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Making big promises come true? Articulating and realizing value in synthetic biology

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Abstract

Synthetic biology is an emerging approach to biotechnology that strives to use engineering principles and practices to design and make new organisms. Proponents of synthetic biology have big aspirations for this field, citing potential for an industrial revolution in biotechnology. This paper is concerned with how value is being negotiated and constituted through practice in synthetic biology — through the promises being made, through the objects and products being produced, through the initiatives and institutions being established, and through the working practices and justificatory strategies of synthetic biologists. In particular, I focus on negotiations surrounding the making, use, and circulation of BioBrick™ standard biological parts. BioBricks are presented as tools that will make genetic engineering more efficient and reliable, and are accompanied by a particular imagination of innovation and value creation in synthetic biology. But exploring valuation practices in action reveals a number of sites of ambivalence and contestation over the BioBrick approach to synthetic biology. Through a series of vignettes, I show how these negotiations over the promises and practices surrounding BioBricks are configuring the epistemic foundations and design space of the field, and are helping to define what value means in synthetic biology.

Keywords biocapital; BioBricks; moral economy; standards; synthetic biology; value

Introduction

Synthetic biology has been gaining visibility over the past decade as an approach to biotechnology that strives to use engineering principles and practices in order to design and make new organisms (Endy, 2005; Heinemann & Panke, 2006). Engineering-based approaches to studying and designing life can be traced throughout the 20th century (see Campos, 2010; Pauly, 1987). This particular iteration emphasizes goals of design, control and predictability in the design of useful biological systems. It takes as a starting point the advances made in molecular biology and industrial biotechnology over the past 30-40 years, in particular the development of recombinant DNA technologies for excising and shuffling genetic sequences. Improvements in the efficiency and accuracy of DNA sequencing have led to the rapid accumulation of genetic sequence information about many living organisms in public databases. Parallel advances in DNA synthesis technology mean that the ability not just to 'read' but also to 'write' DNA is increasing rapidly. This shift from reading DNA sequences to writing and composing them is presented as central to the engineering ethos of synthetic biology.

This paper focuses on the so-called 'parts-based' approach to synthetic biology,[1] which first began to be articulated by a small group of US-based researchers in funding proposals and papers 10-15 years ago (e.g. Arkin and Endy, 1999). Proponents of this approach state a concern with wanting to manage (or 'black-box') the complexity of living organisms by decomposing their genomes into standardized genetic 'parts' that have predictable properties, and in turn using these parts to design new (micro-)organisms with specified properties. Commonly cited examples

[1] A number of different core pursuits are identified under the heading of synthetic biology, including DNA 'parts-based' approaches, whole-genome engineering, and protocell work (O'Malley *et al*, 2008).

include engineering algae to produce biofuels (Service, 2011), or using yeast as 'factories' for the production of antimalarial drugs (Ro *et al*, 2006). Parts-based synthetic biology advances an imagination of DNA as text or code that can be composed and (re-)written for instrumental ends. Rather than simply studying, mapping or representing biological processes, practitioners are explicitly application-oriented and focus on creating new living entities for useful purposes. Furthermore, they are concerned with creating life that performs according to certain metrics or rules; life in which complexity and emergence can be managed, and in which evolution is brought under control. As a means to this end, they propose breaking down the genomes of living organisms into component 'parts' associated with defined functions.

Through practices of isolation, measurement, standardization, and reconfiguration, these biological parts become dissociated from their species provenance and evolutionary histories. A key aim of these efforts is to disentangle genetic material from its biological context so as to facilitate the flow of genetic information across space, time, and organisms, to enable entry into new systems of biological production or "circuits of vitality" (Rose, 2007: 15). Like many genomics-related endeavours, synthetic biology straddles both biological science and information science, in this case also introducing discourse from engineering and design (Mackenzie, 2010). Compared with several core studies of biocapital and biopolitics (e.g. Cooper, 2008; Rose, 2007; Sunder Rajan, 2006), synthetic biology orients our attention towards the molecular and particularly the micro-organismal facets of modern biotechnology, and encourages us to consider materiality and the implications of conceptualizing biological (micro-)organisms as substrates for engineering practice (Helmreich, 2008).

