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Technological biology?: Things and kinds in synthetic biology

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Abstract

Social scientific and humanistic research on synthetic biology has focused quite narrowly on questions of epistemology and ELSI. I suggest that to understand this discipline in its full scope, researchers must turn to the *objects* of the field—synthetic biological artefacts—and study them as the objects in the making of a science yet to be made. I consider one fundamentally important question: how should we understand the material products of synthetic biology? Practitioners in the field, employing a consistent technological optic in the study and construction of biological systems, routinely employ the mantra ‘biology is technology’. I explore this categorization. By employing an established definition of technological artefacts drawn from the philosophy of technology, I explore the appropriateness of attributing to synthetic biological artefacts the four criteria of materiality, intentional design, functionality, and normativity. I then explore a variety of accounts of natural kinds. I demonstrate that synthetic biological artefacts fit each kind imperfectly, and display a concomitant ontological ‘messiness’. I argue that this classificatory ambivalence is a product of the field’s own nascence, and posit that further work on kinds might help synthetic biology evaluate its existing commitments and practices.

Keywords: Synthetic biology, biological engineering, technological artefacts, natural kinds, ontology, classification

1. Introduction

Synthetic biology has captured the attention of scholars from a complex of disciplines, including those concerned with the philosophical and social foundations, properties, and ramifications of this as-yet-nascent field of scientific, technological and engineering practice. The myriad analytic perspectives brought to bear upon synthetic biology most probably reflect this field's own multi-faceted character. However, the profusion of humanistic and social scientific analyses has been quite narrowly focused upon those issues labeled as ELSI—ethical, legal, and social implications—as well as methodological, epistemic, and professional issues relevant to synthetic biology's use of engineering principles, methods, and organizational strategies. Synthetic biology hopes to analyze, model, and construct biological systems for useful ends—it aims to understand, modify, and reliably manufacture predictably functional biological entities. As such, synthetic biology aims at the making of physical products. These material objects—synthetic biological artefacts—have as much to reveal about the discipline as do the practices and epistemic pronouncements of its practitioners.

Studying the objects of synthetic biology is a necessary project in philosophical and social scientific analyses of this burgeoning, but quickly-developing, field of human practice. Much as early science studies looked at 'science in the making', it is necessary to study 'objects in the making'—objects in the making both physically and ontologically. Here I attempt precisely this—a first-look examination of synthetic biological artefacts. To do so, my argument explores the place of these objects vis-à-vis two kinds: those of technological artefacts, and natural entities. I take ontology to refer to that on the basis of which entities are rendered intelligible as specific things. I hold that such intelligibility is not independent of our collective classificatory practices. Setting kinds and classifying objects into such kinds are ontological activities. Thus studying 'objects in the making', which involves studying their ontology, demands a look at kinds.

A study of things and kinds in synthetic biology is of value for various reasons. First, synthetic biology styles itself as an engineering discipline: it frames its products as technological artefacts. Biological systems are abstracted and schematized as electronic systems; organisms are epistemically represented as mechanistic entities; synthetic biological artefacts are to be produced following methods and aims standard in traditional engineering disciplines. It is of value to evaluate such claims. Second, synthetic biological artefacts are physical tokens of the field's practices, its practitioners' aims and epistemic-ontological commitments, and its relation to broader social institutions of law, regulation, and ethics—all key interests to analysts of synthetic biology. Much as the burgeoning knowledge claims of a nascent science can shed light on that field's character and development, undefined and incipient groupings of objects can elucidate the trajectory of new engineering practices. Synthetic biology is young; tracking its things and kinds may serve as a useful method to capture the field's maturation. Last, specifying the character of the artefacts in question serves a number of pragmatic ends for analysts of synthetic biology. In gauging their status as particular tokens of a kind, sociologists and philosophers may discover useful analytic tools from related studies of biology, technology, and engineering, or identify where such tools fail to provide any insight.

One researcher typically employs the mantra 'biology is technology'. Such statements are rhetorically powerful, but ontologically problematic. How are we to deal with this class of objects? This article is not a definitive resolution of this question, but rather a first-look attempt to engage this topic and a spur to further study on the objects of synthetic biology. I begin by exploring synthetic biological artefacts' place within the kind of technological objects. I argue that four key criteria—materiality, intentional design, functionality, and normativity (see Kroes & Meijers 2006)—are applicable to synthetic biological artefacts, although not without complications. I then proceed to consider a variety of definitions of natural kinds, and similarly demonstrate that synthetic biological artefacts only imperfectly fit such accounts. This ontological 'messiness' suggests that synthetic biology as a field is still searching for its kinds. Synthetic biological artefacts are the objects in the making of a science yet to be made.

2. Synthetic biology: An overview

Synthetic biology is notoriously difficult to define (see Benner & Sismour 2005; O'Malley et al 2007; Arkin et al 2009). It is a field of practice that seeks to apply engineering principles to reconfigure existing biological entities and processes or create *de novo* entities for useful purposes; it is also concerned with understanding the workings of microscopic nature through the process of building that very nature. That is, it seeks to create useful biological organisms, as well as to comprehend and model the action of natural entities. It draws together biologists, chemists, physicists, computer scientists, and all manner of engineers.

Despite this pluralism, I suggest that synthetic biology—in its various forms—rests upon a single concept: design. Synthetic biologists aiming to construct functional biological artefacts seek to design nature; synthetic biologists whose goal it is to comprehend existing organisms and processes seek to find their 'underlying' design. This focus on design leads many synthetic biologists to suggest—following engineers—that to understand an entity is to be capable of constructing it. Understanding and construction are seen as partnered practices in synthetic biology.

