/central to your project and submit this part to the iGEM Registry (submissions must adhere to the iGEM Registry guidelines). [...]
>
> Silver: In addition to the Bronze Medal requirements, the following 4 goals must be achieved:
> Experimentally validate that at least one new BioBrick Part or Device of your own design and construction works as expected.
> Document the characterization of this part in the "Main Page" section of that Part's/Device's Registry entry.
> Submit this new part to the iGEM Parts Registry (submissions must adhere to the iGEM Registry guidelines).
> iGEM projects involve important questions beyond the bench, for example relating to (but not limited to) ethics, sustainability, social justice, safety, security, or intellectual property rights. Articulate at least one question encountered by your team, and describe how your team considered the(se) question(s) within your project. [...]
>
> Gold: In addition to the Bronze and Silver Medal requirements, any one or more of the following:
> Improve the function OR characterization of an existing BioBrick Part or Device (created by another team or your own institution in a previous year), enter this information in the Registry. [...]
> The growth of the Registry depends on having a broad base of reliable parts. This is why the improvement of an existing part is just as important as the creation and documentation of a new part. [...]

> Help any registered iGEM team from another school or institution by, for example, characterizing a part, debugging a construct, or modeling or simulating their system.
> iGEM projects involve important questions beyond the bench, for example relating to (but not limited to) ethics, sustainability, social justice, safety, security, or intellectual property rights. Describe an approach that your team used to address at least one of these questions. Evaluate your approach, including whether it allowed you to answer your question(s), how it influenced the team's scientific project, and how it might be adapted for others to use (within and beyond iGEM) [...]" (iGEM, 2014a).

The contrast between the two sets of criteria is stark. For one, the very difference in length is indicative of different degrees of structuring in the competition; while teams in the 2007 iteration were afforded broad freedom in practices, by 2014 the practices valued in the competition had been (lengthily) codified in the medal criteria. For another, there is also a difference in expected sophistication of the projects, with the criteria which enabled a gold medal award in the 2007 competition affording only a bronze medal in 2014. Lastly, and of particular importance, the 2014 criteria envision a practice which goes beyond the initial engineering-biology redux, but point instead to the mantra that *iGEM is wet lab, modelling, and human practices* (field notes, iGEM jamboree, 1st November 2014). Thus, if iGEM organisers retain control over the practices in the competition via these criteria, the criteria themselves suggest a shift in the vision for synthetic biology in the former[77].

While a detailed examination of the (progressive) changes to this vision is omitted in the interest of brevity, two examples of the expansion of the inclusion of additional actors in the *community of vision* provide a useful illustration of the changes in iGEM. A peculiar example of the embedding of civil society actors in the competition lies in the engagement of/with the American Federal Bureau of Investigation (FBI). Starting in 2009, the FBI was a consistent (and significant) sponsor of the iGEM competition. If biosafety concerns had been present for some time, in their engagement with iGEM, the FBI brought to the fore questions of biosecurity. These came into sharp focus during the jamborees, where the FBI consistently held a talk

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[77] This is arguably not the case of the rise to prominence of mathematical modelling, which can be most productively linked to a refinement of the idealisation of the technicity of synthetic biology work beyond the meeting of engineering and biology.

addressing biosecurity as an issue, focused on issues of dual use and terrorism. In these talks, iGEM participants were quite forcefully recruited as agents for the prevention of nefarious use of synthetic biology, as highlighted in this snippet from field notes at the iGEM jamboree:

> "[The FBI agent] claimed there were three rules to follow, on which he would deputise everyone. […] He asked them to be guardians of science. Repeatedly. To protect it. To make sure they never allowed it to be misused or abused. […]
> He then actually – in his words, informally – *deputised* the iGEMmers. He asked everyone to stand up. To put their hand over their heart. And then asked if they promised to have fun, be guardians of science, and pass iGEM on, which the crowd replied to with a bleak and muted "yes". After thanking everyone, the FBI agent cheerfully added that the iGEMmers had just fulfilled article 4 of the biological weapons convention" (field notes, iGEM jamboree, 2nd November 2014)

This (most enthusiastic) tasking of synthetic biology novices with the protection of science from specified and unspecified forms of evil may have come to a head in the talks, but pages on biosecurity appeared on the iGEM website in 2009, and were replicated over the following years; and biosecurity was codified as a dimension of human practices, amenable to study. In this way, biosecurity became incorporated in the vision for synthetic biology under iGEM.

The addition of human practices work to the judging criteria presents, in itself, an interesting dimension of expansion of the vision for synthetic biology under iGEM in the direction of the "new biology" (NRC, 2009), particularly as it was concomitant to the inclusion of experts in various dimensions of human practice as judges in the competition. Still, that movement is problematised by the sheer broadness of what may constitute valued *human practices* work in iGEM, and the observation that, at least until 2012, the practices were mostly guided by a(n information) deficit model (Frow & Calvert, 2013). Among the practices promoted and performed, however, the intersection of iGEM with the EU FP7 SYNENERGENE project is noteworthy. Spanning over three competitions, the EU project provided resources and funding – first to teams based in the European Union, but later to any team – for undertaking work which fell under the broad umbrella of Responsible Research and Innovation (RRI). In this way, the iGEM competition engaged in experimentation under what was one of the EU's novel and key *socio-technical imaginaries* (Jasanoff & Kim, 2015).

With these two examples, I aimed to illustrate the negotiation of practices in the iGEM competition between the organisers and other actors. In particular, I noted the establishment of *human practices* as one of the medal criteria – with the constructive ambiguity associated with the term (which can be productively regarded as an *umbrella term*) – reflects a changing vision for synthetic biology, and enabled the engagement of new actors in the community of vision, with inherent impact on its trajectory. I do not intend, however, to downplay the role of iGEM organisers in the trajectory of the competition. I end my examination of the competition with a return to the focus on the organisers, in the context of the mobilisation of past projects for guiding new practice.

Alongside medal criteria, the competition consistently guided contemporary participation through reference to past work. A key example is the E. *coli*-brator project. Being one of the projects conducted in the 2003 MIT IAP course, it had a life which transcended the context of its genesis. It was alluded to in local presentations by Endy and Rettberg; made it to the "teach the teachers" workshop in 2006 (iGEM, 2006c) (and was even described in the Synthetic Biology 2.0 conference, again by the hand of Randy Rettberg (Rettberg, 2006)). Most importantly, the E. *coli*-brator was used in subsequent years as a guide for iGEM work. In other words, the E. *coli*-brator constituted a well travelled "exemplar" (Kuhn, 2012 [1970]). It provided both a model to the types of problems synthetic biology could address, and how to address them.

Over the late noughties, the reference changed from a single project, to the dimensions of work in an iGEM project (largely codified in the judging criteria). Exemplars were attached to the goals: e.g. the description of parts in the registry was described as one of the medal criteria, and one specific part in the registry was offered as a model for how to do so; this pattern of guiding practice through exemplars was one also present in relation to the project presentation, the project webpage, the characterisation of parts submitted to the registry, or some of the special prizes. In their roles as models for how to successfully attain the individual goals, these constituted piecemeal exemplars, but exemplars nonetheless.

The codification of the judging process around 2012 reintroduced a more holistic approach to the presentation of exemplars. The manuals created for judges (which also increased in complexity with each new iteration) had guidance on the practicalities of the judging process and the expectations of the role of judges as the bulk of their content. However, they also included guidance on what was to be considered a *good* iGEM project. Here, one (or a small number of) project(s) selected from the previous year's competition were either described in some detail, with explicit emphasis on the *why* the project was deemed particularly good. It is also noteworthy that, while these manuals were ostensibly aimed at the judges, they were made available to the student teams as well – with clear encouragement for the teams to study the process thoroughly. So, once more, the idealised practice of synthetic biology in the iGEM competition was guided through exemplars – made available to students and judges alike.

* * *

Over this section, I address the progressive institutionalisation of the iGEM competition from the point of view of the crystallisation of practice allowed and promoted under it. I note the move from a largely open field for practicing synthetic biology, to a competition which was heavily structured. I argue that two (interconnected) movements were key in that structuring. Awards, largely playful at the start, became increasingly formal (and formalised). Through these awards – be they medals or competitive prizes – the competition went through a gradual process of erecting what were (or were not) valued practices; this *boundary work* (Gieryn, 1983) being largely achieved by shaping practice through shaping what counted as successful participation. Alongside these more forceful criteria (and restrictions), I note that practice was further guided by *exemplars* (Kuhn, 2012 [1970]), deployed in different forms over time. Exemplars were deployed so that the novices would "learn to see the same things when confronted with the same stimuli"(Kuhn, 2012 [1970]); reference to past projects can be interpreted asthe use of previous successful participation as model for new participation.

The markers of success, however, also changed across time. I link this to a changing vision for synthetic biology driving the competition, and trace two instances of the expansion of the actors in the *community of vision* (Kastenhofer, 2013) for (iGEM) synthetic biology. I note that the inclusion of such actors impacted on the trajectory of synthetic biology (in iGEM), bringing prevailing s*ocio-technical imaginaries* (Jasanoff & Kim, 2015) closer to the ethos of practice in the competition. Despite these adjustments to the guiding vision, I argue that the standardised packages of genetic material remained central to the vision and practice in the competition – manifested through the distribution of a catalogue of genetic parts from the central registry of standard parts, and in the structuring of the competition towards the production (and/or improvement) of new ones. I now turn to a more detailed examination of the role of that registry of standard parts in the trajectory of iGEM.

8.3 IGEM (AND THE) REGISTRY OF STANDARD PARTS

The main focus of iGEM has consistently been the yearly competition. However, the competition did not (and does not) make up the entirety of iGEM. Two other components exist as the registry of standard parts and "iGEM labs". With the latter two, iGEM expanded its focus from students to a wider (potential) community. Indeed, the registry and iGEM have arguably been *co-produced* (Jasanoff, 2004). The emergence of the registry of standard parts is closely intertwined with the emergence of the competition; it has played an important role in enabling the (vision for the) competition and its parts based ethos. In tandem, it was poised to play a role of catalogue of parts to a wider range of actors. Less closely linked to the competition was the attempt to enrol established research groups, which would contribute to and benefit from the wealth of parts accumulated in the registry. This was done under the banner of iGEM labs. I address the registry of standard parts in this section, and finish the analysis of iGEM with the labs programme in the next.

The registry of standard parts has been an essential component of the imaginary of the parts-based synthetic biology ethos that has developed out of MIT. It serves as the repository arm of iGEM, feeding into and off the iGEM competition and the other iGEM components. In a clear homage to the prevalent epistemic practice of (high-tech) engineering research and industry which has inspired the development of parts-based synthetic biology (and is particularly close to Rettberg's heart, as has been previously noted (Campos, 2012)), the registry was imagined as a giant catalogue of parts. There, the large number of parts were to be listed, categorised and thoroughly described. Such parts were to be thoroughly predictable and provided in a standard format. This vision diverges from the common ambitions and design of repositories within biology[78], making explicit the engineering ethos of the nascent field.

An ethos of openness can also be readily identified in the registry[79]. The sequences and documentation for the parts held in the registry are publicly available; and physical samples available to all iGEM teams and (community) labs (membership of which is also open). Registered users are able to comment on their experiences of using existing parts and / or make their own new submissions. Documentation for the technical standards for submission is likewise open. New part submissions must also conform to these standards of openness. The dimension of openness has arguably been the most successful one of the broader ethos of iGEM synthetic biology; the registry grew to roughly 20.000 parts in 2014, all of which were freely available for re-use. The size of the catalogue, however, obfuscates the epistemic

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[78] This is arguably even the case when biologists converge around model organisms. See Leonelli (2010) for an overview of the pluralism associated with biological databases, and Leonelli & Ankeny, (2012) for insight into how model organism communities and databases have become co-produced.

[79] This has been noted previously by Frow & Calvert (2013).

hardship and (re-)negotiation of the role of the registry in iGEM and synthetic biology more broadly. I address these themes in this section, through an examination of the trajectory of the registry and the unwieldiness of the biology it was to tame.

8.3.1 Versions of the registry of standard parts

The initial formulation of the registry of standard parts predates the iGEM competition, as noted in section 8.1.1. At this early stage it was primitive, taking the form of a single page deep in the MIT servers. This page had nothing other than a table where parts were displayed – one part per row and columns for part number, name / description, version and revision. A hyperlink on the part name directed to a text file with the DNA nucleotide sequence.

This was the registry made available to the MIT IAP course teams and whose parts they were expected to use for developing their projects. After the course ended, all the parts developed there were added to the existing registry and the expanded version was made available to the 2004 course. Similarly, after that finished the parts were added to the existing registry and a collated version was made available to the 2004 competition. This iterative process has been in place for all successive iterations of the competition, which has prompted the growth of the number of parts in the registry from about two dozens in early 2003 to roughly 20.000 at the end of the 2014 competition. Indeed, the iGEM competition has been, by far, the largest contributor of entries into the registry. As such, the speed of growth and resulting volume of parts the registry were directly enabled by the competition. Participating in iGEM came with the expectation that teams would deposit the parts they developed over the course of their work in the registry. In the early competitions this expectation was articulated in the rules for the (structured) competition; and as the medals were introduced, submitting at least one new part to the registry was made a core requirement for receiving a bronze medal (and due to the cumulative requirements for silver and gold, a medal of any kind).