Synthetic biology is in its early stages, rich with promises and yet still facing numerous challenges and uncertainties. Its practitioners aspire to revolutionize biotechnology, and to realize this promise they are working to redirect knowledge, life, and labour into new cycles of production, circulation and wealth creation. As well as proposing to refactor the material basis of biological production through the development of standardized and well-characterized genetic components, synthetic biologists see the complementary reorganizing and restructuring of work practices in the life sciences as necessary for harnessing biological potential to the fullest. In this paper I consider how value in (and the value of) synthetic biology is being constituted and negotiated, through the making (and re-making) of BioBrick™ standard biological parts. Rather than assume a stable or uncontested definition of value, I focus on actions and practices of valuation in synthetic biology – treating value not as a noun but as a verb, *to value* (Muniesa 2012). What is seen as worth knowing, and to what ends? How is value being constituted in synthetic biology, and how are valuation practices shaping this nascent field? To explore these questions, I draw on material gathered from synthetic biology reports, articles and websites, a small number of interviews conducted in 2009 with self-identified synthetic biologists in Europe and the United States, and participant-observation at over a dozen synthetic biology meetings, workshops, and conferences.[2] Similar to a forthcoming volume by Dussauge *et al*, this paper explores valuation practices with reference to a growing body of literature on biocapital and on moral economies in contemporary life sciences. I trace the active constitution and contestation of value in synthetic biology through the promises being made, through the production of biological objects such as BioBricks, through the initiatives and infrastructure being established, and through the working practices and justificatory strategies of synthetic biologists. This work is

[2] It should be noted that I have helped to organize some of these events, in my role as one of the coordinators of a research network in synthetic biology (the UK Synthetic Biology Standards Network, which was funded from 2008–2011 by four of the UK Research Councils).

narrated through a co-productionist lens (Jasanoff, 2004), focusing on the simultaneous constitution of the material and social worlds of synthetic biology, and the entangled practices of knowledge-making and valuation in discipline formation.

A proposal for BioBrick™ standard biological parts

The BioBrick™ standard biological part is sometimes referred to as a 'poster child' for synthetic biology; it is a tangible example of the way in which synthetic biologists are attempting to bring engineering concepts and an engineering mindset to biology, with the aim of codifying biological knowledge and "transform[ing] the field of biology into an engineering discipline."[3] The BioBrick was first proposed by Tom Knight (2002), a senior computer scientist based in the Department of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology (MIT). Explicitly compared with Lego® bricks, BioBrick parts are DNA sequences (encoding known functions) that have been designed in a standardized format to allow their combinatorial assembly into genetic 'circuits'. The word *designed* is crucial. Although BioBricks contain genetic elements that have been studied and used for decades in molecular biology and genetics research,[4] the idea of designing these elements in a highly specified and standardized way to create modular, interchangeable, and idempotent[5] parts that can be assembled into genetic circuits using automated protocols seems to be an innovative proposal. One experienced molecular biologist who runs a laboratory in a cell biology institute described his introduction to the BioBrick as follows:

[3] http://intranet.synberc.org/about (accessed 29 July 2013)
[4] Such genetic elements include for example promoters, terminators, gene-coding sequences, and ribosome binding sites.
[5] Idempotent: not changed in value following multiplication by itself (Collins English Dictionary, 6th Edition).

> …it took me a while to get my head around the concept of BioBricks, so I really, when I went to the first meeting I didn't understand at all how it was supposed to work. But once they explained it, it was like [snaps fingers] 'Why didn't I ever think of that, that's absolutely brilliant!' (synthetic biologist 3)

The BioBrick proposal aims to exploit what some biologists describe as the intrinsic or natural modularity of biological signalling and decision-making systems (Agapakis and Silver, 2009; Hartwell *et al*, 1999; Lim, 2010). Drawing analogies with man-made modular systems such as computers and electrical circuits, BioBricks are presented as foundational components of a biological abstraction hierarchy in which modular component 'parts' can be combined into larger biological 'devices' or 'systems' that are incorporated into different host organisms ('chassis') to carry out defined and predictable functions (Endy, 2005; Campos, 2012). One explicitly articulated motivation for working to such a structured scheme is to overcome what some see as the "ad hoc" (Knight *et al*, 2003: 2) or even the "medieval craft" nature of molecular biology (synthetic biologist 1), and to allow biological engineering to become more routine, standardized, and predictable than existing practices in biotechnology.

BioBricks are thus presented as tools that will make genetic engineering more efficient. Early agenda-setting documents propose a set of desired specifications for these biological parts. First, the parts should be modular in structure, containing standardized interfaces. Second, parts should be easy and efficient to assemble. Designing and assembling DNA constructs can be time-consuming tasks: Drew Endy speculates that "a practicing experimental biologist or biological

engineer can easily spend around 50% of their effort manipulating the DNA just to produce the genetic material needed for an experiment" (Endy, 2005: 452). Accordingly, Tom Knight's BioBrick design is tightly coupled to a specific method for assembling biological parts, and is proposed as a way to improve the automation of DNA assembly, and to circumvent the "tedium and surprise" (Knight *et al*, 2003: 2) associated with preparing DNA constructs. Third, biological parts should be well characterized. In an early research proposal, Arkin and Endy (1999: 3) discuss the need to define and measure the "device physics" for individual biological parts: "each of the components must be sufficiently biochemically characterized such that their behaviour in a larger circuit may be predicted."