As with all nascent fields in science and engineering, synthetic biology displays a cacophony of research agendas, methodological commitments, ontological and epistemic standpoints, and disciplinary principles, norms, and expectations. For instance, Craig Venter's research program has focused in part on 'stripping down' the genome of *M. genitalium* in order to arrive at the so-called 'minimal genome'—one freed from excess, unnecessary, or redundant genetic material (Glass et al 2006). His team's aim is to construct a 'chassis', an organism that can be 'booted-up' with any designed genome (Ball 2007). Jay Keasling's laboratory at the University of California, Berkeley, modified *E. coli* and yeast to develop organisms capable of producing chemical precursors to the anti-malarial substance artemisinin (Keasling et al 2007). Rather than attempt to construct a biological platform for genetic constructs, Keasling's group modified an existing organism and tasked it with a human-defined function. Other laboratories are working on developing biological systems with the capacity to operate as electronic logic gates, switches, and memory devices (Gardner et al 2000; Burrill & Silver 2010). Finally, the Synthetic Biology Engineering Research Center, through its BIOFAB—a 'public-benefit' biological manufacturing facility—hopes to develop and characterize biological 'parts': modular units for biological construction (Sanders 2010). These various endeavors attest to synthetic biology's emphasis on design. If synthetic biology hopes to 'make biology easier to engineer' (Lentzos et al 2008), it intends to do so through intentional design.

The principal distinction that differentiates synthetic biology from earlier forms of biological engineering—such as genetic engineering—is its commitment to employing accepted engineering practices (see Endy 2005; Andrianantoandro et al 2006; Heinemann & Panke 2006). Practitioners sometimes refer to earlier work in genetic engineering as 'craftwork'—laborious, *ad hoc*, and time-consuming. These same individuals hope to replace the 'black magic' of genetic engineering with the (hoped-for) systematic, reliable biological engineering of synthetic biology.

While synthetic biology hopes to develop revolutionary technologies and radically transform human understanding and control of biology, it approaches these challenges by way of entirely non-revolutionary strategies. The practices and principles which underlie much of synthetic biological research are those of conventional engineering disciplines: abstraction of complexity (Endy 2005); standardization of design components (Arkin 2008); and modularity and decoupling of operational elements (Hartwell et al 1999; Endy 2005; Sauro 2008). These specific concepts are most closely associated with the 'BioBricks' school of synthetic biology, although the broader community similarly tends towards technological/functional conceptualizations of organisms. Synthetic biology as a field premises and promises 'engineerable' nature[1]: materials, entities, systems, and events that can be modelled, modified, designed, and constructed intentionally. It aims at *the making of things*—those things and their kinds are the focus of this essay.

It is necessary and important to recognize one characteristic of the objects under study here: synthetic biological artefacts are still very much 'objects in the making.' The technologies needed to design, assemble, characterize, and manufacture these objects have not been established fully, and success in making synthetic biological artefacts work has been limited. The construction of predictably functional organisms is an *aim* and a *driving principle*, rather than an accomplished reality. Accordingly, these artefacts are opportunities to consider the ramifications of a field that, like its products, has yet to be established fully.

3. Are synthetic biology artefacts technological?

Synthetic biology approaches biological entities as technological systems—it studies nature as an artefactual complex—and hopes to develop functional biological artefacts

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[1] Clearly, this ontological-epistemic standpoint is a controversial one, both within and outside the field. See Kwok 2010.

technologically. What place these objects are to have within synthetic biology and as entities embedded in wider social life assuredly rests on their ontological status—a status constituted in relation to long-standing Western dichotomies between the world of the natural and the world of human artifice (see e.g. Schummer 2001; Keller 2008). As such, a first step in studying synthetic biological artefacts is to consider their fit within the kind of technological objects.

By the term 'synthetic biological artefacts', I refer to the *physical* products of synthetic biological work. These include, but are not limited to, cellular 'chassis' (Rasmussen et al 2004; Forster & Church 2006), genetically 'stripped-down' bacteria such as Venter's *M. genitalium* (Glass et al 2006), modified organisms such as the Keasling Lab's artemisinin-producing *E. coli*, 'standardized' biological 'parts' such as BioBricks, and combinations thereof. Not admitting 'ground-up' attempts to synthesize *de novo* organisms, most of these objects are created by modifying or mimicking existing organisms, biological processes, or biological materials. Put otherwise, the materials and entities with which synthetic biology engages are commonly understood to be natural kinds, despite synthetic biologists' employment of a technological optic in analyzing them.

Are these products of synthetic biology technological? This section proffers four criteria for membership in the kind of technological objects, and evaluates the applicability of each to the objects of synthetic biology. As I demonstrate, the four criteria—materiality, intentional design, functionality, and normativity—do not unproblematically map onto synthetic biological artefacts. Synthetic biological artefacts do not sit comfortably within the kind of technological things. This tension is the focus of my discussion below.

The four-fold conceptualization of technological artefacts employed here stems from the 'Dual Nature Programme' in the philosophy of technology (see Kroes & Meijers 2006), although I have amended a number of details. I believe it successfully encompasses both academic analyses of technology and common-sense notions of what constitutes a technological artefact. Most importantly, the four criteria engender more questions than they do answers, and suggest a number of directions for further study.