As the competition grew increasingly sophisticated, so did the registry. In early 2004 it started to encompass technical information of relevance to understanding and creating new parts, besides the parts list itself, which anyone could browse. A major change came in 2006, in the direction of its current format. This entailed the introduction of a searchable database of the parts, which was accessible via a (media)wiki front end. Using this wiki interface, users could now create accounts and add new parts to the registry themselves, thus removing the responsibility of adding new parts from being solely on the shoulders of the curators. It became part of the efforts to be distributed throughout the (implied) community.

Adding new parts entailed providing some housekeeping information – the part creators, its name, type (according to the types available in the registry) – a description of the part, information about its design and, finally, the part sequence. This was also the base for the (standard) information hierarchy of the registry entries for parts, as illustrated in the figure in Appendix E. Notably, alongside subpages providing further details on the design of the part and a general overview of information, the part pages also include an "experience" field. There, successive users of the part are expected to provide feedback after employing the part. As such, the part page is designed with an implicit expectation that validation of the part is a distributed task; and provides further indication of the ideals of openness and diffusion of the epistemic labour which underpins the registry throughout the community.

Alongside the reinvention of the digital repository, the registry also moved from early on to create a material repository. This meant there was an off-line life for the entries in the registry, which started as a -80°C freezer in one of the many MIT cold rooms (as noted by (Campos, 2012)). This was an indispensable feature of the imagined repository; a catalogue of genetic sequences was of little use, if the material parts which it described were unavailable. So, as new parts were created and added to the digital repository, biological material also converged on iGEM headquarters. These materials were stored in the freezers and made available to iGEM teams and labs, either on request or through one of the yearly distribution kits. The material configuration of these artefacts has also varied, depending on the year and number of samples, and in response to feedback (and frustration) from its users.

8.3.2 Standardising (unwieldy) biology

Managing the unwieldiness of biology, the core problem parts-based synthetic biology positioned itself to solve, was also one of the major problems and aims of the registry. Following the engineering ethos that underpins iGEM and concomitant modularisation of biological material, this was an issue which was tackled in great part through efforts of standardisation. All parts were expected to be described and documented in a standardised fashion on the online registry; and, beyond that, they were expected to be designed and constructed following specific standards. From the beginning, this has been the BioVrick RFC10 assembly standard which Tom Knight drew up in 2003 (Knight, 2003) (and refined in 2007). However, the appropriateness of this standard quickly became contested. For one, it had a technical shortcoming which made it impossible to use to create fusion proteins[80]. For another, its reliance on restriction enzymes for assembling DNA fragments means that the specific short DNA sequences those enzymes use to identify the sites for cutting the DNA strand could not exist anywhere in the sequence of the DNA fragment(s) to be joined; this meant that DNA fragments with those short sequences required modification. Although the use of restriction enzymes was common practice at the time the standard was developed, new methods for assembling DNA fragments which were not subject to those constraints were created and gained popularity towards the end of the decade. Consequently, this Biobrick RFC10 soon became an unloved standard, even by its creator and promoters, as argued in Campos (2012).

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[80] Fusion proteins are proteins resulting of the combinations of two (or more) different genes, in a way that the two become joined as one larger protein with the functions of both parent proteins. It is common practice in molecular biology, often with the aim of combining a protein of interest with another which is easily identifiable – commonly via fluorescence or a simple assay.

Over the years, iGEM witnessed the genesis of a number of competing standards designed to overcome the shortcomings of the prevailing BioBrick RFC10[81]. Pamela Silver's lab proposed a standard which allowed fusion proteins (BioBrick RFC23); the Freiburg 2007 iGEM team and a group of UC Berkeley researchers proposed standards which solved multiple RFC10 problems (BioBricks RFC25 and RFC21); and Tom Knight developed a completely revamped successor to its (in)famous standard (BioBrick RFC12). None of these standards was fully compatible with the original RFC10, with the UC Berkeley and the new Tom Knight standards being altogether incompatible. However, none of these standards was able to dethrone RFC10 as the *de facto* standard of the competition. In fact, they hardly made a dent – the vast majority of parts in the registry and of parts being submitted every year conform to the RFC10 standard.

The proliferation of standards problematised the universality that underpinned the early vision for the registry of standard parts. It was becoming clear there would be no unique registry of a unique standard, but that the registry would need expand to encompass multiple standards. In particular, the incompatibility between the new standards and RFC10, and between the new standards themselves made the gracious deprecation of one standard by a newer, universal one difficult. The registry sidestepped this issue by opening submissions to parts which were compatible with any of the BioBrick standards (Registry of Standard Biological Parts, 2008). However, the it maintained the "BioBrick RFC[10] is the Registry's current de facto standard" (Registry of Standard Biological Parts, 2015b); physical parts would only be accepted and made available if they were compatible with RFC10. This was, at best, a partial opening, and one which made the de facto exclusion of a number of standards explicit.

Standardisation efforts in the registry went beyond the assembly standard, with most interactions between the registry and users being subject to standards of vary-

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[81] The proliferation of standards and their technical evaluation / validation were not phenomena under the umbrella of iGEM, but of the BioBricks foundation. This body bears no direct link to iGEM, although the main actors of early iGEM (Drew Endy, Tom Knight, Randy Rettberg and, to a lesser extent, Pamela Silver) made up most of its early board of trustees.

ing formality. This tendency has been accentuated through time; early iGEM competitions had as firm requirements solely that parts were to be sent as part of a (RFC10 complying) plasmid that had been added to and substantively documented in the registry. Using a light touch, the organisers noted the importance of conforming to the use of standard plasmids for the future of the registry, remarking doing so would "facilitate sharing and interoperability and will be greatly appreciated by both your peers and those that come after you" (iGEM, 2008b). By 2010, however, this appeal to communitarianism was replaced by an explicit trend to curb openness in lieu of increased standardisation. Through the registry, iGEM suggested a number of BioBrick standard compliant plasmids[82] for use in assembly; others for use in measurement; but restricted the plasmid to use in part shipments to a single one: pSB1C3. Consistent adherence to the shipping standard was framed as important because it allowed the registry to avoid the "unnecessary complexity" (Registry of Standard Biological Parts, 2015a) of the cacophony of different plasmids which would be used if they followed standard molecular biology practice. Instead, it allowed for the same procedure to be applied to all the parts received, which would help the registry "handle, maintain, and test"(ibid.) the thousand(s of) new parts it received each year. Beyond the benefits of increased efficiency in depositing the parts, the shipping standard also promised to favour users. The use of the same plasmid would allow the latter to have consistent experiences manipulating parts from the registry, with the implication such consistency would increase efficiency and ease of use.

Creating and maintaining the physical part repository required replicating the BioBrick parts received, building stocks which could be stored and further replicated as needed. Once again, the registry opted for a standardised approach, replicating all parts using a common strain of E. coli[83]. This left parts which had been created for use in different organisms (or *chasses*, in synthetic biology terminology) with the added onus of ensuring those parts were not only amenable to being shipped in the rel-

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[82] A significant proportion of which has been added over successive iGEM competitions.

[83] Although the wikis for earlier iGEM competitions make mention of the use of a TOP10 E. coli strain, the differences between that and the current NEB-10 strain are minute to the point they can be overlooked.

evant plasmid, but also that these were parts were amenable to being replicated in E. coli. The unwieldiness of biology manifested here as well, for not all parts designed for / extracted from different organisms are amenable to be replicated in E. coli – an issue which is amplified with either an increase in complexity from *parts* to *devices*, or with the use of eukaryotic organisms[84].

These multiple instances of standardisation – of the parts, the registry pages/information, the plasmids, or the organism around which the material repository is built – foreground not only the drive towards standardisation which stems from the iGEM PBSB ethos, but they also point to the ancillary drive to make biology easier to engineer. Nevertheless, if these multiple efforts at standardisation were conducted with a view to tame the unwieldiness of biology, the latter proved uncooperative. No one standard for biological parts was without downside. Not all parts worked (or worked as expected). Not all parts (nor all organisms) were amenable to be held in the material repository. This unwieldiness of biology tamed the grand, universal vision for the registry. Faced with contention over competing standards, intellectual property models and quality of entries, the vision of the registry as a single, universal repository was left by the wayside. As far back as 2006, Rettberg claimed:

> "The thing that we're working on after the summer is how to arrange the registry so that we encourage a broad community of people working on parts. The answer to that, in my opinion, is to not have a centralised registry. But rather, to make the protocols and technologies, using some of the semantic web-like things, to allow many universities, industrial firms, governmental organisation, to all have their own registry. In a similar way to the semiconductor industry, where lots of vendors offer their own catalogues of parts." (Rettberg, 2006)

Rettberg makes clear that the aim for the registry extends well beyond the iGEM competition to a plethora of other actors. These, however, were actors whom the current registry was ill-suited to accommodate. So, rather than a single universal in-

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[84] This once again points to the relevance of model organisms in the trajectory of synthetic biology, and a tacit reduction of canonical synthetic biology practice to a synthetic biology *of E. coli* in the context of iGEM. While a detailed examination of the role of organisms in synthetic biology remains beyond the scope of this thesis, it is likely to constitute a productive analytic lens in further research.

frastructure, Rettberg put forward a vision of a flexible registry, one which could be taken up, held by, and modified to fit the requirements of the different users. In this way, the registry was discursively downgraded from *the* universal infrastructure, to *a* universal infrastructure. It was not to be a single, centralised entity, but rather a core artefact in the synthetic biology *repertoire* (Leonelli & Ankeny, 2015). The registry (or registries) were still imagined as anchoring synthetic biology – if not as a singularity, as an OPP in the practice of synthetic biology nonetheless.

The rules and standards that rule the registry, then, are important for epistemic practice in synthetic biology. As noted throughout this subsection, they policed what were acceptable formats for artefacts in synthetic biology in/around iGEM; and through these rules on formats, enforced the standardisation ethos which underpinned synthetic biology. So, not only can the registry be appropriately examined as an enactment of the PBSB ethos, but through its central role in the latter's repertoire, it can be afforded a fairly forceful *disciplining* role – a theme I address further in section 8.5. I now return to an examination of the unwieldiness of biology, to explore how it was managed beyond the attempts at standardisation, which bring together the registry and the iGEM competition.

8.3.3 Managing an unwieldy repository of (still unwieldy) biology

Around its tenth anniversary, the registry had already made great strides towards fulfilling its goal of becoming a comprehensive catalogue of biological parts. Indeed, with the number of entries now in the tens of thousands, the sheer volume of the registry was impressive. Nevertheless, the vision of a semiconductor industry like catalogue was still far from reach, for while the registry may have grown to encompass a large number of parts, the quality of those parts left much to be desired.

Issues of quality have long been acknowledged by iGEM and the community emerging around it. In a session during the Synthetic Biology 2.0 conference dedicated to community organisation, Randy Rettberg presented iGEM and the nascent registry of standard parts; delving into some of the detail of the registry he projected a "top 10" table of transcription terminators in the registry and remarked

> "efficiency, which is how good a job they do of terminating, ought to be like, you know, 99 or 100 percent. One might note that a lot of them aren't really very good. Like 0.3 percent. Which means they are more of a resistor. They leak a lot. This one actually is point three and...minus point three. That is because it's a promoter in the other direction. So, the parts actually have a lot of trouble." (Rettberg, 2006)

Parts were deposited and made available, but their functionality often did not match the description. Over subsequent years a number of research articles have also been published that further problematise the quality and use of parts from the ever-growing registry[85]. The issues commonly identified can be distilled down to four dimensions:

- parts in the registry are poorly documented;
- the DNA sequence submitted to the digital repository does not match the DNA sequence of the part physically submitted;
- parts are described as having functions different to what characterisation and subsequent use suggest; and / or
- parts altogether do not work.

Adequately addressing these concerns with registry-wide quality control would be nothing short of a herculean task, one which was beyond reach of iGEM organisers alone. Thus, over subsequent years, iGEM headquarters adopted a two prong strategy: promote a relatively small subset of parts for widespread use; and create incentives for iGEM teams to (further) test / document new and existing parts.

In promoting subsets of parts, iGEM headquarters relied on a combination of a heavy-handed and a softer approach. The heavy handed was pursued via the distribution kits shipped out to teams every year. As alluded to in section 8.2, the distribution kits shipped out between 2006 and 2008 included all parts in the registry. From

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[85] Relevant examples are Peccoud et al. (2008) and Smolke (2009).

2009 onwards, however, their composition became subject to triage. That year's kit included a combination of popular parts introduced in 2008 and a set of "high-quality" parts from preceding years (Registry of Standard Biological Parts, 2009). In 2011 the kit grew to encompass a set of parts that had been highly requested in the 2010, in addition to the popular new parts introduced and the *high-quality* set picked by iGEM organisers. Starting in 2013, however, focus shifted almost exclusively to a set of "high-quality" parts (Registry of Standard Biological Parts, 2013). Thus, the distribution kit, which had started off as an integral physical copy of the repository, was by then a heavily curated object. Considering the distribution kit was shipped to each team participating in the yearly competition, it was an easily accessible and free source of genetic material already in the required BioBrick standard format; and having expanded to include over 1000 part samples, it was large enough to include a breadth of parts which covered the majority of common needs[86].

In parallel with the increasing curation of the distribution kit, iGEM headquarters has also been through a gradual process of curation of the registry. They introduced browsable categories in 2006, which were refined with increased granularity. In the lists of such parts, the hand of iGEM headquarters is particularly visible in the foregrounding of the previous use and physical availability, as well as the ordering according to a rating / measure of use; a hierarchical display of information which provides a tacit nudge for the use of these more prominent parts. Over time, additional categories were introduced that revealed different slices of the registry. Parts were categorised by function; by the organism which they were intended for; and by the assembly standard which they followed. These categories are also at different degrees of curation.