Alongside such seemingly technical specifications, the idea of standard biological parts is also articulated in relation to a set of broader visions and expectations about the future of synthetic biology. BioBricks are presented as more than a technical solution to a limitation in the efficiency of DNA assembly, but also as foundational elements of a new, engineering-led approach to biology that will enable biological potential to be harnessed for the development of new products and applications. In this vision, developing standardized parts becomes firmly aligned with aspirations about the utility, scaling up, and industrialization of bioengineering — the ambition is 'big' in terms of projected scale, scope, and profit. Proponents of synthetic biology tout the possibility of a new 'industrial revolution' in biotechnology (e.g. Kitney, 2009), identifying great potential for parts-based bioengineering to deliver useful (and profitable) applications in areas as diverse as (bio)manufacturing, medical diagnostics and therapeutics, and environmental biosensing and bioremediation. Furthermore, policy reports sometimes frame this approach as imperative for meeting key challenges of the 21st century: "the ability not only to understand, but

also to modify and construct biological systems will be essential if we are to apply the power of biology to diverse environmental, energy, and health problems" (National Academies of Science, 2009: 63). Comparisons are regularly made between the availability of standard biological parts and the Industrial Revolution of the 19th century:

> …the standardization of pitch, diameter, and form of screw threads [provided] the infrastructure which allowed the industrial revolution to take off…We anticipate advantages similar to those which accompany the standardization of screw threads in mechanical design — the widespread ability to interchange parts, to assemble sub-components, to outsource assembly to others, and to rely extensively on previously manufactured components (Knight *et al*, 2003: 2).

Such statements start to invoke a particular imagination of innovation in synthetic biology. Technical characteristics of BioBricks (like standardized interfaces) become associated with broader market logic for the production, circulation, and use of these parts. The goal of developing predictable, reliable circuits at the molecular or genetic level is transposed to the scale of product innovation — creating repositories of standardized, modular and well-characterized biological parts is projected to facilitate innovation and value generation in synthetic biology. The revolutionary rhetoric associated with synthetic biology typically describes its potential in diffuse and future-oriented terms (lots of profit stands to be made by many innovators). It is a vision broadly consistent with post-Fordist logic of flexible accumulation (Harvey, 1990).

Importantly, there is a perceived collective value (O'Connell, 1993: 133-136) to be derived from the wider circulation and use of BioBricks, promoting their incorporation into new and useful biological devices. The idea that a single part might be re-used in the construction of multiple, different genetic circuits is central to the BioBrick (and thus warrants the effort involved in systematically measuring and characterizing part behaviour). The technical datasheet that accompanied Tom Knight's original distribution of BioBrick parts proposes that "much of the power of these assembly techniques arise [sic] from a consistent, widely available set of components" (Knight, 2002: 1). Furthermore, from the outset we see ideas of re-use formulated in terms of the open *sharing* of parts: "we strongly encourage others who develop components in this form to contact us with complete information and samples, if possible. We volunteer to act as a community coordination and distribution point for these components" (Knight, 2002: 1).

The distributed production and assembly of biological parts is suggested as a key benefit of defining standards for BioBrick design (Shetty *et al*, 2008: 2). References to efficiency, economies of scope and scale, and more flexible, distributed innovation feature routinely in reports and articles on synthetic biology. One of the stated goals of developing modular biological parts is to facilitate the 'decoupling' of design and fabrication processes in biological engineering. Endy suggests that this stands to have desirable consequences for the division of labour in a multidisciplinary endeavour like synthetic biology, for "each group need only be expert in their respective tasks" (Endy, 2005: 451). Synthetic biology is sometimes discussed in terms of 'de-skilling' (Schmidt, 2008) or even 'democratizing' biotechnology (Billings and Endy, 2008), opening the door for new researchers, practitioners and hobbyists to enter the world of biological engineering.

In volunteering his research group to act as a community coordination point, Tom Knight clearly imagined that there would be a community of users who would recognize the proposed value of standard biological parts for their research, and who would commit to developing and contributing new biological parts to a common repository. Drawing analogies with open-source software (regarding both intellectual property protection and ideas about distributed innovation), early proponents of the BioBrick have been keen to promote the free and open sharing of biological parts. As individual biological parts typically have low value, the logic goes, there is little point in restricting access to them — promises of commodification and value generation in synthetic biology lie further downstream, in the combination of parts into biological devices and systems with useful properties.