3.1 Materiality

First, *all technological artefacts exist in space and time*; they are physical entities. Unlike 'technological artefacts', the term 'technologies' refers to a much broader class of social phenomena including knowledge, processes, techniques, and practices—including such things as computer models employed in studying natural systems. These are unquestionably important foci of study in their own right, and are inextricably involved in the development, design, manufacturing, dissemination, and usage of technological artefacts. However, this study focuses upon those artefacts that are fundamentally distinct in that they are material objects. This consideration may appear too simple an issue for prolonged discussion, but intuitive responses must not obscure the complexities or ramifications of this criterion.

Synthetic biologists aim to construct *de novo* organisms or substantially reconfigure existing ones. In either circumstance, they are employing physical materials and techniques to produce physical artefacts. Certainly, the scale and character of the materials and techniques differ substantially from those employed in the construction of say, a bridge or tower; nevertheless, scale and character serve to differentiate these from more commonplace construction methods, not to repudiate their physicality. Nucleotides, proteins, and bacteria exist physically, as do pipettes and Petri dishes. This observation is intuitive, but its manifold ramifications are not so.

First of these is the issue of continuity. Conventionally, physical objects are understood to be continuous—spatially and temporally (Grandy 2007). The bridge in front of me is an object in part defined by its physical composition and its persistence in time. If physical or temporal continuity are violated, then generally we understand a physical object as no longer existent. This suggestion is problematic, and does not evade critique, but it does suggest a number of considerations of importance here. The making of an engineered bacterium involves a number of physical transformations, not least among these the material modification of its genome. Strictly speaking, the physical entity that was present before the synthetic biologist is no longer present: physical continuity has been violated. Does this discontinuity suffice to demonstrate that synthetic biology has given rise to a technological thing where previously there existed a natural one? It does not. (Elder 2007).

Consider first the fact that all biological entities are in a state of continuous physical transformation. Bacteria—and people!—are born, grow, change dimensions, metabolize, self-repair, introduce and expel entities from within and outside, reproduce, and eventually cease to be. This is simply a condition of the natural world. Consider as a second foil to the continuity argument that few—if any—organisms are composed of simply ‘their own’ biological materials. Physicality is a complicated arrangement, not a plain continuity of material. Changes to this arrangement occur frequently, and do not signal the end of the entity—either physically or ontologically (Dupré & O’Malley 2009). Both of these considerations should not surprise the student of technology. Technological artefacts grow antiquated, their parts are replaced, and they depend on other artefacts and phenomena to operate; they are likewise not physically isolated entities, nor are they isolated from the vicissitudes of time (Ladrière 1998; Grandy 2007).

The aim and end of these considerations is this: the change enacted by synthetic biologists upon their objects of research and construction cannot be simply physical or behavioral. If indeed these practitioners are in the business of making technology from biology, their products are technological artefacts by virtue of something more than just their physical existence and character, despite the fact that they do exist materially.

3.2 Intentional design

Second, *all technological artefacts are purposefully brought into existence*; they are intentionally designed. This requisite comprises both artefacts’ physical constitution as well as their operational guidelines (Kroes & Meijers 2006; Vermaas 2006). Generally, natural physical entities are not considered entities purposefully brought into existence, thus ostensibly excluding those objects from this definition. However, farmed crops, racing horses, and laboratory rats are all examples of biological entities that *can be* considered to be brought into existence intentionally. Moreover, if synthetic biology aims to and might eventually intentionally design organisms, this second criterion becomes considerably more problematic.

In synthetic biological practice, experimenters engage in the deliberate physical transformations of living organisms—say, by introducing new or modifying existent segments of an organism's genome—with the intent of exacting a defined change in entities' behavior. Practitioners may choose to disable particular sets of genes in order to curtail a specified behavior, or they may introduce foreign genes with the aim of adding to the organism's behavioral repertoire. In either case, an intentional physical change is carried out according to a particular design aim. Often, this approach to synthetic biology consists of assembling 'standardized' biological 'parts' with the aim of making a functional organism. Experimenters select operating components, design a system, and intentionally construct it. As with much in synthetic biology, 'standardized' parts operate unpredictably, and designs often fail when constructed. Nonetheless, the *aim* of intentional design is fundamental to the field. Exerting rational control over the process of biological engineering—enabling systematic, intentional design—is a core value in synthetic biology, a principle underlying its expectations, and a practice it employs and hopes to perfect. Current research aims to empower practitioners with the tools necessary to carry out this kind of design.

An affirmative response to the question of purposeful design results in two key complications. First is the problem of physical transformation. If synthetic biological artefacts are intentionally brought into existence, at which point are organisms brought into existence *as artefacts*? That is, when does the intentional construction of synthetic biological artefact *qua* synthetic biological artefact produce a definitive product? If an existing organism is being transformed, surely a natural entity that existed at one point must cease to be and a new, technological entity must begin to be. This difficulty is similar to the above problems with materiality, and is not one limited simply to technological artefacts produced with biological materials. The making of a stone hand-axe is a relatively simple process, but identifying the moment at which chipping and sharpening give way from stone to axe is certainly not easy. Clearly, intentional modification of material is not enough (again). Some attribution of 'artefact-ness' is demanded.