A redesign of the registry in the run up to the 2014 competition unveiled a number of curated collections which deviated from the all-encompassing nature of

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[86] This has also created a small subset of parts which are overwhelmingly used. The registry puts the number of subsequent uses of parts in the top 10 of most used between a lower bound of circa 500 and a top one of 3750. This means the most used part in the registry has been included in more parts than were submitted in both the 2012 and 2013 iterations of the competition combined.

the existing ones. The most prominent of these collections was dubbed "frequently used parts". It included five top ten tables: one with the overall top 10 most used parts in the registry, and four others with the top 10 of four part types: coding regions, promoters, ribosome binding sites and terminators. Another generalist category was "well documented parts", where a similar top 10 table structure applied and the parts were ranked according to a measurement of the volume of documentation available for them. The remaining curated collections were more thematically focused, such as "CRISPR" or "Metal Sensing & Binding". They also followed a different structure to the preceding ones, giving prominence to (hand picked) projects which had been developed in that specific theme. The projects were listed in (different looking) tables with details on the teams, years and specific projects undertaken, as well as links to each of the team wikis and pages of submitted parts. Some of the collections even included a section of highlighted projects, which were described in some detail. Lastly, the tables listing the BioBrick parts were displayed, (sub)thematically divided and with parts organised according to physical availability / integrity.

The unwieldiness of the registry is thus addressed via these (in some ways overlapping) efforts at categorisation and curation. The choice to create and foreground the categories of frequently used and well documented parts is reflective of the epistemic practice promoted under iGEM. The former embodies a core tenet of the parts-based ethos – that the existence of a part which fulfils the user's requirements obviates the need to create alternatives[87].

Despite all the effort devoted to curating the distribution kit and a number of collections in the registry, many thousands of existing parts were still largely ignored; and with the submission of parts by teams in successive years of iGEM competitions this number could only be expected to go up. So, while there was a substantive number of potentially useful parts in the registry and new ones being added

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[87] Randy Rettberg illustrated this point by referencing the computer industry, noting "It's not like you figured out how to make a processing chip. You struggle, struggle, struggle, and then you have got to go start all over. [Instead,] you build on everything you've had before. That goal, of can you build on what you have previously done in biology is kind of summed up by this idea of parts" (Rettberg, 2006).

every year, it was unclear which ones they may be (a problem exacerbated by the four issues highlighted at the start of the subsection). It was clear, though, that an effort to document and prune the registry would be large-scale, time-consuming and would demand a wide range of expertise and resources. So, rather than take on the challenge themselves, iGEM headquarters devised a strategy to delegate it to the successive teams taking part in the iGEM competition. They did so through successive changes and refinements to what constituted successful participation, as noted in section 8.2.

Starting in the 2008 competition, any recognition beyond a silver medal demanded further work in documenting at least one of the new parts. Teams were explicitly asked to evidence their part worked as intended in fulfilment of one criteria; and to further document the part by a more broad effort of characterising its function – a change directed at mitigating the poor standard of documentation and functional characterisation of new parts added to the registry. This strategy was complemented by the introduction of a criteria for a gold medal (in a later competition), where students were rewarded by helping a fellow team document one of their parts. iGEM organisers were also not dismissive of the existing catalogue of parts by focusing on the future. In the early 2010s, the medal criteria were modified again to reward the use of an existing part in the registry part in a *new application*; and not only the re-use itself, but the award was contingent also on the submission of *outstanding documentation* of that part. For the highest award, teams could also elect to further characterise or improve the function of an existing part. In either case, documentation was to be an integral part of the task.

The introduction of the medal criteria, as well as the (gradual) changes they were subjected to over the years, with increasing demands on documentation, proof and improvement of function of registry entries, can effectively be interpreted as an effort by iGEM headquarters to enrol the competition participants in a bid to materialise their vision of a registry made up by a wide range of well documented and well performing biological parts. Taken together with iGEM headquarters' own long-standing efforts to curate the registry, the foregrounding of this knowledge infrastructure in the competition is blatant; so is the dissonance between the idealised epistemic practice of parts-based synthetic biology and the unwieldiness of the parts which were to enable this practice; and the drive to reconcile the two.

In this sub-section, I aimed to make explicit the importance of the registry of standard biological parts in the PBSB vision, as well as the efforts to build an infrastructure which conformed with the ethos of the former against the unwieldiness of biology. I argue that the registry can be productively framed as an OPP in the practice of synthetic biology, having a role of prominence in its repertoire; and that the use of the registry was prescriptive of particular types of practice. I note that these practices are associated with efforts to build an infrastructure which were guided by a PBSB ethos, which is particularly salient in the multiple dimensions of standardisation. I contend, however, that the unwieldiness of biological material hampered the materialisation of the registry, leading to a re-imagination of its role in the wider field; and that the combination of that unwieldiness and poor deposit practices further problematised the establishment of the registry. I note two strategies from iGEM organisers to address those shortcomings, which were built on the recruitment of the iGEM competition not only for the population, but also to the improvement of the entries in the registry. In this very deliberate way, the iGEM competition and the registry of standard biological parts were co-produced (Jasanoff, 2004).

The registry, however, was not aimed solely at the competition, but was imagined as an infrastructure with life far beyond it. In this section, my reference to actors beyond the competition was focused on their critique. In the following section, I address that shortcoming and examine the registry in the context of a programme created for the enrolment of established researchers in synthetic biology – iGEM labs.

8.4 IGEM LABS

The vision for the development of parts-based synthetic biology has, from early on, encompassed a wider range of actors than the student body which makes up the bulk of participation in the iGEM competition. In particular, enrolling established research groups has been framed as key for enabling parts-based synthetic biology to come to fruition. A number of research groups became enrolled via the iGEM competition, but the latter's main focus is on students, rather than on more senior researchers. The participation of but a subset of established researchers (potentially) aligned with parts-based synthetic biology meant the competition was not an ideal vehicle through which to address established research groups. A third arm of iGEM was thus created to enlist, draw upon and accommodate the needs of established research groups, in the form of iGEM labs.

Similarly to the competition and registry, iGEM labs went through a period of progressive institutionalisation. Only a handful of labs were involved in the early years and the arrangements were informal[88]. The degree of formality increased in 2006, following the registry redesign. Contributing labs became listed in the registry, and parts submitted by each lab browsable. The number of labs, however, was still modest – only two were listed in 2006, growing to 15 in 2008. Two years later, and after the list of participating labs had been moved to feature in the iGEM homepage, their number had flourished past the 100 mark.

iGEM labs thus became the third arm of iGEM – alongside the competition and registry – and one which iGEM headquarters also held with a tight grip. Participation in the labs programme was conditional on acceptance from iGEM headquarters. Such an arrangement made salient the question of access, for while the digital registry was available to all, including documentation and sequence, only passive modes of interaction were fully open. Adding, editing or documenting parts were activities which required a user account, access to which iGEM headquarters restric-

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[88] It is noteworthy that there was great overlap between groups involved in the informal labs program and in the early iGEM competitions.

ted to participants in the iGEM competition and iGEM labs. The same applied to the biological repository, meaning the distribution kits and ad hoc requests of parts were restricted to members of the two groups above. For any research groups not participating in the iGEM competition, access to these features and materials was thus only possible from via enrolment in iGEM labs. This gatekeeping role was nowhere more visible than in the confinement of participation in iGEM labs to academic, non-profit research groups. Although iGEM headquarters alluded to the possibility of exceptions, this general rule has been in force for the duration of the labs program. The community emerging around iGEM and its ethos of parts-based synthetic biology was thus forcefully an academic one.[89]

For labs that fit these requirements, however, iGEM headquarters displayed significant openness. From the inception of the registry, it has sought to facilitate access to the parts to established laboratories in much the same way as teams participating in the competition. There was no firm obligation for the academic labs to submit parts to the registry as there was in the competition, but they were still expected to follow the registry's philosophy of openness and communitarianism, which was referred to as "get some, give some" (iGEM, 2014b). Labs were expected to contribute to the documentation of parts which they obtained from the registry; improve and resubmit parts when appropriate; and also submit wholly new parts of their own design. In this way, the epistemic practice promoted in the iGEM competition was thus envisaged as expanding to the epistemic community at large; and these actors were imagined as contributing to the synthetic biology repertoire by creating and refining the artefacts (and, to some extent, the infrastructure insofar as it refers to the registry) which underpin parts-based synthetic biology ways of working. Much as in

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[89] It is worth noting that the vision for iGEM labs as an academic / non-profit only endeavour – and the concomitant exclusion of companies – is a departure from the vision of synthetic biology which permeates European (-level) endeavours. This observation further drives the point that the inclusion of profit-driven organisations as part of the EU synthetic biology community is not a decision propelled by epistemic considerations. It points instead to it reflecting the negotiation between the epistemic and the non-epistemic, and the incorporation of an explicit economic role for research as part of the emerging ethos of EU synthetic biology, as described in greater detail in Chapter 5.

the case of the competition, iGEM (headquarters) was poised to keep a grip over the epistemic trajectory, but populating the repertoire was a distributed task.

The implied value of enrolling established research groups under the iGEM umbrella was large enough that the materials were not only freely available, but they were also made available at no cost to the labs. This is in stark contrast with participation in the iGEM competition, which consistently charged participation fees in the order of magnitude of thousands of dollars. This arrangement lasted for a decade, after which iGEM headquarters deemed free participation in the labs programme unsustainable and introduced a yearly fee of $500, which would provide the labs with the yearly distribution kit and any other parts upon request, plus a small number of perks. Despite the change, this amount was still dwarfed by the charges levied on teams participating in the iGEM competition, where the registration fee for the 2014 iteration alone was seven times higher than the iGEM labs fee. Thus, the iGEM competition has effectively been used to subsidise the running of iGEM labs, suggesting that alongside the desire to build a community from the bottom up via the competition there is also considerable effort devoted to cultivate a community which adheres to the iGEM ethos among established academic researchers.

8.4.1 Get(ting) and give(ing) in iGEM labs

Data on the parts used by the research groups and overall contribution of iGEM labs to the documentation of parts in the registry is, unfortunately, inaccessible[90]. Nevertheless, the registry lists all participants of iGEM labs and specifies part submission from each lab. Over 3000 parts have been submitted by participants in iGEM labs[91], from a universe of slightly over 250 groups at the end of 2014. A brief analysis of the submission trends in this group yielded an interesting submission pattern, as illus-

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[90] While that data is formally available, it would require inspecting multiple pages of revision history of over 20,000 entries, thus making it *de facto* inaccessible.

[91] There is an entry for the registry in the list of iGEM labs, which encompasses close to 1000 parts. Considering the registry is run by iGEM headquarters, it would be inappropriate to report it alongside labs which have grown entangled with iGEM.

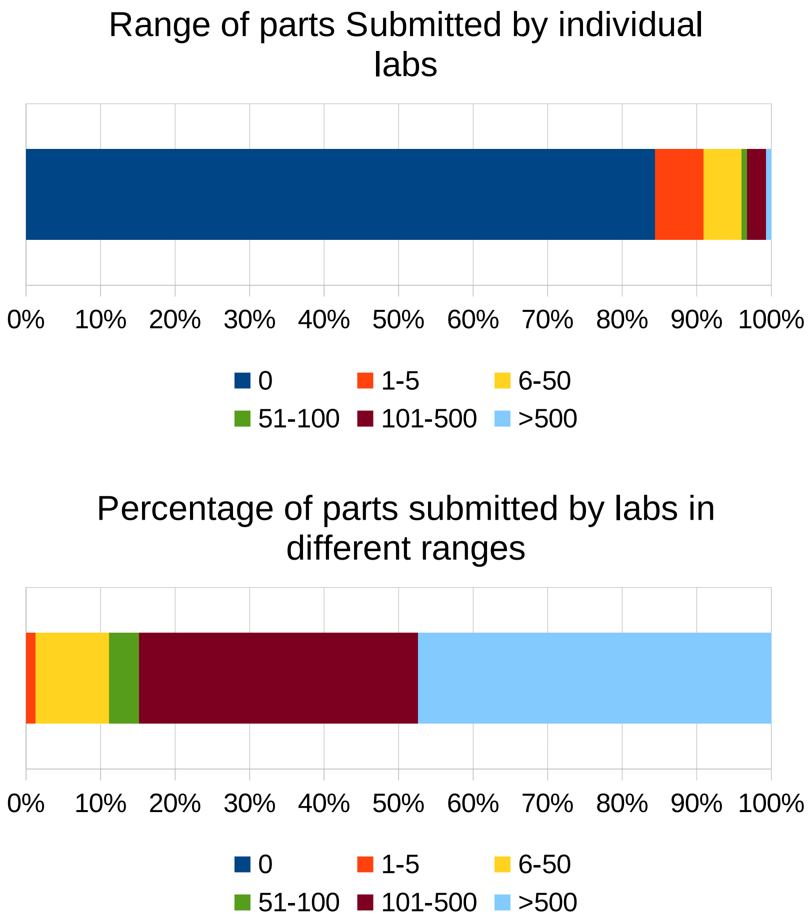

Figure 14: Submission of BioBrick parts by individual labs. (a) Number of parts submitted by each individual lab as a percentage of the total number of labs. (b) Number of parts submitted by each individual lab as a percentage of the total number of parts.

trated in Figure 14. Over 80% of the labs represented did not submit any parts to the registry; and over 90% submitted 5 parts or fewer (Figure 14-A), which meant that the vast majority of the submissions were made by less than 10% of the participating labs. The concentration of submissions in the hands of a small number of labs becomes even clearer by exploring the proportion of parts submitted by labs against the total (Figure 14-B). Grouping the labs according to the volume of parts submitted, it is stark that close to 90% of parts can be attributed to labs which submitted 51 parts or more – a subset which makes up only 4% the total. The concentration is even more acute when one considers close to half of the total number of submissions was made by labs which submitted over 500 parts each. Only two labs fit that description: the Endy lab and the Knight lab.