In summary, the idea of the BioBrick standard biological part — and indeed synthetic biology more generally — can be said to relate to the organization of scientific practice as much as it does to a particular understanding of how biology works. Built into the technical specifications for BioBrick parts (modularity, easy assembly, predictable function, reusability) are ambitions about how biological parts might be produced, circulated, and (re-)used to facilitate innovation. Synthetic biologists propose to use engineering principles and material artefacts like BioBricks as a basis for reorganizing the biotechnology landscape, so as to overcome current limits to biocapital and generate new and diverse sources of wealth. In this context, we see that the disentangling of genetic parts from their biological context, and their standardization and characterization in BioBrick form, is associated with a promised multiplication in the value of this genetic material for the bioeconomy. Calvert (2008) argues that the practices involved in

isolating and formatting genetic sequences as BioBricks makes them well suited to commodification and appropriation regimes (be they open-source or more proprietary mechanisms). In such promissory formulations, the epistemic and market success of synthetic biology become coupled to the availability of standardized and characterized biological components, as well as tools for designing, assembling, and testing genetic circuits.

Negotiating value in/of synthetic biology

Since the first distribution of BioBrick parts to a small number of research laboratories in the United States in 2002, a highly interdisciplinary and international community of researchers has been forming around the 'parts-based' approach to synthetic biology (Molyneux-Hodgson & Meyer, 2009). Early proponents of BioBricks have been working to establish initiatives including open-access repositories of biological parts (such as the Registry of Standard Biological Parts, founded at MIT), tailored intellectual property agreements for sharing BioBrick parts, community standard-setting mechanisms for developing the technical basis of the field, and not-for-profit organizations to promote synthetic biology. At the moment, most of these efforts are small in scale, experimental in nature, and operate with minimal funding. Furthermore, they are being developed against a wealth of established infrastructure in engineering and the life sciences. Taken together, these initiatives are trying to delineate a space both for the establishment of a technical platform for synthetic biology, and for the development of a community of practitioners with common professional identities revolving around collectively owned concepts and materials like the BioBrick (e.g. Kelty, 2012).[6]

[6] See Kohler, 1994, for an account of the moral economy developed by genetics researchers using *Drosophila* as a shared model organism.

As an increasingly heterogeneous 'community' of synthetic biologists begins to form around this parts-based approach, they are simultaneously negotiating both the technical characteristics of biological parts and the social world of synthetic biology. What design should BioBrick parts have to maximize the design space for bioengineering? What does it mean to characterize a part so that someone else can pick it up off the shelf and use it in their own biological system? Is there (sufficient) demand for the re-use of parts? These are questions that concern the constitution of both knowledge and value in synthetic biology. They interweave understandings of the biological systems being engineered with choices about the desired future of the field. They are being (re-) articulated and (re-)negotiated as new stakeholders join the community, as knowledge about biological systems deepens, and as the broader market and societal value of synthetic biology is debated.

In what follows, I present a series of short vignettes derived from interviews, reports, and ethnographic fieldwork that begin to tease out a number of tensions emerging as the value of synthetic biology is being defined in practice. In particular, we see contrasts between the revolutionary and somewhat homogenizing rhetoric of standardization in synthetic biology, and an observed diversity in the local practices, understandings, and imaginations of researchers. What we encounter might be described in terms of tensions arising from the performance of 'a flank movement' in valuation (Muniesa, 2012) — instances where the difference in meaning of value as a noun and valuation as a verb come to the fore. In contrast to the future-oriented ambitions outlined in the previous section, these vignettes highlight the value of synthetic biology not as a static or pre-determined property of the technology, but as a contested and contingent

attribution that is always in-the-making. Tensions are revealed through an ongoing dialectic between the projected value(s) of synthetic biology as a fixed attribute, and the present-day practices of valuation that are shaping the field. In the examples that follow, we see the complex intertwining of epistemic, academic, ethical, and market values that researchers are negotiating while trying to establish synthetic biology as a discipline.