A second difficulty with intentional design is more exclusive to products of biological engineering, and finds no easy resolution here. Certainly, synthetic biological artefacts, as entities still possessive to some degree of natural biological capabilities and characteristics, are susceptible to the pressures of natural selection and the processes of evolution. A particular set of intentionally designed bacteria might be unique in their constitution and resemble their designers' intentions maximally, but once generations begin to multiply, there exists the significant chance that some—if not all—entities will 'drift' from the original design. It is no accident that one synthetic biologist refers to the ‘tyranny of evolution’ (Specter 2009). Clearly, the issue is linked to the problems of physical and temporal continuity, but it more precisely deals with the specific character of synthetic biological artefacts. Nevertheless, while synthetic biological artefacts may drift from their intended design, intentionally designed they are, and the second condition of technological artefacts is fulfilled as a result.

3.3 Functionality

Third, *technological artefacts have functions*; humans mobilize them in order to carry out particular tasks (Kroes & Meijers 2006; Vermass & Houkes 2006; Hansson 2006; Houkes 2006). They are employed in the acquisition of an objective. Without a sense of ‘for-ness’, physical entities cannot be said to have functionality; without function, intentionally-designed objects are not technological artefacts. The attribution of function is at the core of synthetic biological work with natural entities and processes, and leads to an intuitive belief that synthetic biological artefacts should be understood as technological. However, the issue is not quite so unambiguous. The precise character of functions is a contested matter within the philosophies of technology (Preston 2006; Scheele 2006) and biology[2].

As with other technological objects, synthetic biological artefacts have function insofar as practitioners design, develop, and construct them in order to accomplish particular ends and users intentionally employ them toward those ends. Before continuing to a justification of this claim, an important observation is necessary. Of concern here is the notion of *technological* function, rather than that of function as a biological property linked to adaptation (Wright 1973), genealogy (Millikan 1984, 1999), fitness (Walsh 1996), or systematic capacity and decomposition (Cummins 1975). Despite attempts to develop unified conceptualizations of technological and biological functions (e.g. Krohs & Kroes 2009), I retain a distinction for a series of reasons. This topic is explored in greater detail below; here, the role of technological function is central.

The making of synthetic biological artefacts is the making of entities capable of achieving ends specified by practitioners. Ongoing work in biological ‘memory’—data retention and re-delivery—seeks to construct entities capable of storing specified blocks of data and subsequently releasing that data upon command (e.g. Ajo-Franklin et al 2007). The processes of intentional design, construction, testing, and manufacturing are all linked to the synthetic biological artefacts’ capacity to accomplish this function. A prominent synthetic biologist speaks of comparing synthetic biological artefacts to robots, insofar as the former, like the latter, can ‘do things’. Both in those synthetic biological artefacts that exist—such as Keasling’s artemisinin-precursor-makers—and those that are in development—such as entities that can quickly and cheaply produce bio-fuels (Savage et al 2008)—their ability to accomplish specified tasks (their function) is central to their promotion as ‘biological machines’ (technological artefacts).

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[2] This literature is extensive. Useful collections on function in biology include Allen, Bekoff, & Lauder 1998, Ariew, Cummins, & Perlman 2002, and Buller 1999.

In considering function, it is also necessary to address functional attribution and functional improvement. While some practitioners intend to construct entities from the ground up, or radically transform existing organisms and task them with entirely novel functions, many other synthetic biologists hope to make existing processes more efficient (Dougherty & Arnold 2009). Rather than introduce a previously non-existent process into an organism, they hope to engineer and 'improve' processes naturally present in the entity. As such, the transformation has been one in efficacy. Strictly speaking, can I state that the organism has been attributed a function? Yes. Function exists as a result of practitioners' collective understanding and categorization of the entity as one possessive of function (see Author 2009). Function—like materiality and intentional design—extends beyond the physical processes necessary to bring it into being. Function necessarily depends upon the physical, but it also demands contingent practices of design and use.

3.4 Normativity

Last, *technological artefacts may be characterized as possessing a normative component* in two senses. First, we routinely speak of agents using an artefact 'correctly' or 'incorrectly'; second, specific tokens of an artefact type are habitually categorized as 'good' or 'bad' (Dancy 2006; Franssen 2006). Both of these commonplace judgments indicate the fundamentally normative quality underlying our interaction with technological artefacts. Moreover, this requirement proves a necessary element in the study of design criteria, production standards, and operational evaluation. This final criterion is the most problematic of the four; it is unclear whether synthetic biological artefacts display either form of normativity. Nevertheless, I believe that arguments can be proffered in support of an affirmative response.

First, consider the role played by functional success. Normative evaluations necessarily draw upon function: a token is either 'good' or 'bad' at accomplishing a determinate end; someone is using an artefact 'correctly' or 'incorrectly' in relation to an intended goal. Technological function and technological normativity are bound together. Nevertheless, it is not self-evident that one can speak of 'good engineered *E. coli*'. The aims and principles of synthetic biology, however, make such evaluation more appropriate than may be apparent initially. A synthetic biological artefact—an engineered biological entity—will satisfy or disappoint its designer to a variety of degrees, but ultimately it will satisfy or disappoint. Synthetic biologists routinely refer to things 'working' or 'not working'. If the intended aim—the function—of a particular strain of engineered bacteria is to produce bio-fuel, these entities can succeed or fail in different manners. Succeed, perhaps, in producing bio-fuel at the desired rate, or fail by say, producing no bio-fuel whatsoever. More likely, some combination of success and failure will ensue: some bio-fuel but not quickly enough, fast enough but not of a good quality, the process worked for the most part but did not achieve the desired result, etc. Switches and 'flip-flops'—biological equivalents of their electronic namesakes—may be 'leaky' and thus of inferior quality and performance to 'better' engineered ones.