Giving (parts) appears to be a significantly stratified activity. A very small number of labs which are highly invested and highly prolific stand at the core. These are followed by a bigger second layer of labs which are less prolific, but still significantly invested in contributing new parts. From then on, the number of labs involved increases sharply, in inverse correlation with the number of parts submitted. Furthest away, with no parts submitted, stand the bulk of labs. Building capacity in parts-based synthetic biology by creating and distributing parts was thus far from the widespread community effort envisaged by the iGEM ethos.

On the other hand, *getting* parts appeared to have a broader appeal. A short survey of participants in iGEM labs was run in the lead up to the 2014 competition[92], which included a multiple choice question on the desired outcomes of participation in iGEM labs. The top four choices in this question were, in ascending order: part sequences, part samples, part documentation and DNA distribution; and were picked by between 75 and 80% of respondents. This pattern suggests that access to parts is of paramount importance for participants in the programme[93]. Thus, iGEM labs contributes to cement a parts-based ethos in professional practice and, in tandem, foregrounds the (curated) distribution of DNA parts and the wider digital and material infrastructure as key in enabling (or at least promoting) that practice.

In sum, much like the iGEM competition, iGEM labs appears to encapsulate widely varying modes and levels of engagement. In itself, it is a branch of iGEM which clearly promotes a similar ethos as for the iGEM competition. As a result, iGEM headquarters enables community-building in multiple ways: by building the

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[92] Survey ran by iGEM headquarters, response rate 40% (iGEM, 2014c).

[93] A detailed examination of the use of artefacts acquired via iGEM labs is beyond the scope of this thesis. However, if anecdotal, it is nevertheless of relevance to note that materials acquired through this programme were used in the research project described in part 3. As such, iGEM labs has, at least in one case, mediated epistemic practice of (EU) synthetic biology.

repertoire which grounds and enables synthetic biology, either in the form of new/ modified parts or documentation; by allowing research groups to use existing parts in their own work; or through a combination of both.

Unlike the iGEM competition, however, there is no strict enforcement of norms. This means that, while the different modes were available, they were not taken up in a uniform way. Instead, active production of DNA sequences / documentation (the *giving* part of the ethos) was concentrated in a small number of labs. Chief among these were the labs headed by Endy and Knight – both researchers heavily involved in the genesis of synthetic biology at MIT, the early iGEM competitions and the Biobricks foundation. As such, the productive dimension of iGEM labs was driven by a "core set" (Collins, 1985), which overlaps considerably with an ostensible core set in the early emergence of synthetic biology. Yet, the distribution kits and the wider set of digital and material artefacts were widely taken up by what were, by 2014, hundreds of labs.

This pattern suggests a disconnect between the *getting* and *giving* halves of iGEM labs. From a community-making point of view, this disconnect may be usefully interpreted through the lens of Deglsegger-Márquez's (2017) notion of "communities of production" and "communities of utilisation". This dichotomy (with the caveat that these categories constitute ideal types, their boundaries (Gieryn, 1983) are difficult to establish and porous, with membership not being necessarily exclusive) overlays neatly with those two halves. As such, there was a clear effort to create the artefacts which grounded synthetic biology (and its community) at the core. At the periphery, however, there was no such fundamental concern. Here, iGEM labs contributed to the incorporation of these parts (and ancillary artefacts) into the practice of the research groups. In the community of utilization, it is the enactment of the synthetic biology repertoire (its ways of working and its artefacts) which is of key relevance; this enrolment of the researchers into the parts-based synthetic biology epistemic project. As such, there is the growth of the community through the expansion of its constituency(ies) through the contribution to and/or alignment with the repertoire promoted by the iGEM structure; a repertoire which was not policed as in the iGEM competition, but which was nevertheless strongly guided by the former through the establishment of the ethos of the Labs programme, the control over the digital infrastructure and the control over the material artefacts which were (or were not) made available to the participants.

8.5 CONCLUSION

Over the course of this chapter I traced the trajectory of iGEM, against the iGEM competition, the Registry of Standard Biological Parts, and the iGEM Labs programme. In this final section, I reflect on the making of epistemic community over each of these three prongs of iGEM, and some important ways in which they were entangled.

The iGEM competition, in its meteoric rise, has come to hold a place of prominence in synthetic biology. It has established itself as a key *community-making device* (Molyneux-Hodgson & Meyer, 2009) in/for synthetic biology. Its organisers have, over the years, made a case for the *need* of community with funders (and wider actors in governance), as well as within domains of the scientific community (with the SBX.0 conferences being a case in point). Moreover, the competition itself tacitly and explicitly articulated this point, repeatedly, over each iteration. This was, in no small part, self-referential – with the competition promoting *movement* in the sense of convergence around it. This was particularly saliently articulated in the ambassador programme – an arguably missionaristic enterprise dedicated to the *enrolment* (Callon, 1984) of new participants. Yet not only did the competition promote convergence, but it went to some lengths to make their members *stick*. In some ways, this was accomplished through a focus on playfulness and fun, but it was also accomplished through the creation of roles for enabling previous participants to continue to be engaged in the competition; as well as the support of an alumni programme.

Beyond this role as a *marker and maker* of community, the iGEM competition also played an important role in defining and fleshing out a (parts-based) synthetic biology *repertoire* (Leonelli & Ankeny, 2015). iGEM established synthetic biology (epistemic) practice as driven by an *engineering ethos*, with practice sitting at (and crossing) the borderlands of biology and engineering. It is noteworthy, however, that while iGEM adopted the engineering ethos as a rhetoric device, "we should be [...] wary of treating engineering itself as homogenous, because there are many different types of engineer" (Calvert, 2013, p. 415). This ambiguity makes for an appropriate parallel with the ambiguity and practices of the competition in its initial years; but what that engineering ethos came to encapsulate (although the ambiguity was, to some extent, retained) were the PBSB principles of abstraction, modularisation, standardisation, decoupling and the practice of (mathematical) modelling. The latter, in particular, came to be part of the iGEM mantra of work in the competition revolving around *wet lab, modelling, and human practices*. In moving acceptable epistemic practice from that initial open configuration to that of wet lab, modelling and human practices, iGEM organisers played a key and dominating role.

As I note in section 8.2, what practices were valued under the iGEM competition changed over time, and was mediated through an evolving reward system. This reward system also became increasingly prescriptive of the practices which were accepted; and was policed by an increasingly formalised system of judging. For interpreting how these increasingly formalised criteria impacted on the epistemic community, I build on Bulpin & Molyneux-Hodgson (2013)'s argument that the Foucaultian lens of "disciplining" is a productive way to explore emerging scientific communities (and, as they did, I do against the context of iGEM). Very briefly, in Foucaultian terms, the process of disciplining is one of the exertion of control and surveillance over subjects, which culminates with the subjects becoming *self-disciplined*. While participation in the iGEM competition will surely have been more agreeable than incarceration in his Panopticon, this disciplining dynamic between a *knower* – the competition judges / iGEM organisers – and a *known* – the iGEM competition participants – remains a useful analytic tool. Modes of participation, practices and understanding of the iGEM competition were oriented towards submission to the judging criteria. This process culminated with the *examination*[94] – the evaluation of the teams' projects by the judges in the iGEM jamborees. iGEM projects which had met the criteria were rewarded (with medals and prizes); projects which had not met the criteria were punished, by withholding rewards.

While the Foucaltian notion of *disciplining* is enveloped in a punitive metaphor, it would be reductive to frame punishment as the sole disciplining tool. Alongside it, and with a more positive connotation, participants were also disciplined through the deployment of *exemplars* (Kuhn, 2012 [1970]); of iGEM projects whose practice they were to emulate. These were chosen by iGEM organisers, thus imprinting their vision for the competition (and, concomitantly, for synthetic biology) in the participants' practice. Indeed, as I note throughout 8.1 and 8.2, iGEM organisers fought hard to retain control over the trajectory of the competition. Ultimately, through the control over exemplars and the judging criteria, they were gatekeepers of epistemic practice in the competition and, thus, of the budding *repertoire*. Yet, the (direction of) expansion of the judging criteria belies the intervention of other actors. This was epitomised by the interest/engagement of the American FBI in the competition. In addition, iGEM also became a space for experimentation with EU (socio-technical) imaginaries, as was the case of RRI, brought by the SYNENERGENE project. If iGEM organisers held the reins, other actors nudged their hand, with the synthetic biology practiced in the competition (and resulting epistemic subjects and repertoire) creeping ever closer towards that of the "new biology" (NRC, 2009).

Pushing the notion of disciplining slightly further, a peculiarity of the iGEM competition is that it did, in fact, go to great lengths to create the "new breed of researchers who are familiar both with fundamental biology and with the methodology of engineering, as well as having requisite skills in areas such as computational sciences and chemistry" (NEST High-Level Expert Group, 2005, p. 7). Inevitably,

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[94] The examination is key in Foucault's view. "The examination combines the techniques of an observing hierarchy and those of a normalizing judgement. It is a normalizing gaze, a surveillance that makes it possible to qualify, to classify and to punish. It establishes over individuals a visibility through which one differentiates them and judges them. That is why, in all the mechanisms of discipline, the examination is highly ritualized" (Foucault, 1977, p. 184).

this will have been achieved with different levels of success, depending on the extent to which the novices became *self-disciplined*. As such, this problematises the hierarchical relationship between the *knower* and the *known*. Indeed, at least to some extent, the development of this *individual interdisciplinarity* (Calvert, 2010) disturbs this relationship – to a potential extreme where it flips it on its head.

From the point of view of senior (or at least established) researchers, the early iGEM competitions went to great pains to *discipline* the researchers in much the same way as described above for novices. In particular, competition was contingent on attendance of a workshop where the rules for participation and exemplars were imparted on the instructors (and/or advisors). In the dedicated strand of iGEM created for the enrolment of such established researchers, iGEM organisers attempted to impart the same ethos, but in the absence of forceful attempts at disciplining. Indeed, for the better part of a decade, participation in iGEM Labs was free – in an ostensible attempt to extend iGEM beyond the competition. iGEM Labs yielded, at best, a modest contribution to the shared repertoire. Moreover, it revealed a faultline in the epistemic community. That is, the contribution of parts to the registry was strongly concentrated in the hands of a small number of groups; a collective which largely mapped onto the MIT, PBSB *core set* (Collins, 1985). The use of parts, however, had far more widespread appeal. In this way, the epistemic community engaging with iGEM Labs crystallised as a largely dichotomous *community of production* – engaged in the epistemic project of building the (iGEM articulation of a) synthetic biology repertoire through its parts – and *community of utilisation* – which made use of their parts in their epistemic practice (with contribution to the repertoire sitting downstream) (Deglsegger-Márquez, 2017)[95]. Against this backdrop, from a community-making perspective, the key success of iGEM Labs sits with the popularisation of the iGEM distribution kit.

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[95] I speculate that this chasm is not so much due to differences in epistemic practice, but rather to resistance / different levels of engagement with the "attempt to establish a new moral economy for biotechnology" (Frow & Calvert, 2013, p. 14) which took place under iGEM.

Indeed, the popularity of the distribution kit in iGEM Labs and in the iGEM competition – two arguably different constituencies of synthetic biology, with different epistemic commitments – suggests a role for the kit as a *boundary object* (Star & Griesemer, 1989). It is less clear if the same can be said about the Registry of Standard Parts (its ostensible home). Nevertheless, it is clear that the registry (and the distribution kit) constituted an OPP in the iGEM competition. Access / contribution to the registry became a cornerstone of epistemic practice in the competition. Further, in orienting (some) judging criteria in the competition to reward (and arguably mandate) the contribution of parts to the registry, as well as the improvement of new/existing parts, iGEM organisers attempted to mitigate the shortcomings of the registry via the competition. That link also established a co-productive relationship between the iGEM competition and the registry.

In recruiting the iGEM competition to populate/improve the registry, iGEM organisers positioned the former in making synthetic biology community, which was enduring and went beyond the competition, through the contribution to the repertoire. The aims of making the registry an OPP in synthetic biology, as I note in section 8.3, have not been (yet?) fulfilled. Such plans have met with resistance from an unwieldy biology and unwieldy contributions. Yet, the role of prominence of *the* registry in synthetic biology has contributed to establishing the use of *a* registry as appropriate epistemic practice. As such, it has been enshrined in the community's repertoire. As a final point, it is noteworthy that other registries (many professional) have started to proliferate.

I now move to a the final chapter of this thesis, where I bring together the themes addressed over the course of Parts II, III and IV.

PART V

CLOSING THE CURTAIN

9 A PARTICULAR SYNTHETIC BIOLOGY, IN PARTICULAR COLLECTIVE(S), FOR A PARTICULAR SOCIETY

This thesis has sought to explore the emergence of community in synthetic biology, with a focus on its emergence in Europe. As noted in the first chapter, this exploration was guided by two guiding research questions, as well as three interrelated sub-questions:

- What does community in an emerging synthetic biology look like?
    - In what ways do the global and the local intersect in the emerging of a European synthetic biology?
- How is a synthetic biology community emerging?
    - What role does governance (and, in particular, funding) play in the trajectory of the emerging community?
    - In what ways are the trajectories of European synthetic biology and of the European Union entangled?