Negotiating epistemic value through BioBrick design

Synthetic biology offers a rich case study for exploring the negotiation of epistemic value, as engineers, biologists and computer scientists come together in an attempt to determine whether and how engineering principles and practices might be applied to the design of living systems. One particularly clear site where epistemic dimensions of value are being contested relates to debates over BioBrick design standards. Although many synthetic biologists see the general principles underpinning BioBrick design as innovative and potentially useful (whether their prior training is in engineering or biological sciences), they have repeatedly clashed over how much biological knowledge is necessary in order to develop an 'appropriate' BioBrick design. Since the initial design standard for BioBrick parts was proposed (Knight *et al*, 2003; Knight, 2007), researchers from a number of laboratories in the US and Europe have advanced alternative standards.[7] (See Campos, 2012, for a historical account of the micropolitics underpinning BioBrick standards development.) Within the growing community of practice, many see the original BioBrick standard (known as the BBa or RFC10 standard) as inherently flawed and as

[7] The precise number of alternative standards proposed depends on exactly how one defines the standard, but at least six variations on the original BioBrick design have been formally proposed by individuals and laboratories in the US and Europe.

constraining the design space for synthetic biology. This technical 'flaw' in BioBrick design could be spotted immediately by experienced molecular biologists:

> …I think that, it's quite a typical thing that the MIT folk, they do very nice conceptual work but they are not necessarily having their hands deep down in the, uh, in the biological side of implementation. I mean a lot of those people are coming from computer science, and Tom Knight himself also comes from other engineering areas, so uh, a lot of people looking at this thing, like molecular biologists would look at it and say 'Come on! Why did you do that?' It's obvious that you should do it in another way to allow protein fusions, because that's a typical task that a lot of people do, and they just didn't think about it basically. Or didn't think <u>of</u> it. (synthetic biologist 4)

This comment comes from a postdoctoral researcher explaining to me that he didn't even have to try using the BBa standard to see that it wouldn't work for his research; he could see just from looking at the design on paper that it was inappropriate for his needs. Such examples highlight the different epistemic commitments of synthetic biologists as they set about making and using BioBrick parts. In practice (and unsurprisingly to those trained in molecular biology), it turns out that the design specifications of a BioBrick (in this case, the specific sequences of its DNA 'prefix' and 'suffix' regions) affect its biological properties, and that this has functional consequences for synthetic biologists who bring different research interests to the field, or who work with different model organisms. It seems that the engineers who first proposed the BioBrick didn't (or perhaps couldn't?) imagine the variety of purposes to which more biologically inclined researchers might be disposed to use them. And that the initially imagined value of the BioBrick

– advanced as a general tool for all researchers and across the spectrum of molecular biotechnology work – is being recalibrated by researchers with different epistemic aims. The general idea of a standardized biological part does seem to have wide appeal, but precisely what constitutes a valuable design is still a matter of contention within the synthetic biology community (Mackenzie *el al*, 2013).

Such tensions between the push to develop 'universal' standards and the need to be sensitive to local research questions and practices are commonplace when it comes to standards development (see e.g. Fujimura, 1987; Jordan and Lynch, 1992 for examples in molecular biology practice). One consequence for synthetic biology is that many individual researchers or laboratories are now developing their own collections of biological parts — in formats often incompatible with others' collections. This proliferation of incompatible toolkits of parts is a demonstration of valuation-in-action by community members that challenges the projected market value of synthetic biology, which associates central repositories of widely interchangeable parts with efficiency gains and more flexible innovation for biotechnology.

What biological knowledge is appropriate or even possible to codify at this stage in the development of synthetic biology has surfaced as an important topic for discussion in the context of BioBrick design. Although an important foundational component for synthetic biology, in many respects the technical details of BioBrick design are just the tip of the iceberg. In practice, the development of BioBricks is testing ideas about the scope and limits of modularity in biology; for example, it is proving challenging to design standard modules that work predictably under any biological conditions. Indeed, even the question of what it means for a part to 'work' is

not clear. (Similar definitional issues have complicated efforts to standardize stem cell lines, see e.g. Eriksson & Webster 2008.) At present, it is far easier to make a BioBrick than to characterize one; agreeing on what to measure in order to characterize a biological part is acknowledged as a crucial issue for the progress of the field (Arkin, 2008), but has received less community attention to date than the issue of what design standard(s) BioBricks should conform to.[8] The epistemological challenges involved in developing standards and adapting engineering principles to working with biology are far from trivial, even a decade into the BioBrick project (Kwok, 2009). The details of these technical exercises are revealing sites for exploring the ongoing constitution of epistemic value in the field.

The moral economy of synthetic biology: Balancing academic, community and market values in creating repositories of parts

> …what I also see is that, it's very easy to spend a lot of time on this, you know, standardization discussions and community efforts and whatever, and in the end it's difficult to show anything off for it. Because in the end I am judged by my publications (synthetic biologist 4)

Early proponents of the BioBrick outlined a vision of standard biological parts housed in one or more central repositories (physical and/or virtual) that would be readily accessible by anyone. Such community resources, it is proposed, will promote distributed innovation in much the same

[8] Some high-profile synthetic biology institutions are now beginning to devote concerted resource and attention to the challenge of characterizing biological parts, including the Centre for Synthetic Biology and Innovation at Imperial College London, and the BIOFAB: International Open Facility Advancing Biotechnology, based in California.

way as free availability of software code is seen to encourage innovation in programming. This is a powerful and attractive vision, and one that imagines a moral economy for synthetic biology grounded in the widespread exchange and circulation of biological parts. But it does not fit seamlessly with either the dominant reward system in academic research, or with existing models of ownership in industrial biotechnology (Rai & Boyle, 2007).