Second, consider the standardization of biological ‘parts’. Those involved in characterizing and classifying biological ‘parts’—discrete sequences of DNA with specified capacities—apply engineering principles to measure their quality. Developing standard indexes of engineering parts demands subjecting each categorized object to a system of evaluation. As such, current work in synthetic biology is driven very much by a normative impulse—one linked to a systematic ordering of objects. Competing ‘parts’ are being judged by established and newly-developing engineering values and norms. While the methods of measurement are still under construction, they draw consistently upon notions of efficiency and functional success.

A final consideration is that of use. Regularly, technological use is evaluated with reference to ‘correctness’ / ‘incorrectness’, ‘proficiency’ / ‘ineptness’, and so on. In synthetic biology, operational components can be employed ‘correctly’ or ‘incorrectly’. Synthetic biological ‘parts’, which are combined to form ‘devices’ (which, in turn, are combined to form ‘systems’), have particular uses and requirements. Not all ‘parts’ that function as promoters or terminators for a specific gene will work identically. Each part will work well only in a particular context. The use of a specific object of synthetic biological will be ‘correct’ or ‘incorrect’ given the particularities of the entity under construction. ‘Parts’ and ‘devices’ can be used well or not so. Surely, this is a normative evaluation.

3.5 Technological biology?

Synthetic biological artefacts fit the four criteria of technological artefacts, but they fit these criteria imperfectly, as might be expected intuitively. Categorizing synthetic biological artefacts as technological entities leaves a few things to be desired—both an analytic suspicion and a commonsense impression that engineered organisms must somehow differ from corkscrews, airplanes, and towers. This impression—that something is missing if synthetic biological artefacts are simply subsumed into the kind of technological artefacts—rests on a series of ontological issues. Most importantly, the entities under consideration are not devoid self-evidently of their place in the kind of natural entities simply because they have undergone modifications. Moreover, these objects carry with them a range of considerations not applicable to other technological artefacts. Synthetic biological artefacts are self-reproducing, self-repairing, and have the potential to ‘subvert’ their designers’ intentions through the process of evolution. Insofar as such considerations distinguish this class of things, further work on kinds is demanded.

4. Synthetic biological things and natural kinds

Synthetic biological artefacts are by no means prototypical technological artefacts, as hammers may be. There is both something missing and something more to these objects that makes their study a difficult process. It is possible to make a similar claim regarding their relationship to ‘the natural’. This section explores this problematic relation by way of several prominent accounts of natural kinds. I have selected essentialism, homeostatic property clusters, and promiscuous realism as the arguments to explore; these I take to represent the key analyses of natural kinds, and each provides an important insight into synthetic biological artefacts. Ultimately, however, each fails to provide a full accounting of such objects. This discussion brings into focus the ontological ‘messiness’ of the products of synthetic biology. This ‘messiness’ suggests that synthetic biology, as a field still in the making, has yet to find its kinds, to place its objects within appropriate ontological orders.

4.1 Natural kinds I: Essences and clusters

It is useful to begin a consideration of natural kinds and synthetic biology with the most strict delimitation of what constitutes a natural kind. I take this position to be natural kinds *essentialism*. Wilson succinctly defines this position as follows:

> Natural kinds are *kinds* (rather than mere arbitrary collections) because the entities so grouped share a set of intrinsic properties—an essence—and *natural* (rather than conventional or *nominal*) because that essence exists independent of human cognition and purpose. (Wilson 1999: 188, emphasis original)

According to this account, natural kinds are groupings of similar entities. Such groupings are justified by essential properties possessed by each member of the kind. Since such properties are independent of human intention and activity, the kinds are natural. Thus, the appropriate focus of enquiry is finding such essences. Wilson, again writing on essentialism, states:

> … natural kinds are individuated by *essences*, where the essence of a given kind is a set of intrinsic properties, each necessary and together sufficient for an entity’s being a member of that kind. (Wilson 1996: 304, emphasis original)

Essential, intrinsic properties constitute necessary and sufficient conditions for an object’s belonging to a particular natural kind. What such properties may be is a contentious issue. Morphological similarities and genetic commonality both face the problem of heterogeneity. Members of species, which are often considered tokens of a natural kind, display morphological and genetic diversity. While common descent from an earlier species might satisfy the essentialist demand, phylogeny is a *relational*, rather than *inherent*, property. Moreover, it is an unsatisfactory criterion for the numerous species for which no genealogy has been established, or for which establishing such a history is not feasible.

Characterizing synthetic biological artefacts as natural following this account faces all of these difficulties, along with several others. If we take essence to constitute either morphological or genetic similarity, genetically transformed entities cannot properly be classified within natural kinds. Consider the following transformation: the making of artemisinin-producing *Escherichia coli* (Keasling et al 2007). This alteration to the organism includes a genetic modification. It also involves a morphological change; the organism now produces particular chemicals not found in natural strains. Even if the organism is otherwise unaltered, it is markedly different from natural variants. Members of the natural kind *Escherichia coli* do not fluoresce.

However, the issue is not quite so simple. In every other respect, a transformed organism may be similar to its natural variants. It may possess every single necessary and sufficient property needed for membership in its kind, despite its possessing something *additional*. This difficulty becomes even more apparent where natural kinds are conceived as *homeostatic property clusters* (HPC).