Over the course of the thesis, I have sought answers to these questions in the context of three novel accounts – the trajectory of synthetic biology in Europe; the account of a (European) synthetic biology project in actu; and the account of the dimensions of iGEM (the competition and beyond). Through these, I have sought to explore the aesthetic of epistemic community in synthetic biology, examining its membership and repertoire. I have aimed to investigate the processes through which this epistemic community was built. And I have also sought to address how the embeddedness in particular (and changing) governance regimes impacted on how community was able to emerge, and how the former (mediated through funding) impacted on the trajectory of the community, the range of repertoires which were made available and its membership.

In doing so, I have made 3 key observations. Firstly, the relevance of iGEM for European synthetic biology and its exposition of a generational divide; I note the competition was progressively embedded in EU synthetic biology, but that the disciplining of novices (in the competition) was not matched by enrolment of senior researchers (in the competition or other dimensions). Secondly, the co-production of a European synthetic biology and a particular European Union, which I argue evidences a strong role for governance mediated though funding, and the concomitant impact on the trajectory of the epistemic community. Thirdly, the creation of what I term "communities of need" as transient assemblages of relevance in the process of community-making, brought to the fore by the changes to the governance regime and the ancillary forcefulness of funding regimes.

9.1 IGEM AND EU SYNTHETIC BIOLOGY

In Part II I argued that funding played an important role in the creation of a particular European synthetic biology. In this section, I reflect on the incorporation of iGEM in the EU synthetic biology imaginary.

As noted in Part IV, from its humble beginning in an MIT classroom, iGEM has grown to a global behemoth of synthetic biology. Over this decade, iGEM gradually became an enormous, robust, "community-making device" (Molyneux-Hodgson & Meyer, 2009); one concerned with the wholesale building of synthetic biology. This was a drive characterised by the insistence in building the synthetic biology repertoire (Leonelli & Ankeny, 2015) and its epistemic subjects; and a synthetic biology repertoire firmly guided by an evolving "vision" (Van Lente, 1993) for synthetic biology as PBSB. Over time, iGEM became increasingly strict in policing the evolving repertoire, in large part through a reward system which promoted an increasingly narrow set of practices, artefacts and identities. This reward system was, thus, ultimately geared towards fulfilling the evolving vision for synthetic biology. So, as iGEM became established as a community-making device in the global scene, synthetic biology became championed by this project of epistemic purity.

In the same section, I also describe the move from iGEM as an American competition to iGEM as a global community-making device as taking place with the involvement of EU researchers. In particular, in the early years, with the involvement of prominent European synthetic biologists; researchers who were arguably an important part of the contemporary EU synthetic biology "core set" (Collins, 1985) – a role which was recognised (and arguably "co-produced" (Jasanoff, 2004)) with participation in the EU's synthetic biology NEST Pathfinder programme (and ancillary / subsequent activities).

This European core set was and continued to be firmly enrolled in the iGEM competition and its pedagogic model. This shines through in the focus and resources the researchers dedicated – and channelled – towards iGEM. As noted in chapter 5, half of SYNBIOCOMM is devoted to iGEM, and the competition was also afforded a pivotal role in the work packages of subsequent (researcher-led) European projects addressing the education of novices into (EU) synthetic biology. The commitments of these researchers towards iGEM thus led to the mobilisation of resources towards the participation of EU teams in the competition; and also to the (re)casting of synthetic biology summer schools as de jure (when participation was restricted to students who were also iGEM team members) and/or de facto iGEM "boot camps" (events whose main purpose was to prepare the students for participation in the competition). Summer schools became arenas where the students would be imbued with the knowledge and practices required to successfully cross the biology-engineering divide – an ability which was deemed essential to succeed in the competition. Analysed through a community-making lens, the summer schools were arenas for initiating these novices in the PBSB repertoire which underpinned the iGEM competition.

This “alignment” (Fujimura, 1987) of iGEM with EU synthetic biology is of particular relevance, for the (multipolar) drive towards the latter foregrounded the absence of epistemic subjects with an appropriate epistemic arsenal as a key challenge for synthetic biology; the *promissory* (Hedgecoe, 2003) synthetic biology hinged on overcoming that challenge if it was to attain its potential. What that epistemic arsenal was envisioned as entailing was also nothing short of transformative, with an explicit call for the creation of epistemic subjects characterised by “individual interdisciplinarity” (Calvert, 2010). This particular casting of desirability of epistemic hybridity was already a hallmark of iGEM. Thus, given the preponderance of the core set, which meant the futuring exercises were conducted by or included a subset of these key researchers (as well as the participation of – iGEM’s – Randy Rettberg), there is a clear link between iGEM and EU synthetic biology in the idealisation of practitioners (and, by extension, of practice and concomitant repertoire).

As I noted in the same chapter, the early promissory work (of which the training of novices was an important part) was successful in mobilising resources for building EU synthetic biology. Under the guise of EU projects administered by members of the core set, project resources were used to finance the training of novices in the lead up to iGEM, as well as labour and participation costs of EU teams (as noted above), but also the competition itself – all while the participation of EU teams (either enabled with access to FP funds or not) steadily increased. What is particularly striking, however, is that the shift of control over the (resources of) projects with a community-making aim from the core set to institutional actors (in the ERA-SynBio ERA-NET project) did not diminish the discursive or material support for iGEM in European circles. In fact, the vision document produced by ERASynBio touted iGEM as a desirable and successful pedagogic enterprise; and ERASynBio was a key source of financial support for the European regional iGEM competition (as well as directly to EU teams in 2014). Thus, from the support of a small core set to the backing of a coalition of national funding bodies; through successful promissory work which was enabling of a vision of synthetic biology which enabled iGEM and an institutional drive to create epistemic subjects capable of performing a synthetic biology which was productive (and thus contribute to the EU's reinvention as a KBBE); and across the participation of circa 350 EU teams in a decade, iGEM became firmly embedded in the EU's vision for synthetic biology. As a result, iGEM became a de facto training ground for EU synthetic biology.

9.1.1 iGEM and the (EU) synthetic biology repertoire

The competition went through a gradual process of institutionalisation, which I describe in section 8.1. Over the same period, it also witnessed a narrowing of the range of practices which were valued and/or possible under iGEM. As noted in 8.2, this was largely accomplished through a combination of the introduction of a reward system in the form of medals – in a progressive system, where the more valuable awards required the performance of a wider range of practices valued in synthetic biology (under iGEM); the increasing robustness and formalisation of criteria on which the projects would be judged; and through heralding successful past projects which encapsulated the practices and outcomes valued under iGEM as "exemplars" (Kuhn, 2012 [1962]).

Over time, and through sheer size, iGEM HQ became a key arbiter of the synthetic biology repertoire. For all the competition's discursive focus on fun and enjoyment, iGEM's policing of the allowable repertoire, rewarded or punished through the processes referenced above, disciplined (Foucault, 1977) the novices. For the latter, the repertoire made available was underpinned by a parts-based, engineering ethos and a productive focus; the iGEM repertoire synonymous with the synthetic biology repertoire – to the extent potential purity of synthetic biology practice was measured against the iGEM (synthetic biology) repertoire, as noted briefly in Chapter 7. As such, not only did iGEM become embedded in the EU synthetic biology imaginary, but through its role as a (arguably the) major pedagogic device available to European novices, it also became a key marker of EU synthetic biology at the bottom rungs of the career ladder.

iGEM's impact in the trajectory of EU synthetic biology from the point of view of established researchers, however, is less clear. There were EU researchers clearly committed to iGEM (several of which in the core set, as noted in chapter 5), though continued participation in the competition was restricted to a small proportion. Moreover, the initial impetus to mirror the registry of standard parts in European servers did not translate to meaningful interest by EU researchers in the incorporation of the former in their epistemic practice. As noted in Part IV, the use of the digital registry remains residual (particularly the submission of parts). Access to physical parts, however, appeared to be of considerably greater interest. A sizeable minority of the roughly 250 groups registered in iGEM labs as of 2014 was based in Europe. As iGEM labs membership revolves around recurring access to the competition's distribution kit, as well as on demand access to any part in the registry, this suggests the researchers valued access to those artefacts. Indeed, this hypothesis is strengthened by the observation from the case study of Part III, that the use of parts from the distribution kit (owned by several of the researchers) is the main glimpse of iGEM under CyanoBioFoundry. As such, for established EU researchers, iGEM is peripheral, mainly contributing to the promotion/sustainment of their *alignment* (Fujimura, 1987) with a PBSB ethos through the circulation of artefacts.

From a beginning as an American project, iGEM has grown to be a global driver for synthetic biology; through promissory work, this global driver has been incorporated into the making of a (regional) European synthetic biology. iGEM became institutionalised as an important dimension of the training of novices in support of the vision for EU synthetic biology. A non-trivial number of novices has been disciplined into (an iGEM vision for) parts-based synthetic biology, which is coming to be integrated in the EU synthetic biology repertoire. However, this deep integration is not matched in the (general) practice of senior researchers; for the case of the latter, the iGEM repertoire has bled into practice through access to artefacts enabling of PBSB practice. Thus, iGEM is embedded in, central and peripheral to EU synthetic biology to different actors in the epistemic community. This dissonance can be productively interpreted by drawing on Bartlett, Lewis, & Williams' (2016) notion of "generations of interdisciplinarity". In the study of bioinformatics, the authors noted a sharp difference between the epistemic arsenal of older researchers, who had witnessed the genesis of the field, and junior researchers, who had been trained into / were expected to perform interdisciplinary research. A parallel to the case of EU synthetic biology is clear: meaningful (individual) interdisciplinary training in synthetic biology emerged with iGEM; only junior researchers were routinely disciplined into iGEM. Senior researchers, while potentially committed to PBSB, were less likely to hold iGEM as a key referent, particularly given its status as a pedagogic tool.

It follows, then, that the embeddedness of iGEM in EU synthetic biology, coupled with a strong commitment to the repertoire promoted under the competition and a generational divide affords the latter a role of increasing preponderance in EU synthetic biology. It is noteworthy that, as I argued in section 5.1, European synthetic biology has consistently been cast as a broad church – as an epistemically plural (Chang, 2012) endeavour, enabling the coexistence of multiple, overlapping repertoires under the banner of (European) synthetic biology. As such it is remarkable that in the dimensions described above, this iGEM, PBSB repertoire has become dominant in European synthetic biology. Thus, while to speak of *a* European synthetic biology may be a misnomer, some repertoires appear to be gaining a foothold.

9.2 PRODUCING EU (AND) SYNTHETIC BIOLOGY

It is well established that the emergence, reproduction and dissolution of epistemic communities does not hinge solely on epistemic criteria. As noted in Chapter 2, public policy and science policy have grown increasingly closer since the postwar period. Science policy has thus come to embody political priorities and channel research towards providing technical solutions to societal challenges. A key avenue for the enforcement of these priorities has been the mobilisation (or withholding) of resources. This attempt at "governance by funding" (Gläser & Laudel, 2016) has been described as having different effects on different fields of research, with the potential for impact correlating broadly with the degree to which fields relied on the mobilisation of such resources for the performance of epistemic labour.

The work presented in Parts II and III of this thesis exposed the high degree to which EU synthetic biology – at the macro and micro levels – leveraged EU funding throughout its emergence, and the extent to which funding was a sine qua non condition. In parallel, it traced the ways in which the changes to the EU and the role available to research at the EU scale enabled European synthetic biology – but a particular synthetic biology. As such, the tale of EU synthetic biology is one of the co-production of an epistemic community (including the repertoire on which it became grounded) and of a geopolitical entity in the form of the European Union. In this section, I reflect on the processes through which these two communities were articulated and built, with particular emphasis on the interplay between promissory work and funding in mediating the trajectory of both.

9.2.1 Promising EU synthetic biology

The genesis of EU synthetic biology is strongly characterised by promissory work, as I detail in Chapter 5. The casting of a systematic, productive synthetic biology as a (key) theme of the European Union's FP6 NEST Pathfinder programme provides a first indication of the framing of (that) synthetic biology as *promissory science*. Promissory work only intensified from that point on, with an increasingly detailed vision for the field travelling through subsequent NEST reference documents; a formal vision being produced in the context of the NEST programme; and futuring exercises and a roadmap being produced in the context of an ancillary NEST project. Throughout these exercises and documents, synthetic biology began to take meaningful shape as a (potential) epistemic project. The potential epistemic project of synthetic biology, as well as the transformative potential it held, however, were consistently made contingent on the continued mobilisation of resources in support of the emerging field.

Such promises and visions travelled widely and were, to varying extent, incorporated in the EC programmes and materials. As noted in the same chapter, after the NEST programme they travelled mostly in the context of KBBE (both the EC division and KBBE-NET) and, later, reached the coalition of funding bodies which made up the ERASynBio project. At all points, resources were mobilised in a bid to fulfil the vision set out. The (EU) synthetic biology epistemic community, then, was leveraged through a "community of promise" (Brown & Michael, 2003). Still, this community of promise operated under a complex research, policy and governance landscape, which impacted on trajectory of synthetic biology (and the community which underpinned it).