The synthetic biologist quoted above is a postdoctoral researcher who is an active participant in international synthetic biology conferences and community initiatives. However, he has also adopted an alternative BioBrick design standard that suits his research needs rather than using the early community standard, and he has created his own personal collection of standard biological parts — a collection that he did not feel comfortable depositing in the centralized Registry of Parts until his project had been formally published in research papers. He is a community-minded researcher, but finds himself continually calibrating his actions to navigate between the strong community-oriented agenda of synthetic biology and the pressures to perform according to more traditional valuations of academic success. At his career stage, he could be disadvantaged by being too open about his work, sharing too freely, and spending too much time on community infrastructure development. This situation is not unusual among the synthetic biologists I have spoken with (similar concerns were also described in Knorr-Cetina's 1999 study of molecular biology laboratories).

The innovation potential and projected market value of synthetic biology are held up as justification for the open-source model of sharing parts. But at the level of laboratory practice, valuation of the BioBrick approach revolves around a somewhat different of concerns — it is a

more localized and individual process, in which prospective future value must be weighed against actions in the immediate present.[9] Here we see a tension emerge between future commercial value and more traditional academic measures of reward and recognition. Publications and research grants remain the predominant reward system for most academic researchers, and with such metrics the pursuit of an individual, original research agenda is still seen as the most effective way to get ahead. The degree to which academic researchers are prepared to recalibrate their practices in relation to the BioBrick thus becomes based on a complex array of factors, related for example to their disciplinary training, the nature of their research project, and their career-stage. The standardization emphasis of synthetic biology might be seen as useful insofar as it helps individual researchers to streamline their laboratory workflows and make meaningful improvements in the efficiency of their own research and curation practices. However, at the moment it is not clear that most researchers see themselves deriving sufficient value (over a relevant timescale) from contributing to broader, community efforts. Furthermore, the dominant ownership model in biotechnology is one of patenting, encouraging protectionist behaviour for those researchers pursuing clearly application-oriented work.

Prominent leaders in synthetic biology are trying to establish new mechanisms that fall in between the established academic and market systems of valuation, to reward those who contribute actively to community initiatives – for example, they have proposed formal publications like BioBrick characterization datasheets (Canton *et al*, 2008) and 'Request for

[9] See Brown (2013) for an exploration of similar deliberations between present and future value in the context of umbilical blood cord banking.

Comments' (RFC) documents,[10] as well as a bespoke intellectual property agreement, a contract-like arrangement called the BioBrick Public Agreement.[11] But for a given individual, the enthusiasm to subscribe to the proposed moral economy of synthetic biology must be weighed up against the need to maintain standing according to the metrics valued in one's primary discipline of training, and also in relation to existing models of intellectual property protection in the life sciences. Several researchers have commented that they have started using BioBrick-style approaches to help restructure their laboratory practices, but this stage a majority of the synthetic biologists I have spoken with have not made their personal collections of biological parts available to a public repository like the Registry of Standard Biological Parts, providing justifications ranging from laziness to concerns over ownership. Nor do many of them use others' parts from the MIT Registry, citing problems with reliability and a lack of part characterization data as key issues (see also Peccoud *et al*, 2008).

Routine measurement and characterization work is not typically ascribed the sort of academic value that would be rewarded with a high-profile publication; this may help to account for why there has been comparatively little BioBrick characterization undertaken so far. However, the issue of part characterization is emerging as a central concern in synthetic biology. One might argue that the value of a BioBrick lies less in the availability of the material artefact itself than in the metadata associated with the artefact. As more and more characterization data about a given part gets collated, its behaviour in principle becomes more predictable (Arkin & Endy, 1999). Achieving (more) predictable design and construction of biological circuits is a central aim for

[10] The Requests for Comments process is borrowed explicitly from the standard-setting approach used by the Internet Engineering Task Force, and for the synthetic biology community is managed by the BioBricks Foundation; see http://biobricks.org/programs/technical-standards-framework/ (accessed 29 July 2013).
[11] See https://biobricks.org/bpa/ (accessed 29 July 2013). Since its launch in June 2011 there has so far been little uptake of this mechanism across the synthetic biology community.