The HPC account of natural kinds shares with the essentialist account a concern for properties, but it incorporates a recognition of heterogeneity. Boyd writes:

> The natural definition of one of these *homeostatic property cluster kinds* is determined by the members of a cluster of often co-occurring properties and by the ("homeostatic") mechanisms that bring about their co-occurrence. (Boyd 1991: 141)

There are no necessary and sufficient conditions. Natural kinds comprise groupings of entities that share *some, but not all* properties that define the kind. If there are ten such properties, one entity may possess traits 1, 2, and 8, where a second entity may have 2, 5, and 10. While properties may vary across members of the kind, their correlation is determined by natural causal mechanisms such that a dynamic homeostasis is the result.

Now consider the case of our artemisinin-making *Escherichia coli*. Assuming its only modifications are the introduction of this chemical-making capacity and the genetic material responsible for that trait, the transformed organism may suit the HPC natural kind of which its natural variants are members. This suggests that genetically modified organisms may still be considered token of a natural kind—or at the very least, that they are not self-evidently excluded from such kinds.

I believe the matter hinges on the question of homeostasis. The HPC account argues that natural kinds are historical. The homeostatic mechanisms that ensure the co-occurrence of properties are natural causal laws linked to evolution. Organisms share properties because "other members exhibit them" and because "there is a certain kind of historical link between the members" (Boyd, 1999: 68). Such a conception of homeostasis fails when technological properties are under consideration.

That our transformed *Escherichia coli* display artemisinin-production is not a result of natural causal mechanisms. This is a trait introduced by intentional human activity. Its persistence is a result of continuous oversight by human agents. Moreover, there is no historical link between the foreign trait and those which may constitute the property cluster. While the latter may exist because of a natural homeostasis, the former does not. It is not there because of inheritance or genealogy; it is there because someone put it there.

While synthetic biological artefacts may satisfy the property condition of the HPC account, they present complications for the homeostasis condition. Simply stated, synthetic biological artefacts display properties present for reasons entirely distinct from natural mechanisms of homeostasis.

That the organisms share properties with their natural variants is a testament to their problematic ontology. That they are subject to human-intentional causal mechanisms is a reminder that they cannot be simply subsumed within natural kinds.

4.2 Natural kinds II: Promiscuity and pluralism

A more promising framework for studying synthetic biological artefacts begins with Dupré's notion of 'promiscuous realism', which is best understood as a "metaphysics of radical ontological pluralism" (Dupré 1993: 18). While 'promiscuous realism' fails to justify classing synthetic biological artefacts as members of natural kinds, it serves to make sense of ontological 'messiness'. This section addresses the account in relation to natural kinds. The following section engages with its uses for my argument.

Dupré's concern is reconciling a realist account of natural kinds with the empirical reality of such kinds' semantic and metaphysical variation. He describes his position as follows:

> The position I would like to advocate might be described as promiscuous realism. The realism derives from the fact that there are many sameness relations that serve to distinguish classes of organisms in ways that are relevant to various concerns; the promiscuity derives from the fact that none of these relations is privileged. (Dupré 1981: 82)

Thus while natural kinds may exist, there is no single, privileged definition of what constitutes such kinds. Dupré's focus is species. What may be the correct and useful species definition for a taxonomist interested in morphological similarity is not necessarily equally valid for an evolutionary biologist concerned with phylogeny. Neither is 'better'. Both are useful in their respective domains. Importantly, this pluralism extends beyond the various spheres of scientific practice:

> The vocabularies of the timber merchant, the furrier, or over the herbalist may involve subtle distinctions between types of organisms; there is no obligation that these distinctions coincide with those of the taxonomist. (Dupré 1981: 81)

Kind-setting is contextual and pragmatic. Below, I will argue that such kind-setting is a useful way to conceive of synthetic biology's relationship to its products. First, it is necessary to discuss where Dupré's 'promiscuous realism' fails to account for synthetic biological artefacts.

The central difficulty is the framework's realism itself. Although Dupré advocates ontological pluralism, he insists on the fundamental reality of similarity relations. Such a position is understandable. After all, Dupré's concern is with practitioners whose goal it is to explore and explain natural entities and phenomena. Where similarity relations are consequences of intentional human activity, as with synthetic biology, such realism becomes problematic. A colony of artemisinin-making *Escherichia coli* has similarity relations between entities that are not independent of human acts. It may be pragmatically desirably to establish a grouping of such organisms. This kind will involve natural organisms grouped by virtue of a non-natural property.

Dupré's 'promiscuous realism' is most relevant to the present argument where its ontological pluralism is emphasized, and its realism is considered to be a special case of a broader phenomenon.

4.3 Disciplines, kinds and things

The preceding discussion of synthetic biological things and natural kinds demonstrates that the problematic relationship that these objects bear towards a technological classification is also the case with respect to natural kinds. The things of synthetic biology do not reside without complication in either grouping. I term this classificatory ambivalence *ontological 'messiness'*. It is not wholly clear where boundaries between a number of ontologies—natural organism, biological material, engineered natural organism, and technological artefact—can be drawn. I believe that employing Dupré's work with pluralistic kind-setting has much to reveal about this complication. Namely, synthetic biology is a field and practice still searching for its kinds. In its ongoing attempt to consolidate its aims, priorities, and practices, synthetic biology is also trying to define the kinds of objects which it hopes to design and manufacture. The ontological 'messiness' of synthetic biological artefacts is a symptom of the field's developing character, its lack of a coherent identity, and its limited concern for conceptual problems.