The enrolment of EC in the community of promise as early as in the NEST programme can usefully illustrate that point. In the early stages of emergence of synthetic biology, where several approaches operated under / competed for the same *umbrella term*[96], the EC's role in promoting a vision for synthetic biology above competing ones; institutionalising it through the creation of the synthetic biology NEST pathfinder programme; and performing explicit "boundary work" (Gieryn, 1983) through the exclusion of any alternative (non-productive) vision, provides a striking example of the power the institutional actor could exert over the trajectory of synthetic biology. Yet, the enrolment of the EC in the community of promise should not be seen as a validation of the intrinsic epistemic value of any given synthetic biology approach.

Instead, the enrolment of the EC is best viewed through an examination of the changing role for research in the European Union. As noted in Chapter 4, what was allowable as research under a common umbrella (codified under the concept of EAV) changed considerably over the lifetime of the EU (and its predecessor organisations). Over the process of European integration, an increasing range of activities was deemed as providing EAV. In the lead up to FP6, the expansion of EAV to in-

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[96] At this stage, given the absence of meaningful visions for the multiple synthetic biologies and a similar absence of coherent practice (or repertoire), synthetic biology could also be interpreted as an (orienting) ideograph (Van Lente, 1993).

clude the structuring of "the EU R&D and 'fabric'" (Arnold, 2012) meant it became possible for the EC to address entire research fields (both existing and emerging ones). In parallel, the EU also championed a wholesale overhaul of its economic engine, under the knowledge economy policy (and imaginary), which was later further specified to include a dimension as a KBBE. Thus, it was this formal structural change which enabled the very possibility of an EU synthetic biology driven by the former; and I argue throughout Chapter 5 that the KE/KBBE imaginaries are pervasive in the EC's documents and decisions regarding synthetic biology.

Against this backdrop, the multiplicity of synthetic biology is cast onto the limelight. In the European sphere, it was an epistemic project in its own right; and it was also a vehicle enabling of an economic transition to a model reliant on (biological) knowledge as an engine, with value attached to outputs (and not epistemic practice). EU synthetic biology can thus be productively framed as what Meckin, (2016) dubbed an "unfolding multiple". This is a concept close to Mol's popular "object multiple" (Mol, 2002)[97]. Meckin builds on this, pairing with the concept of absence and Knorr-Cetina's (1997) notion that absences are mediated through the articulation of the object (*unfolding*), which then recurses, embedding the solution in the object. I have thus far argued that, for the researchers, the *unfolding* of synthetic biology was driven by an absence of an epistemic community (and the grounding repertoire) and articulated through promissory work. I now turn to the *unfolding* of synthetic biology by the EC – driven by an absence of European, economically relevant research, and articulated through governance.

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[97] In The Body Multiple, Mol performs a deep dive into atherosclerosis as disease and illness. She investigates the ontology of atherosclerosis, noting its changing meaning in different contexts and the reliance on those contexts in imbuing and stabilising that meaning. Atherosclerosis, then, remains in "permanent possibility of alternative configuration" (Mol, 2002, p. 164). Its meaning is not singular. It is not one object. It is, instead, a *multiple* object.

9.2.2 Funding and governance in EU synthetic biology

The researchers' promissory work was undoubtedly successful. They were successful in mobilising resources for the practice of synthetic biology, as well as for the building of a community on which to embed it, as I note in Chapter 5. Funding for these activities was, over time, allocated through different streams and under different governance regimes. Moreover, institutional actors would come to play different roles in the development of the field over time. In this section, I briefly address how these dynamics impacted on the trajectory of EU synthetic biology and the emergence of the epistemic community.

Through its membership in the community of promise, the EC became invested in the building of an EU synthetic biology (community). As such, rather than a passive disburser of funding, the former took an active role. As I argue in Chapter 5, the EC broadly followed a governance model of "steering at a distance" (Leišytė, Enders, & de Boer, 2010) regarding the epistemic development of synthetic biology in FP6. However, NEST was a programme dedicated to the nurturing of fields. In these ancillary activities, the EC took a considerably more prominent role. Of particular relevance was the specific request for projects with a community-making aim, whose absence was deemed detrimental for the development of the field; and the call for and funding of TESSY – a project broadly addressing the potential of the field and roadmapping it. If both moments evidence the commitment towards bringing synthetic biology to fruition, the commission of TESSY provides an early indicator of an epistemic shift in the development of the field.

The first vision exercise, under NEST, was commissioned by the EC and carried out by a HLEG – a group composed entirely of researchers, as noted in Chapter 5. TESSY, however, was led by the Fraunhofer institute – synthetic biologists played a key role in the materials produced, but were no longer in the driving seat. The second vision exercise (under ERASynBio) held researchers even further at bay – they were consulted, but the document was spearheaded by BBSRC staff, and addressed the field through the lens of its (multifaceted) role in promoting a particular vision for the EU. These shifts are relevant for two main reasons: for one, they illustrate a process which Dunlop (2017) dubbed "the irony of epistemic learning". This refers to a shift in epistemic authority and relevance, whereby researchers who initially produced the bulk of relevant knowledge lost prominence as competing actors learned to produce policy relevant knowledge as well. In developing a role in the epistemic community, these actors of governance impacted on its trajectory.

Reflecting on this process a little further, the (increasingly) strong involvement of such actors from far beyond the bench provides a stark reminder of the relevance of the *epistemic* community as a relevant locus; and that these actors can (and did) actively impact on its trajectory – by actively contributing to its repertoire. Thus, they should not be framed as (always) passive entities, kept at arm's length, as articulated by the authors in the original papers. I propose instead it is productive to explicitly widen the focus beyond just researchers as the active contributors to repertoires. Indeed, if repertoires ground (epistemic) community, they must be cast in a way that includes it in its entirety.

For another, these shifts also foreground the increasing embeddedness of synthetic biology into constitutive visions for the EU (namely, the ERA, KBBE and the then novel RRI). This gradual enrolment of synthetic biology in the EU visions went beyond activities and projects ancillary to epistemic labour. As noted in Parts II and III, not only did these increasingly manifest, but they were also forceful. In the move from FP6 to FP7, the ability to perform collaborative synthetic biology without any demands (other than the participation of researchers from multiple member states – a core, long-standing dimension of EAV) disappeared. Dedicated funding streams for synthetic biology – be they under KBBE or ERASynBio – embedded one or several of the aforementioned EU policies. Funding streams across other programmes also included these (and potentially additional, sectoral specific ones). This offered funding an explicit role in shaping the trajectory of EU synthetic biology, which I will examine now.

9.2.3 Funding and the trajectory of EU synthetic biology

The visions for the EU manifested through the call texts, articulated through demands such as the production of tangible outputs of potential economic relevance and/or the inclusion of commercial/industrial partners; or the inclusion of notions of value through transnational collaboration in evaluation criteria. However, these visions travelled beyond the written articulations. As noted in chapter 7, the perception of the EU's expectations regarding what would be an acceptable geographic distribution of participants (linked to the ERA agenda) or an appropriate tangible output (linked to the KBBE/Bioeconomy agendas) was performative. The forcefulness of these requirements was also further amplified by the acknowledgement that successful funding required strict adherence to the conditions set out in the call.

Through the enforcement of such conditions, the EC performed "governance by funding" (Gläser & Laudel, 2016). It impacted on the trajectory of synthetic biology without picking apart and exerting control over the epistemic practice – there was no "hierarchical steering" (which alludes to the complexity of scientific labour and the limitations to potential intervention) (Whitley, 2008; Whitley & Gläser, 2014); yet, by enforcing a collaborative, transnational and productive model of synthetic biology research, and one which would provide contributions to a transforming European Union, the EC steered the trajectory of EU synthetic biology.

In sum, the operation under a projectified model of research, exacerbated by the foregrounding of *fundability* as a dimension of "do-ability" (Fujimura, 1987) afforded the EC a considerable degree of control over the content of research. This is particularly poignant in the case of synthetic biology (and other emerging fields/communities), on the basis that there is no established repertoire (including identities, artefacts and epistemic practices) on which to ground a community. Therefore, emerging fields/communities are less able to resist these pressures.

I propose the emergence of synthetic biology in Europe, then, can be readily interpreted as the emergence of a European synthetic biology; as a field and community sitting at a co-productionist nexus of synthetic biology and a particular

European Union. As an emergence where the promises of researchers were successful in enabling a trajectory for the field, but whose trajectory was linked to a process of *governance by funding*. I note in the section above how this interplay impacted on the composition of the community. In the following section, I will build on this theme, and explore the aesthetic and process of the making of this community, with emphasis on the repertoire which was built, as well as the membership of the European community.

9.3 FUNDING AND COMMUNITY-MAKING – COMMUNITIES OF NEED

The projectification of contemporary research (funding), coupled with the gradual demise of block grant funding, presents a particular challenge to fields for which epistemic labour relies on the availability of (non-trivial) resources – be they artefacts, infrastructures or subjects – and therefore require sizeable and consistent funding streams. The reliance of the life sciences on this type of support has been well documented (as I note in Chapter 5) and synthetic biology is no exception. Arguably, given the early stage of development, the established (and establishing) epistemic practice as a broadly collaborative, interdisciplinary, resource intensive affair – and one which aims to provide tangible solutions to societal problems, no less – synthetic biology is a field towards the resource-heavy spectrum of the life sciences. If, as some of its key proponents have long argued, it will become a systematic, cheap, widely available and democratised avenue for work in the life sciences, that time has yet to come.

Indeed, as I argued in Part II, early synthetic biology in Europe relied on resources made available through the European Framework Programmes to bring it into being, and EU funding continued to play a key role in its emergence. From an organisational point of view, research projects were a cornerstone of EU synthetic biology and its trajectory. Research projects which varied in form and aim across time, with an increasing emphasis on, and varied types of material outputs. Over

Part II, I described how the changing requirements that projects were tied to a changing role for research in the European Union (Chapter 4), and how a combination of those evolving imaginaries and the funding instruments available under FP6 and FP7 (Chapter 5) came to impact on the trajectory of EU synthetic biology. Research projects were, thus, a key conduit of that impact – through explicit requirements formalised in calls for proposals, or through the performative power of expectations, which prompted the consideration of non-epistemic criteria and the (de)valuing of particular epistemic criteria.

In spite of the absence of dedicated support for work in the research projects beyond their expiration date (or the absence of a meaningful plan for the funding of EU synthetic biology in the FP6-FP7 transition, as I argue in section 5.1.), it would be short-sighted to frame the projects as purely ad hoc assemblages; or to inexorably tie them to the specific applications (in the case of FP7 work), in a fashion such as posited in Gibbons et al. (1994) *Mode 2* style of contemporary research. Instead, I noted throughout this thesis (and illustrated in Parts II and III) that epistemic communities matter – and they matter not only to researchers, but also to funders (be they the EC or national funding bodies). Thus, it follows that (EU synthetic biology) community is built in, and travels across, research projects; or, cast through an organisational lens, community travels through the temporary assemblages put in place to conduct (temporally bound) research projects. To explore the process of community-making in these settings, I will turn to the work presented in Part III, and reflect on the making of an EU synthetic biology community across that string of (potential) projects. I start, however, with a brief detour through conceptual work on a potential aesthetic of community.

9.3.1 Community and the realpolitik - zweckgemeinschaft

Leonelli & Ankeny (2015) and Ankeny & Leonelli (2016) make the case that research projects are capable of leading to the formation of new research communities through the development of a shared repertoire. While I argued in chapter 6 that it was the case the work described was pushing forward a (sub-)community in the synthetic biology of cyanobacteria, with a developing repertoire at the junction of (EU) synthetic biology and cyanobacteria research, to focus on this outcome would be to obscure the messy process through which it emerged. Unlike the case of iGEM, epistemic purity was in no way attainable. Instead, this was community-making characterised by performing a balancing act between the epistemic and the non epistemic; desirability and feasibility; imposition and resistance. It was community-making which proceeded through assemblages which were heterogeneous, incongruent and unstable; and, prominently, assemblages explicitly utilitarian.

To explore the making of epistemic communities against such a background, I draw on the German concept of *zweckgemeinschaft*, presented in section 2.3.1. As presented there, *zweckgemeinschaft* is a concept firmly within the realm of realpolitik. It encompasses assemblages which are pronouncedly instrumental, rather than idealistic; which may be fleeting or enduring, depending on the persistence of what drove their establishment and/or sustains them; and which may superimpose on other assemblages, potentially feeding into / feeding off them. *Zweckgemeinschaft* are thus assemblages rooted in difference, but stabilising all the same. Nevertheless, the inherent (potential) contradiction renders them (temporally) fragile. There is a clear parallel to be drawn between the assemblages described as examples in 2.3.1, and those examined over Part III, put in place towards sustaining work in the (EU) synthetic biology of cyanobacteria. I move now to the exploration of *zweckgemeinschaft* in the community-making process observed.

As I describe at length in Chapter 7, the preparation of the CyanoH2Modules, CyanoBioFoundry and the (myriad of) potential successor research projects was guided by a combination of epistemic and non-epistemic criteria. Chiefly among the latter is that of *fundability*. Considerations of fund-ability are more muted in the case of CyanoH2Modules, but it is nevertheless noteworthy that this was an explicit synthetic biology project where, at its start, only two out of six research partners were led by PIs with commitment towards synthetic biology. Olga, Oliver, and Oscar's research interests, in particular, were tied to the (model) organism, in what can be broadly deemed to be the biology of cyanobacteria. Their involvement in the project was not driven by the epistemic allure of synthetic biology, but through the practical allure of funding for their extant research interests.