synthetic biologists. But characterization work is far more than a simple technical request; it is closely coupled to questions of exchange, credit, and reward – in short, to the moral economy of synthetic biology. The process of characterization reflects a transfer of labour and productive capacity from the body of the researcher to the biological part, but a transfer without immediate exchange value. The researcher is meant to invest (time, money, effort) in characterizing a part. In the proposed moral economy for synthetic biology, this labour does not translate into ownership or academic reward for the part(s) in question – quite the opposite, it is intended to disentangle the part from its (biological and institutional) context of production, so that it may circulate freely for others to use. A tension between the logic of a gift economy and that of a market economy thus emerges around the BioBrick part. The increased speculative value of the BioBrick as biocapital is achieved through the invisible labour and altruistic behaviour of researchers.[12] At this stage in the development of the field, the actions and characterization efforts of researchers do not seem to unequivocally support this proposed relationship between labour and capital.

Revolutionary or incremental change? Bypassing the BioBrick in the name of efficiency

Coupled to BioBrick design is the suggestion that the production of complex DNA constructs for genetic engineering will become less onerous and more predictable. BioBricks are projected to add value through efficiency gains in laboratory practice — with knock-on effects for innovation in biotechnology more generally. Although the assembly of BioBricks can in principle become a more standardized and routine procedure (that a robot could perform), in many laboratories

[12] As Lezaun notes in his contribution to this issue, practices of both valuation and de-valuation are simultaneously at play in structuring new moral economies in the contemporary life sciences.

combining BioBrick parts still seems to be a time-consuming process rife with possibilities for error. The BioBrick proposal relies on traditional molecular biology methods for assembling DNA – its novelty rests in reorganizing and streamlining existing techniques, rather than offering a distinctly new set of DNA assembly technologies. Using these methods, it seems to take about a week to combine two BioBrick parts (although multiple BioBrick assembly reactions can be performed in parallel if wanting to generate a DNA construct comprising several parts). One researcher described how "…in the beginning I had a lot of trouble to actually set it up," and suggested that "if you do a lot of assemblies, I don't think it's going to, it's not a technique that is going to survive for 15 years or 20 years. It's something that is ok for now, but uh, I think you need something that is more efficient still" (synthetic biologist 4). Another researcher explained his motivation for investigating alternative, more 'radical' DNA assembly methods in terms of a certain frustration with BioBrick assembly:

> It just never worked as well as it ought to in my hands, or certainly in the hands of inexperienced students, who'd spend ages trying to combine two BioBricks. Whereas it was relatively easy to make a BioBrick…even when we'd had a bit of experience, combining two BioBricks was never all that reliable. (synthetic biologist 3)

In practice, BioBricks might not be as straightforward and efficient to assemble as hoped for. We might ask whether difficulties being encountered with BioBrick assembly at this point relate to technical issues that might be overcome with time and effort, or whether codifying the tacit knowledge and expertise required for DNA assembly is a more challenging task than anticipated. Regardless, there are now several academic laboratories and companies working on alternative,

more efficient methods for DNA assembly, some of which no longer rely on the availability of BioBrick-style parts (e.g. Gibson *et al*, 2009). Similar to the rationales provided for the fractionation of BioBrick design standards (see above), the choice of DNA assembly method is suggested to depend on the size of the DNA construct being built, and epistemological questions such as the purpose for which it is being designed (Ellis *et al*, 2011). In practice, members of the growing synthetic biology community bring with them a diversity of interests that are starting to challenge the imagined value of the BioBrick as the foundation of a parts-based synthetic biology. What future, then, for freely available repositories of well-characterized biological parts? Whether BioBricks as currently conceived will remain central to synthetic biology remains to be seen; as one researcher put it: "I'm not too excited about thinking about the future of BioBricks as they are today, because they are biologically constrained" (synthetic biologist 5).

Valuing life: plasticity, evolution and control

Evolution = tyranny

(Mutation without representation)

This is the text on a presentation slide sometimes shown by Drew Endy when he talks about the potential for synthetic biology not just to stimulate innovation, but to bring the process of biological evolution under control. It points to another site where value is being contested in synthetic biology: between the engineering or design logic underpinning the BioBrick, and biological complexity and emergence (see Davies *et al*, this issue).

Postdoctoral synthetic biologist Christina Agapakis notes that "evolution plays an uneasy and complicated role in synthetic biology" (Agapakis, 2011, p.9). Evolution might be central to our understanding of life, but it surfaces as a biological characteristic that could threaten the success of synthetic biology.[13] This engineering-led discipline aims to increase spatial and temporal control over biological production and reproduction. Evolution, with its "directionless and irrational changes" (Agapakis, 2011, p.9), is not a characteristic typical of engineering substrates, and over time risks corrupting careful biological designs. There are lively conversations underway within the synthetic biology community about whether and how evolution could be viewed as a characteristic to be harnessed in the pursuit of biological design, rather than a biological complexity to be eliminated (as suggested in the quip 'evolution = tyranny'). To engineer reliably with biology, some suggest it will be necessary to work with, not against, evolution, and to create "new design and computational tools that take biological variability, uncertainty and evolution into account" (Purnick & Weiss, 2009, p.420).

