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Knowing use: An analysis of epistemic functionality in synthetic biology

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<u>**Knowing use: An analysis of epistemic functionality in synthetic biology**</u>

Abstract

Social studies of knowledge have contributed many insights into the making and the character of scientific and technological knowledge. However, studies of knowledge *use* are scarce. This article engages with under-examined topics concerning epistemic utility. I posit and demonstrate that scientific and technological knowledge claims are functional. I argue that knowledge and its functions are mutually-enabling and mutually-sustaining constructs. To substantiate my claims, I present useful conceptualisations of 'function' and 'functionality' and employ them in an empirical case study. I examine knowledge use in synthetic biology, a young form of biological engineering. I demonstrate that knowledge in the field is brought into existence with function in mind, kept in existence through functional use, qualified and situated by its functionality and evaluated by its functional operation. The case study reveals the effectiveness of my conceptualisations and offers lessons about knowledge as both an end-result of epistemic work and a mechanism for practice. My theoretical and empirical contributions expand understanding of scientific and technological knowledge and shed light on an area of study awaiting investigation. I conclude with open-ended reflections on work yet to be done.

Keywords

knowledge ; function ; utility ; sociology of knowledge ; synthetic biology

Knowing use: An analysis of epistemic functionality in synthetic biology

Many things that humans put together humans put to use. Among those are certain forms of knowledge. Science studies and the sociology of knowledge have contributed great insight into scientists' knowledge-making work. Social scientific theories and methods have supported research on the collective making and social validating of knowledge claims. Less attention has been given to the *use* of scientific and technological knowledge.

Here, I examine knowledge use in synthetic biology, a form of biological engineering, in order to explore knowledge functionality. I demonstrate that knowledge producers in synthetic biology create knowledge claims with utility in mind. Intended functions form part of their knowledge-making. Once produced, knowledge claims exist through their functional use. Synthetic biologists give their knowledge its substance by using it for functional ends. Use qualifies and situates the knowledge. Finally, evaluations of knowledge, including of its truthfulness, depend upon functional performance.

I employ my empirical study to establish three claims. First, knowledge in synthetic biology has functions. Put differently, synthetic biologists' knowledge claims are functional constructs. Second, synthetic biology knowledge and its functions are mutually-enabling. Knowledge claims make possible particular functions; those functions in turn support the knowledge claims' existence. Last, knowledge and function are mutually-sustaining. Because knowledge claims persist, their functions carry on; because they remain functional, the knowledge claims persist.

I present conceptualisations of 'function,' 'functionality,' 'mutually-enabling' and 'mutually-sustaining' as tools with which to analyse knowledge functionality. My study of synthetic biology demonstrates their usefulness. It also demonstrates that knowledge functionality in science and technology deserves study.

A gap and my aims

The birth of science studies in the 1960s gave rise to novel perspectives on scientific knowledge. The field cast aside commonplace understandings of concepts like objectivity and truth, and rejected those offered by epistemological traditions like rationalism. Science studies replaced previous social studies of knowledge with approaches like the sociology of scientific knowledge (SSK). It introduced new theoretical perspectives, such as the Edinburgh Strong Programme (Bloor 1976, 1981; Barnes 1981), the Empirical Programme of Relativism (Collins 1983) and Actor-Network Theory (ANT) (Latour 1993, 1999). My research and this article sit within this social scientific tradition.

Science studies also introduced new methodological principles, such as the Strong Programme's four tenets (Bloor 1976) and ANT's generalised conceptualisation of actors and agency (Latour 1993; Callon 1986). Researchers encouraged detailed observations of practice and analyses based on causal explanations (Bloor 1976). They produced myriad empirical studies of scientific and technological knowledge-making (Knorr-Cetina 1999; Knorr-Cetina and Mulkay 1983; MacKenzie 1993; Pickering 1992). Studies of laboratory practices led to insights about tacit knowledge (Collins 2001) and the interdependence of theory and observation (Pinch 1985). Research on scientific controversies explored consensus-building and epistemic closure (Collins 1981). Together, these studies examined knowledge as something produced and made legitimate through concerted social practice.

However, researchers have overlooked or marginalised knowledge *use*. Studies of scientific and technological knowledge as something employed (Pitt 2001; Mulkay 1979; Vincenti 1990, 1992) are not nearly as abundant as are those of knowledge as something made. Empirical studies have overlooked many use practices and analyses have not accounted for functions as causal factors. Some works in technology studies (Bloor 2011; MacKenzie 1993) and engineering studies (Vincenti 1990, 1992) have examined the topic, but much remains unaddressed. For instance, such studies often focus only on technological skills and artefact use (Collins 2001; MacKenzie 1993). They overlook other forms of epistemic utility, such as expanded scientific understanding.

I address this empirical and theoretical gap with an original case study and novel conceptualisation of function and functionality. Fields like the philosophies of biology and technology have produced many definitions of function, commonly meant to resolve perceived problems such as functional teleology and indeterminacy. My work is social theoretical, but it draws from and contribute to such philosophical scholarship. My ideas offer different ways to understand existing concepts and suggest a new approach to epistemological debates about the nature of knowledge.

Because the study of epistemic functionality in science and technology is a project too large for one article, my contributions are purposefully open-ended. I hope to foster discussion and new social scientific and philosophical inquiry. And while my empirical investigation is restricted to synthetic biology, I believe that my argument can apply to other fields and knowledge.