In contrast, fund-ability took centre stage in the case of CyanoBioFoundry. Despite the willingness to work together, the researchers were reliant on the publication of calls for proposals which were enabling of their individual and collective research goals; and even when a suitable candidate emerged, fund-ability was further articulated through explicit requirements in the call text and/or through the performative character of expectations (Brown & Michael, 2003). In particular, it was articulated through (perceived) demands on temporality, nature and tangibility of outputs, and composition of the consortium – in terms of size, expertise (and *path dependence* (Arthur, 1989) in expertise), inclusion of SMEs and geographic distribution. Thus, the project was not constructed around epistemic criteria alone, but through a combination of epistemic criteria and the above from the very beginning. The resulting project was not one dedicated to synthetic biology, but one where the spotlight was shared between synthetic biology and the development of particular reactors; where the membership of the SMEs was contested and framed as superfluous; where synthetic biology (and its epistemic practice) was valued by only a portion of the membership; and where epistemic conflict was commonplace.

Lastly, the importance of fund-ability peaked in the imagination of and preparation for potential new coalitions which could materialise after the end of CyanoBioFoundry. Despite the group having laid the groundwork for a productive, common repertoire, and having developed a sense of community over the course of the project, there was an expected (and articulated) inevitability to its break up. The consortium was expected to splinter and new coalitions to emerge. Once again, fund-ability was key in guiding these potential new coalitions. This became visible in the submission of two grant proposals for work which built on the accomplishments of CyanoBioFoundry, but took it in new directions; these projects were to build towards different outputs (towards which the CyanoBioFoundry participants had no particular commitment) and included new partners (with demonstrable expertise in those outputs). There was little perceived advantage in this shift for the researchers; the value was rooted mostly on the ability to acquire resources for another period and further established (synthetic biology) research goals, while the new partners would advance their research agenda on the particular outputs.

The instrumentality of the new coalitions was also foregrounded in the open days detailed in section 7.2.3. As noted there, the open days served as community-making devices (Molyneux-Hodgson & Meyer, 2009), and ones where the participants were carefully hand-picked. The inclusion of American researchers in these events was, from a purely epistemic lens, not warranted. American and European researchers belonged to largely mutually exclusive "model organism communities" (Leonelli & Ankeny, 2012), which would render collaborative work problematic. Yet, their presence was justified by fund-ability – the existence of dedicated H2020 funding calls for EU-USA collaboration in the biosciences. Similarly, a Japanese researcher (and project) was consistently involved in the open days, in large part also due to the expectation of funding streams for EU-Japan collaboration in the biosciences.

All the assemblages described – the two which materialised, the two which did not, and the potential new ones – evidence the incorporation of participants, ways of working and goals which do not map onto epistemic criteria. Instead, they provide a window into the process through which funders exert control over the content of research at a micro-level. This affords a key role for funding in the trajectory of EU synthetic biology (and its community), for these are assemblages created specifically in response to funding pressures. This becomes visible through the correlation between the increase in salience of non-epistemic criteria in the projects and the increasingly stringent funding environment; the temporal fragility of the assemblages, which emerged and dissolved according to the temporality of funding streams; and the (re)organisation of (potential) work around criterium of fund-ability, even when that was potentially problematic from an epistemic standpoint.

The concept of *zweckgemeinschaft* brings into sharp focus the organisational facet of the making of community across the projects mentioned. To fully capture the relevance of these assemblages in the process of community-making, however, it is important to also link them to the epistemic entanglements and labour which took place in the research projects and in the preparation of potential new iterations. As I argue in Chapter 6, it is productive to explore these themes through the concepts of *enrolment* (Callon, 1984) and *repertoires* (Leonelli & Ankeny, 2015).

CyanoH2Modules was a project created as a quasi ideal type of parts-based synthetic biology – an endeavour towards which neither of Olga, Oliver and Oscar ostensibly held any commitment. At the end of the project, however, they had firmly enrolled in a synthetic biology community, to the point where they were key in pursuing a new (synthetic biology-driven) iteration. Moreover, their students had been explicitly trained towards the development of the modes of *individual interdisciplinarity* (Calvert, 2010) which were valued in PBSB. Overall, the project lay the groundwork for a synthetic biology of cyanobacteria, with the production of key artefacts (promoters, chassis, models, etc.) and the building on existing synthetic biology practice and adapting it to the relevant model organism.

In CyanoBioFoundry, the epistemic practice reflected a broader diversity of epistemic subjects and commitments. In particular, the project displayed tension between the focus on the development of synthetic biology and the focus on scale-up, photobioreactors and production of outputs. There was a deliberate decision to keep the two foci as separated as possible through the shaping of the work packages, but entanglement was nevertheless designed into its ways of working. As it finished, the project echoed the key outputs of CyanoH2Modules – the enrolment of (some) epistemic subjects into synthetic biology (at the top and bottom of the career ladder), the development of (individual) interdisciplinary epistemic arsenals and the further development of a synthetic biology of cyanobacteria. Yet, successfully completing the project also required epistemic labour which went beyond (existing) boundaries of the synthetic biology repertoire. Biologists performed shear tests and changed media composition at the request of the bioreactor (and process) engineers; engineers changed bioreactor designs to enable preferred epistemic practice by biologists. Modellers moved beyond the confines of the cell to develop a model of how light penetrated the bioreactors. Choices of cyanobacterial strains, genetic parts and/or modifications to the *chassis* were, in some cases, driven by 'omics analysis in the context of the large-scale bioreactors (in detriment of the small, research ones). As I note in Chapter 6, the extent to which these artefacts and ways of working were incorporated into the synthetic biology repertoire was contested across time and among the researchers. Yet, it is not contested that, from the point of view of artefacts, this work yielded several, like a common, standardised photobioreactor (at the research scale), which was desired by the synthetic biologists; or, from the point of view of an epistemic arsenal, that PhD projects were predicated on work alongside photobioreactor development – the PhD project on the development of a mathematical model of light penetration in the reactors being the most poignant example.

Lastly, it is important to briefly reference the epistemic work which took place in anticipation of a joint project; I will do so solely in the context of the potential collaboration between the EU and the Japanese projects which I describe in Chapter 7. I argue there that this *zweckgemeinschaft* has epistemic relevance in three main dimensions: the dissemination of the photobioreactor (to Japanese researchers), the epistemic exchange associated with researcher visits, and the mutual orientation of research agendas promoted in the *community-making devices* (Molyneux-Hodgson & Meyer, 2009) held in both territories. This was, then, an assemblage which promoted epistemic convergence between the leading European and Japanese researchers in the synthetic biology of cyanobacteria, through the work towards a shared repertoire – through a shared key artefact, converging ways of working, and converging (already close) research goals.

9.3.2 From *zweckgemeinschaft* to communities of need

Epistemic communities are, at their very core, what Gläser (2001) dubbed as "producing communities". They are communities characterised by and organised around knowledge production, which is itself grounded on a shared *repertoire* (Leonelli & Ankeny, 2015), produced and reproduced through the performance of epistemic labour. In the case of EU synthetic biology, I argued in Parts II and III that funding (itself recruited as a tool of governance) played a key role in the trajectory of the field. I noted in the section above a key conduit of that effect, in the examination of the coalitions nurtured by the funding landscape at the micro level as *zweckgemeinschaften*. In this last sub-section, I step back my analysis from the data to conceptualise these assemblages in the process of the making of epistemic communities.

I have argued throughout this section that a concept which encapsulates utilitarianism in the making of epistemic communities is both lacking and a useful addition to the collective toolset. Thus far, I addressed that gap by deferring to the German concept of *zweckgemeinschaft*. There are, however, two key shortcomings to codifying that concept: it is neither readily intelligible, nor is an epistemic dimension to the assemblage overt. Instead, I believe a new concept in the language of writing and which is not hampered by the connotation of the former is warranted.

As such, I propose the concept of *communities of need*; this concept would denote assemblages in the process of (re)production of epistemic communities which would not have come together in the absence of a given *need* – in the case of the EU projects, that need being funding for carrying out epistemic labour. As such, by their very essence, I see communities of need as transient assemblages, aligned with what Cain (2002) proposed as "transient communities". Much as in the case Cain described, however, their temporal fragility is not synonym with inconsequence. Epistemic community travels through such communities of need. Thus, this is a concept well positioned to address contemporary processes of (epistemic) community-making.

A broad typology of the concept can be further specified as foregrounding (epistemic) heterogeneity, temporary (epistemic) stability, and (epistemic) legacy. As noted throughout this section, this is a concept which aims to address assemblages which transgress epistemic silos; these are, consequently, assemblages which are borne into being through the preponderance of non-epistemic criteria in the organisation of epistemic labour. As such, they foreground the shift in what Whitley (2010) dubbed to be authority relations for the conduct of research. They reflect forceful intervention in the organisation, goals, process and/or outputs of research[98]; an effect which is exerted through scripting (Akrich, 2010) of the latter – both explicitly and through the performative power of expectations (Brown & Michael, 2003). This can be illustrated by the inclusion of SMEs, the development of photobioreactors, the geographic spread of participants, or the association with a Japanese project in/alongside the synthetic biology epistemic labour described in the case study of Part III.

The second key feature of these assemblages is linked to the (temporary) stability they provide. Despite their inherent heterogeneity, the assemblages provide a veneer of commonality, (perhaps not exclusively, but mostly) in the form of addressing a shared *need*. While that *need* remains (shared), so are dissonant arrangements stabilised. Linking back to the case study, the shared *need* stems from the combination of the reliance on FP funding for the conduct of research and the conditions of how those resources may be acquired. Amidst the heterogeneity, the stability of these assemblages is relevant beyond shared *need*, for they provide a space for (other) communities to emerge / be nurtured. They enable *repertoires* to be built; novices to be trained; researchers to be *enrolled*. And through the above and deliberate community-making efforts (through the form of *devices* (Molyneux-Hodgson & Meyer, 2009)), they enable the *movement* and creation of the *stickiness* (ibid.) which binds epistemic communities. Once more, this is illustrated in the case study of Part III in the enrolment of Olga, Oliver and Oscar, in the first instance, and the enrolment of Joachim later on; a gradual development of the ways of working and artefacts enabling of synthetic biology in cyanobacteria; and an articulation of the need for community in the synthetic biology of cyanobacteria both within and outside the consortia, which culminated with the building and stabilisation of links with researchers from Japan.

While these assemblages will inevitably travel through projects, it is also important to make clear they cannot be subsumed under that heading. Arguably, there will

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[98] An intervention which Gläser & Laudel (2016) have argued has funding as its main conduit, and which I have corroborated throughout the thesis.

be value in conceptualising assemblages which dissolve after only a sole project is concluded as communities of need. For one, there will be *residue* (a theme I'll turn to shortly). For another, even in these cases, the temporality of the community would not map onto the temporality of the project – if nothing else, it would extend to the project preparation, similar to what I described in sections 6.1.1 and 6.2.1. Nevertheless, community-making is a longitudinal process, and that clashes with the short temporal horizons of project-based work.

Indeed, the case study presented in Part III suggests the greater value of the concept is in addressing assemblages which, if transient, are more enduring; where *process time* outlasts *project time* (Ylijoki, 2016), and where a shared need is sustained, for community-making is, again, a longitudinal process. This is nowhere clearer than in the slow march towards a repertoire which supports the synthetic biology of cyanobacteria, which after two full projects still struggles against the unwieldiness of biology.

Still, this is not to say the community is immutable over time. As shown in Part III, quite the opposite was true – be it because of changing research interests, or a changing *need* (largely propelled by changes to research funding). Thus, the transience of these assemblages is brought to the fore in that they change or dissolve once the shared *need* changes, or it no longer exists (e.g. through a change in the funding landscape). However, they do not (change or) dissolve without leaving what Rip (2000) dubbed "residue". Rip proposed the concept in the context of "fashions" (ibid.) in science policy; he argued that science policy goes through cycles, which change in tandem with political priorities. Expectations and the instruments (are) changed in a bid to implement the new policy. Yet, the previous regime would not fully disappear. Making a parallel with Downs' (1972) issue-attention cycle[99], Rip ar-

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[99] Down's issue-attention cycle has clear parallels to the (later) hype cycle. Studying the prominence of ecological concerns, he proposed they went through a cycle in 5 stages: "pre-problem", "alarmed discovery and euphoric enthusiasm", "realizing the cost", "gradual decline of intense public interest" and "post-problem". In short, he argued the issue started as a peripheral concern, gained immense notoriety, which peaked with the acknowledgement of the size of the challenge, then gradually slumped to a low, and then stabilised at a *residual* level of attention.

gued that, as science policies were replaced they would reach a stage similar to Down's (last) "post-problem" stage; they would not completely dissolve, but wane to a *residue*, in the form of enduring research programmes, networks, institutions, etc. Modern policy regimes, then, combine the contemporary political priority with an accumulation of past policy *residue*.

In the context of communities of need, the strategies for dealing with the pressure to realise work which contradicts epistemic canon are likely to include *resistance* (Hackett, 1987; Fowler, Lindahl, & Sköld, 2015) and *window dressing* (Laudel, 2006), but *accommodation* (Hackett, 1987; Fowler, Lindahl, & Sköld, 2015) is virtually unavoidable. As such, these communities encompass the performance of epistemic labour which is not (strictly) desired and/or valued by the epistemic communities which travel through it. That labour should not be dismissed. As the community dissolves, it does not do so without making a mark on the artefacts, identities, epistemic practice and/or relationships between its members; the dissolution of the community does not take place without "residue". It is through the latter that communities of need (potentially) make cumulative, enduring contributions to epistemic communities. They expand the repertoire, be it through artefacts and infrastructure (like the photobioreactor designs and the knowledge base of the EU projects); ways of working (like the creation of a largely new synthetic biology of cyanobacteria in the EU projects); and identities (like the promotion of intradisciplinarity in the case of the EU projects novices' epistemic arsenal). They expose researchers to different epistemic communities, and cultivate the development of commitments towards those (as in the case of Linus, who was tentatively moving towards synthetic biology in the EU projects).