Dupré proposes a "metaphysics of radical ontological pluralism" (1993: 18), and draws emphasis to the pluralism inherent in kind-setting. That which is pragmatically or epistemically desirably for a particular community may be of no interest to another. There are no "universally decisive" desiderata which underlie the organization of things under kinds (Dupré 2001: 209). In a sense, fields of study must take a stand on kinds; these are not pre-given, nor are they self-evident.

5. Setting a kind for synthetic biology

Dupré gives to epistemic communities the prerogative of setting their kinds. Similar arguments are presented by Kitcher (1984), Brigandt (2009), and Keller *et al* (2003). Speaking to the issue of natural kinds, Hacking states:

> Kinds are important to the agents and artisans who want to use things to do things. (Hacking 1991: 114)

This claim holds relevance beyond the matter of natural kinds. Kind-setting is of paramount importance to the pragmatics of countless practices. What a community wants to use, and what it wants to accomplish through that use, will help determine what kinds hold relevance for that community. De Sousa argues that the 'Modern View' of natural kinds rejects understandings of natural kinds that posit an ontological dependence to epistemology (1984). It is my position that ontology—and therefore kind-setting—

depends not simply on epistemic needs and commitments, but *methodological* ones as well. What practitioners want to do, and how they want to do it, matters.

Synthetic biology wants to use biological things to fabricate technological objects. In constructing synthetic biological artefacts, practitioners aim to make these objects as 'engineerable' as possible. That is, they aspire to make them conform to practice and principles of engineering. Kinds in synthetic biology must take their form from these commitments, while at the same time acknowledging that which makes functional organisms different from hammers, automobiles, and towers.

5.1 Building with biology

Synthetic biologists aim *to build*. They hope to produce *technological things*. Ultimately, however, the substrate with which they intend to do so is of a qualitatively different character than that employed by say, civil engineers. Such engineers also draw upon a natural substrate. They employ purified natural ores, create girders from transformed molten metals, and erect bridges. This end product resides comfortably within the class of technological things. A bridge and the natural ores from which it ultimately originates are physically and ontologically distant from each other. Not so with synthetic biological artefacts: physical modifications are tenuous and limited, and ontological discrimination is by no means self-evident. Those qualities which keep synthetic biological artefacts tethered to the world of natural things are precisely what must inform this discipline's understanding of its kinds. Here I consider two such qualities: self-reproduction and evolution.

The matter of self-reproduction is fundamentally one of origins. Technological artefacts are purposefully brought into existence through processes of design and construction. Natural organisms are self-generating—one generation of a species brings into being the next generation. Technological artefacts do not reproduce; living organisms are almost always defined by their capacity to do so. The engineering of organisms for useful purposes—the making of synthetic biological artefacts—is not necessarily intended to curtail these entities' ability to reproduce. After all, self-reproduction may prove to be an immensely useful property of synthetic biology biological artefacts. Nevertheless, such objects also have an origin in intentional human design and fabrication, as I discussed above. It thus becomes necessary to consider the place of *both biological reproduction as well as intentional human making* in the crafting of synthetic biological artefacts. What kind contains entities with concurrent natural and artefactual origins?

It is possible to consider this dual form of origin as an ambivalence or tension between *genesis* and *poiesis*. Following Ladrière (1998)*, genesis* denotes the origin of an entity through processes entirely independent from human agency, while *poiesis* designates intentional bringing-into-being of an entity through human practice. Synthetic biological artefacts arguably display both forms of origin, and consequently make problematic membership in either a natural or an artefactual kind. I believe that synthetic biology—as a practice in intentional design and construction—harnesses the mechanisms of *genesis* with a view to *poiesis*. That is, synthetic biology hopes to make of natural reproductive origins systematized technological processes. This may appear like the reconciliation of two incompatible phenomena, but this is not the case.

Consider that for millennia humans have employed natural reproduction to produce objects of value or interest. The domestication of animals, the breeding of such animals for competition, and agricultural breeding for quality and yield have all involved the harnessing of natural reproduction for human ends and within artificial constraints. Our capacity to control such processes has been refined over time, but fundamentally, the question of origins persists. Synthetic biology is unique within this form of practice only insofar as it aims to make natural entities the products of *systematic engineering practice*. Otherwise, the tension in origins is identical. Synthetic biological artefacts are no more self-evidently technologies or natural things than are milk cows or championship race horses.

The bringing-into-being of synthetic biological artefacts might be understood as ‘constrained reproduction’. Ontologically, the entities that result from intentionally-modified natural mechanisms resemble technological artefacts because their makeup has been altered and their origins have been constrained by human agency. That reproduction is a quality of biological things simply serves to differentiate the biological substrate from that employed by other forms of engineering practice. The co-presence of *genesis* and *poiesis* may form a fundamental basis for the making of synthetic biology’s kinds. After all, practitioners already employ the two in meaningful and productive ways. Synthetic biologists often employ ‘directed evolution’ (Andrianantoandro et al 2006; Dougherty & Arnold 2009), by which organismic change is brought about via a combination of both natural processes and human agency. That this option is available to practitioners distinguishes synthetic biology. The synergy of *genesis* and *poiesis* may do the same for the field’s kinds.

Evolution poses a second complication. If synthetic biologists hope to predictably and reliably design and build functional living organisms, evolution is the inevitable rub. Entities subject to the pressures of natural selection may ‘drift’ from their designers’ intentions. While synthetic biology might eventually control the making of synthetic biological artefacts to a satisfactory degree, it may never develop the capacity to curtail the pressures of evolution. As such, synthetic biological artefacts present a problem not immanent to traditional products of engineering.