In *Culturing Life*, Landecker suggests that "the history of biotechnology from 1900 to now may be described as the increasing realization and exploration of the plasticity of living matter" (Landecker, 2007, p.232). She argues that through techniques such as cell culture and cryogenics, contemporary biotechnology has become expert at starting, stopping, suspending and accelerating cellular processes. This ability to temporarily suspend, refactor, and reanimate genetic material and biological organisms (particularly microorganisms) is central to the practice of synthetic biology, and the added dimension of engineering design might be seen as a natural extension to the trajectory of 20th century biotechnology that Landecker describes. Synthetic biologists are

[13] In a similar vein, Melinda Cooper notes that ideas of emergence in biology are also framed as being problematic in US policy discourse around infectious disease and bioterrorism, which talks of 'waging war' or mobilizing against biological emergence (Cooper, 2007, p.28-31).

concerned with harnessing the generative potential of life, but also steering it down predictable and controllable paths determined by human design and intent. They want to mobilize the reproductive agency of living organisms while restricting their evolutionary potential. They propose the application of engineering principles as a way of walking this line between plasticity and predictability.

Sitting at the confluence of information science, biological science and engineering science, synthetic biology arguably opens possibilities for exacerbating the temporal discontinuities described by Landecker. The physical repositories of cells and genetic material that have been a focus of her work are now being complemented by online repositories of sequence and characterization data. The capacity to store and manipulate DNA sequences on the computer, and to synthesize and format long sequences of DNA from scratch, do mark changes in practice that liberate researchers from the constraints of evolutionary timescales and relationships when designing new biological systems (Pottage, 2006). The design approach of synthetic biology (as manifest in examples like the BioBrick) works to disentangle or decouple living organisms from their evolutionary pasts and futures. It cannot dispense entirely with the materiality of living systems or the temporal processes of reproduction – the animation of designed genetic circuitry still requires a physical, cellular context. But it may contribute to a transformation of our understanding of the biological (Landecker, 2007; Mackenzie *et al*, 2013), to promote an understanding and valuing of life that is less dependent on lineage and evolution.

Discussion

Negotiations over the promises and objects of synthetic biology are helping to define what value means and how value is being constituted in practice for the field. As material artefacts and foundational elements of a new approach to biotechnology, BioBricks are simultaneously technical and social objects that serve as a focal point for different disciplinary approaches to working with biology, and around which different systems of valuation are operating. The BioBrick proposal is certainly proving generative in terms of identifying epistemic practices and assumptions among engineers, biologists and computer scientists entering the field. However, tensions between some of the future-oriented value claims made by its early proponents and the practices being followed by BioBrick users mean that at this stage the future of BioBricks seems far from certain.

Treating value as a verb, and adopting a sociological lens to explore valuation practices in action reveals a number of sites of ambivalence and contestation over the BioBrick approach to synthetic biology: between the pragmatic push for standardization and the epistemological trade-offs this necessitates; between the immediate present and the prospective future value of restructuring laboratory practices according to new workflows; between the economic logics of gift exchange, academic credit, and market commodities; between dreams of revolutions and realities of incremental change; and between the plasticity and predictability of living systems. The registers of epistemic, academic, ethical and market value we encounter are centred at different levels of abstraction, operate on different timescales, and are concerned with different objectives. This is not a case study satisfied with revealing a simple gap between the promises and practices of synthetic biology; it shows how value is being constituted in these in-between

spaces, how it requires both promise and practice to emerge and form, and how it both shapes and becomes embedded in the material and social worlds of an emerging field. I reveal in empirical detail how the making of an epistemic community and a discipline involves coordination and alignment among different valuation systems, and the challenges involved in performing this work.

Although focused on synthetic biology, the negotiations of value identified here arguably apply more broadly to developments in the life sciences, and to studies of biocapital and moral economies. Synthetic biology is just one of several emerging fields of research and practice that promise to reconfigure the life sciences in pursuit of market goals and broader societal needs. Much of the literature on biocapital to date has focused on research and commodification practices as they relate to human materials, identities, and subjectivities. Importantly, synthetic biology also draws our attention to the non-human and micro-organismal facets of biocapital, which also stand to have important roles in our understanding and exploitation of life in the bioeconomy.

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