In sum, I propose the concept of *communities of need* as a tool to study the making of epistemic communities in contemporary research – against a context of projectification of research, with concomitant irregular and disconnected performance of epistemic labour; and increased direct recruitment of research in addressing policy objectives, with the governance of the former being exerted to a large extent through the allocation of funding. I contend a concept of community-making which incorporates instrumentality and transience is a useful addition and enables the analysis of the effect of funding in the trajectory of epistemic communities. In doing so, I foreground the stabilising effect of the assemblages in that they provide a space for communities to be nurtured; but also the consequence of their heterogeneity, which I argue results in the creation of *residue* which impacts on the trajectory of the epistemic community beyond the demise of the assemblage. I further contend that, against a research environment where funding plays a preponderant role, it is a useful concept to empirically investigate the impact of funding on what Braun (1998) called the "cognitive development of science".

I contend also this is a concept whose applicability is in no way confined to synthetic biology. It is true that synthetic biology is a current standard bearer for the "new biology" (NRC, 2009), but the stated ambition of the US National Research Council is nothing short of a wholesale reimagining of biology along those lines. As biology which is conducted in a projectified model, in collaboration with natural/physical sciences and/or engineering, and with a view towards fulfilling a particular societal goal. At the end of this thesis, I trust such an aim will ring familiar to the reader, for that is the model under which synthetic biology operates.

I argue further that the concept is not confined to the realm of biology either. Taking the case of EU research, as I describe in Chapter 4, the focus of the framework programmes has shifted away from the support of particular research avenues, but towards particular themes of societal relevance. As noted, this was a trend which became stronger in the move from FP6 to FP7; and the same has taken place as FP7 gave way to Horizon 2020, with the latter framing the tackling of *societal challenges* as a policy and research priority. Inevitably, this has meant further (re)orienting of resources towards research work at a large scale, and which cuts across disciplinary boundaries – all while exacerbating the trend towards the *projectification* of work.

This backdrop strongly suggests that the changes to the science system I identified in the study of synthetic biology are widespread. As such, I propose this is fertile ground on which to apply and develop the concept of *communities of need*.

9.4 LOOKING FORWARD

With this thesis, I aimed to provide a glimpse into synthetic biology in the making. Nevertheless, there were numerous questions this study could not answer, as well as new ones it raised. This is both inevitable in any such work, and exacerbated by the longitudinal nature of the process of emergence of epistemic communities (foregrounding the conflict between the PhD project time and research process time). In this last section, I reflect on the potential avenues for future work.

Firstly, I see merit in progressing further along the same track as the PhD. In work which addresses community as a moving target(s), it would be important to examine how that changed in the period since the fieldwork took place (and towards the future). In particular, it would be relevant to sustain engagement with the community of need identified – as well as its (many potential) offshoots. At the same time, and in tacit recognition of the strong role of governance in knowledge production and the trajectory of communities, it would be productive to engage more meaningfully with what Frickel et al (2010) dubbed "undone science"; that is, research that is desired (at least by a subset of actors), but does not materialise. To bring the absences to par in the analytic frame would enable the researcher to examine both the picture and the negative, providing a window into a dimension of epistemic communities (and community-making) which is fleeting and hard to access.

The thesis was also one which put considerable focus on the emergence of European synthetic biology, sketching its trajectory over the years. However, it provides only a partial view of the understanding and role of synthetic biology in the context of its key governance actor (the European Commission) and its core set. It would be valuable to address this knowledge gap in further research, so as to enrich our understanding of European synthetic biology and how it travelled research, community-making, bureaucratic and policy rooms. Lastly, and given the extent to which science is placed, there is likely to be productive work to be done in addressing European synthetic biology in a comparative frame. There is already a considerable body of work investigating American synthetic biology (and an emerging one on the Chinese counterpart) which may be drawn on; there is little work, however, focused on Japanese synthetic biology. Particularly given the latter still enjoys considerable support in the form of block grants, a comparative study would likely prove challenging, but rewarding.

On this note, I bring the thesis to an end. How appropriate to do it trying to gaze beyond the horizon, standing on the shoulders of giants.

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APPENDIX A

TRUNCATED LIST OF RELEVANT ACTORS IN THE PROJECTS PRESENTED IN PART III

Alias	Participant role
Bran	Doctoral researcher (wet/dry lab)
Clara	Postdoctoral researcher (wet lab)
Eduardo	Doctoral researcher (dry lab)
Fabio	Principal investigator (industry)
Fátima	Predoctoral researcher (wet lab)
Fernando	Postdoctoral researcher (wet lab)
Gregor	Principal investigator (industry)
Henrik	Doctoral researcher (dry lab)
Hernando	Project leader of CyanoH2modules (dry lab)
Ignacio	Principal investigator (dry lab)
Jiro	Leader of Japanese project analogous to CyanoBioFoundry
Joachim	Principal investigator (dry lab)
Leonardo	Doctoral researcher (dry lab)
Linus	Principal investigator (wet lab)
Luka	Principal investigator (wet lab)
Natalia	Doctoral researcher (dry lab)
Nuno	Postdoctoral researcher (wet/dry lab)
Olga	Principal investigator (wet lab)
Oliver	Principal investigator (wet/dry lab)
Oscar	Principal investigator (wet lab) + CyanoBioFoundry leader

APPENDIX B

PROOF OF ETHICAL APPROVAL

The University Of Sheffield.

Department
Of Sociological
Studies.

Celso Gomes
Department of Sociological Studies

Department Ethics Co-ordinator
Dr Harriet Churchill

The University of Sheffield
Department of Sociological Studies
Elmfield, Northumberland Road
Sheffield, S10 2TU

Telephone: +44 (0) 114 222 6440
Fax: +44 (0) 114 276 8125
Email: h.churchill@sheffield.ac.uk

28 February 2014

Dear Celso

PROJECT TITLE: ***Community-making in synthetic biology: a European case study***

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 25 February 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 form dated 14 February 2014
- Participant information document dated 14 February 2014
- Participant consent form dated 14 February 2014

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

APPENDIX C

PROJECT INFORMATION SHEET

Information sheet for research participants

Project title

Community-making in synthetic biology: a European case study

Invitation

You are being invited to take part in a PhD research project that is studying the development of the field of synthetic biology in a European context. 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).

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 if there is anything that is not clear or if you would like more information.

Thank you for reading this.

Purpose of the research

The research aims to investigate and understand:

- how the scientific field of synthetic biology is evolving and becoming successful;
- how successful collaboration is achieved in a large European project;
- why synthetic biology is seen as a potential solution to the energy crisis.

What to expect

It is up to you to decide whether or not to take part in my research. If you do decide to take part you will be given this information sheet to keep as it contains my contact details. You will be able to withdraw from taking part in the research at any time by contacting me directly.

I will sit in on project and work package meetings and record (often written notes) some of the activities that take place there. You may also be asked to take part in (audio) recorded conversations or individual / group discussions about your research. There will hopefully be little disturbance to you and your ongoing 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.

Confidentiality

Any information that I collect will not be attributed to individuals without their explicit agreement. Any reports or papers that I write will contain anonymised information and I endeavour to keep the identification of labs and institutions to a minimum where this is appropriate.

Any digital recordings (audio/photo) made during this research will be used during my 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 the project will be allowed access to the original recordings. If being interviewed using audio tape, you will be asked to give verbal consent to the interview.

Absolute confidentiality, however, is problematic due to the public listings of project members. Thus, in addition to all efforts to ensure confidentiality outlined above, I will also ensure transcripts of interviews will be passed back to interviewees for comment/correction or further elaboration, and draft papers and articles will be circulated to participants for comment and discussion prior to submission to journals, to ensure they feel their views are appropriately represented.

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 or concerns about the work or you do not consent to participating in the project , then please contact the me, Celso Gomes:

Email: c.gomes@sheffield.ac.uk

If there are any problems that arise in connection with my work, please contact my doctoral supervisor at University of Sheffield, Dr Susan Molyneux-Hodgson:

Email: s.hodgson@shef.ac.uk

If you decide to take part on the research, please sign the Consent Form attached.

MANY THANKS

APPENDIX D

PROJECT CONSENT FORM

University of Sheffield

Participant Consent Form

Title of Research Project: Community-making in synthetic biology: a European case study

Name of Lead Researcher: Celso Leandro Garcia Ferreira Gomes

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. ☐

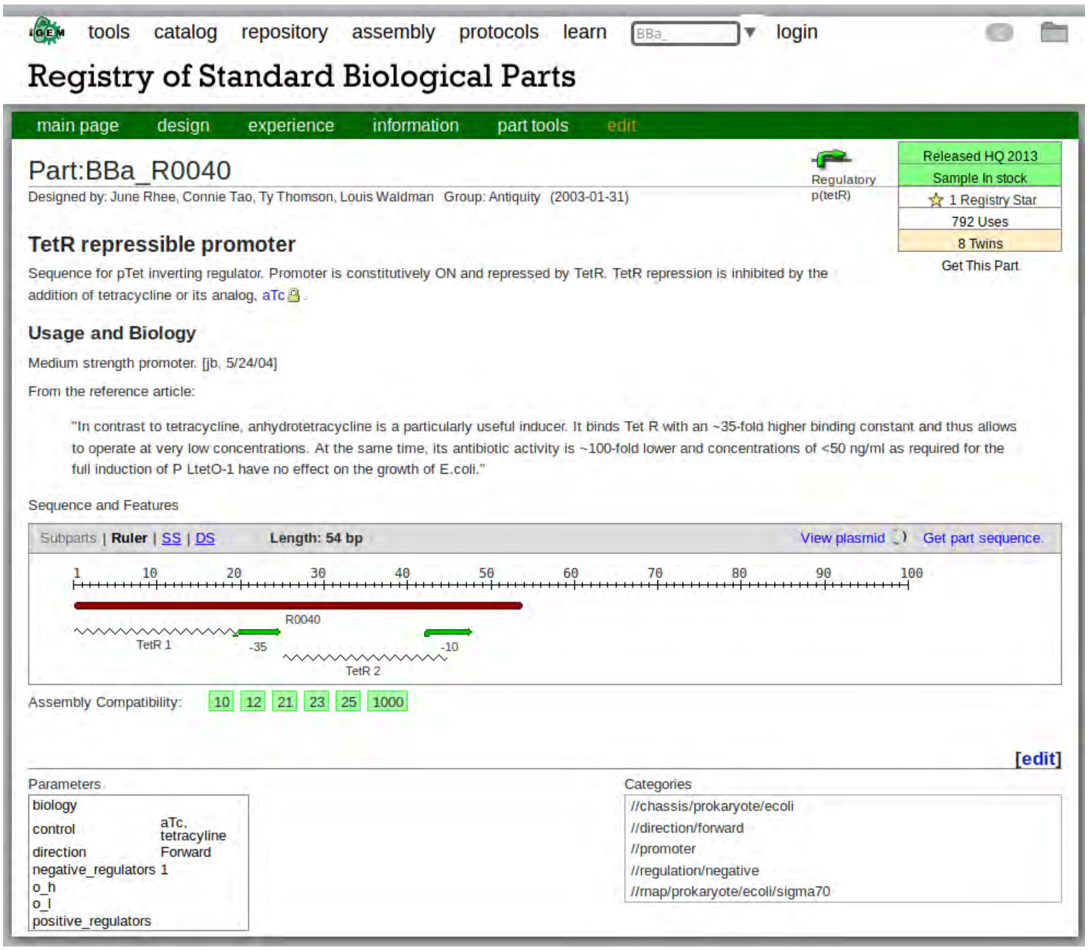
____________________________	___________________	_______________________
Name of Participant (	Date	Signature
____________________________	___________________	_______________________
Name of person taking consent (*if different from lead researcher*)	Date	Signature
____________________________	___________________	_______________________
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.

APPENDIX E

SNAPSHOT FROM THE REGISTRY OF STANDARD BIOLOGICAL PARTS



Registry of Standard Biological Parts

Part:BBa_R0040

Designed by: June Rhee, Connie Tao, Ty Thomson, Louis Waldman Group: Antiquity (2003-01-31)

TetR repressible promoter

Sequence for pTet inverting regulator. Promoter is constitutively ON and repressed by TetR. TetR repression is inhibited by the addition of tetracycline or its analog, aTc.

Usage and Biology

Medium strength promoter. [jb, 5/24/04]

From the reference article:

> "In contrast to tetracycline, anhydrotetracycline is a particularly useful inducer. It binds Tet R with an ~35-fold higher binding constant and thus allows to operate at very low concentrations. At the same time, its antibiotic activity is ~100-fold lower and concentrations of <50 ng/ml as required for the full induction of P LtetO-1 have no effect on the growth of E.coli."

Sequence and Features

Assembly Compatibility: 10 12 21 23 25 1000

Parameters

biology	
control	aTc, tetracycline
direction	Forward
negative_regulators	1
o_h	
o_l	
positive_regulators	

Categories

//chassis/prokaryote/ecoli
//direction/forward
//promoter
//regulation/negative
//map/prokaryote/ecoli/sigma70