Conventional engineering practices can ensure a high degree of physical and functional stability in their products, while synthetic biology is prevented from doing so by the very substrate it employs in making artefacts. This practical reality demands recognition, and has received some limited attention. Synthetic biologists have written on ‘evolutionary reliability’ (Canton, Labno, & Endy 2008) and have attempted to develop measures of artefact stability in terms of genetic change across generations (e.g. Canton & Labno 2004).

Note that while evolution is a unique consideration for this kind of building practice, drift and change are not phenomena exclusive to synthetic biology. Consider the process of large-scale conventional manufacturing—the making of millions of tokens of an artefact kind. Inevitably, some token will fail to meet manufacturing standards of quality; some screws will be misshapen, some engines will have performance problems. It is entirely unsurprising to discover that manufacturing processes do not proceed flawlessly. Moreover, technological artefacts age with time and use. Engines require maintenance, new parts, and perhaps even complete overhauls. Vigilance against malfunctioning artefacts is a mundane facet of technological practice.

The process of making synthetic biological artefacts may be entirely different—*genesis* made *poiesis*—but attention to malfunctioning tokens is no less important. The quality of synthetic biological tokens produced via *genesis-poiesis* is evaluated as is that of other technological artefacts: functional success. Should errors in cell division produce organisms incapable of operating as intended, practitioners would and do evaluate these as products that 'do not work', as objects with compromised performance (Canton, Labno, & Endy 2008). The onus is upon practitioners' normative evaluations of functionality, as with all technological objects. Evolution may simply be a synthetic biological equivalent to human error, aging machine tools, and imperfect manufacturing procedures.

As one researcher notes, everything has a 'shelf-life'. Functional degradation is no more surprising in synthetic biology than it is in traditional engineering. The key difference is one of temporal scale. Synthetic biological artefacts may be functional for only a matter of days, where computers may last many years. It should be noted, however, that time scales of functionality already differ greatly within engineering. Products of electrical engineering may require replacement sooner than those of aeronautical engineering. The latter in turn are not constructed with the time-scale relevant to products of civil engineering, such as bridges or highways. The rapid change associated with synthetic biological artefacts may be an unavoidable facet of building with biology. If so, this may serve to distinguish the field's kinds.

5.2 Setting a kind for synthetic biology

Following Hacking (1991), kind-setting matters for those who intend to *do things with things*. Synthetic biologists aspire to build with biology. Their aspiration points to a technological kind, while their substrate points to a natural kind. Consequently, neither class captures the character of synthetic biological artefacts, much less the subtleties of engineering with living materials. I posit that this complication in kind-setting reflects a broader dilemma for synthetic biology.

As matters stand, synthetic biological artefacts are uncomfortably positioned as technologies. Practitioners have appropriated the language and practices of conventional engineering practices—design, modularity, standardization, and so on—as foundational guiding principles. As a consequence, their products are viewed as entities within the kind of technological objects. However, synthetic biological artefacts fit this kind imperfectly, as they do the kind of natural things. It is my contention that this imperfect status is a result of the field's failure to study its kinds.

Synthetic biological artefacts may represent distinct tokens of a new kind—a grouping of things sufficiently distinct from natural entities and conventional technological artefacts to warrant a unique class. This possibility attests less to the novelty of synthetic biology, nor should it be considered a contribution to the excessive hype surrounding this very young field. Instead, my claim should be taken as a challenge to and question for synthetic biologists. Is conventional engineering the most appropriate model on which to pattern synthetic biology?

Kind-setting is pragmatic. It serves specific ends. Classifying synthetic biological artefacts as tokens of existing technological kinds has clear ramifications for the making of these objects. If synthetic biology is to be successful in building with biology, it may have to accept that this form of human artifice is not reconcilable with traditional engineering. Its products may demand new and different methods, require new and different expectations, and serve unique ends. Alternatively, our understanding of technology may itself have to adapt vis-à-vis a new substrate of design and construction. The matter is an open empirical question. Answering this question may begin with an exploration of things and kinds.

6. Conclusion

This first-look analysis of synthetic biological artefacts focused on the 'fit' between these objects and two kinds: those encompassing technological things and natural entities. It was my intention to systematically study the appropriateness of applying these categorization to the material products of synthetic biological research. In doing so, I identified key areas of congruence as well as the central difficulties in studying engineered biology as either a technological or natural phenomenon. Beginning from a broadly accepted definition of technological artefacts, it has been shown that synthetic biological artefacts may be classed technological objects, but only uncomfortably so. Similarly, it has been shown that several prominent definitions of natural kinds fail to account for synthetic biological artefacts fully. This ontological 'messiness' suggests that synthetic biology may benefit by examining its kinds.

Following Dupré (1981, 1993, 2001) and Hacking (1991), I argued that kind-setting is discipline-specific and serves pragmatic ends. Kinds follow the ontological-epistemic commitments, methodological practices, and goals of given fields. For disciplines lacking a consolidated body of practice, things and kinds are messy affairs. This is the case for synthetic biology. 'Objects in the making' are not dissociable from 'science in the making'.

To grasp the character of this discipline's products is to comprehend the discipline itself. To track the objects of synthetic biology is to follow the development of the field. Things and kinds point to knowledge and practice. This essay has not closed the discussion on synthetic biological artefacts, but it has framed a problem needing further examination and offered a perspective on the current state of affairs. Synthetic biology has yet to find its kinds; synthetic biological artefacts are the objects in the making of a science yet to be made.

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