The role of synthetic biology

I examine epistemic functions in synthetic biology. Function and functionality play roles in defining synthetic biology's character, practices, objects and knowledge. Practitioners engage explicitly with different forms of functionality: biological, technological and *epistemic*. Many synthetic biologists use traditional engineering disciplines as templates when doing such things as organising their communities, selecting aims and practices, and establishing norms. One result is a commitment to particular kinds of knowledge use. Because the field remains under construction, my research participants were able to reflect critically on their emerging knowledge work. Finally, the field's diversity results in a multiplicity of epistemic utility, which included both technological applications and expanded scientific understanding.

My research employed social scientific methodology. I used ethnographic methods for extended and short-term observation of synthetic biologists. As a member of laboratory groups, I documented routine discourse and practice. I attended organisational meetings and disciplinary events to learn about ongoing research and to watch discussions of technological and epistemic functionality. I also gained insights into knowledge practices during collaborative projects with practitioners.

I interviewed 45 synthetic biologists, who capture the field's diverse research aims, topics and methods, and its many perspectives on knowledge. My argument employs data from all of the interviews, but relies principally on 34 that addressed knowledge and function in the greatest detail.

Knowledge and function

Fields like the philosophies of biology and technology are replete with definitions of function. Different definitions serve different ends, such as excising teleology from the concept of biological function[1] or distinguishing 'proper' from 'accidental' technological functions[2]. Here and in previous work[3], I neither seek nor offer a definition of 'function' like those. My goal is neither to resolve perceived problems like teleology nor to establish criteria for distinguishing valid functions.

My theory serves social scientific methods and empirical study. My conceptualisations do not take the form of ‘necessary and sufficient conditions’ or of ‘if and only if’ formulae, such as Hansson’s ICE theory of technical function (2006) or Millikan’s definition of ‘proper function’ (1998, 1999). These do not serve social theory as well as they do certain philosophical traditions.

My conceptualisations of ‘function’ and ‘functionality’ examine them as entities, practices, qualities and conditions. These four dimensions enable a comprehensive understanding of epistemic function. Given my concern for knowledge—something planned, produced and *employed* by people—my conceptualisations reflect the character of things that people build. As a result, I draw philosophical insights from the study of technological, rather than biological, functions. I employ their understanding of technological artefacts to conceptualise knowledge constructs.

Function

My understanding of ‘function’ consists of three components. First, function refers to purpose: that for which people have planned and built something. For instance, makers design and construct a ball-point pen in order to enable users to transfer ink from an inbuilt vessel onto a surface, such as a sheet of paper. Vermaas and Houkes’ ‘intentionalism’ also emphasises the importance of design purpose (2006). However, intentionalism overlooks the contingency of use by treating designer intentions as determinative essences ‘built into’ artefacts.

Next, ‘function’ concerns use. It consists of practices enacted by people, such as writing on a notebook page or sketching on a drawing pad. Like Scheele (2006), I view user practice as a crucial component of how functions exist.

Last, 'function' concerns those encompassing activities which serves. Writing on a notebook page might serve writing a poem. Sketching on a pad might be preparation for painting a portrait. Such activities operate as contexts within which objects are given functional meaning (Preston 1998, 2006). One result is functional contingency and plurality.

My understanding of function offers useful insights. First, function depends on people. People design and build artefacts. They use artefacts and carry out encompassing activities. Second, function is not inherent. Someone must endow an artefact with capacities (Scheele 2006) and its functions exist because someone puts it to use (Schyfter 2009). Third, functions are not immutable. They can and do change, and people routinely use artefacts for tasks other than those intended by makers. Capacities circumscribe what an artefact can do, but the artefact cannot will users to employ it only in certain ways. From this originate discussions about 'proper' and 'accidental' technological functions, such as a chair's use for sitting and for reaching a high shelf, respectively (Hansson 2006). To comprehend function, one must examine its contingency and its mutability (Preston 1998, 2006). Finally, functions exist in different forms at different levels of activity. A pen's immediate function is to transfer ink onto a surface. That function is encompassed by a broader function—to write a poem—which in turn forms part of a third function—to develop a writing career. An artefact's historical, social and physical situatedness shape what it 'does' and 'is for' (Preston 2006). Such contingency is comparable to that of 'situated knowledges,' as described by Sandra Harding (1991) and Donna Haraway (1988). An artist's pen and a poet's pen both transfer ink, but that function is situated differently within its encompassing activities.

Situatedness also demonstrates the analyst's role in giving meaning to functions. A function is contingent and context-dependent; so is the analyst's understanding of that function. Does she care about the mechanics of ink-transfer, or about the tools of poetry-writing? There is no sole or self-evident way to define functions, and there is no inherently superior or sole question to ask about what an artefact does. Social theory emphasises situatedness and contingency; that includes the epistemic contingency of the researcher herself.

Functionality

My understanding of 'functionality' consists of three components. First, functionality refers to character, such as a device's distinctive traits. Attributes of a particular ball-point pen include its form and feel. Another attribute (perhaps its key attribute) is its function. Put differently, one can use functionality to describe and distinguish an object. Houkes similarly argues that knowing an artefact depends on knowing its functions. Functionality shapes its physical makeup (Vermass 2006) and its place in society (Schyfter 2009). Both qualify it as something with a distinct character.

'Functionality' also refers to a condition of being capable of realising a function. A particular ball-point pen's functionality is its present state, which enables it to transfer ink successfully onto a surface. In this case, 'functionality' means something similar to the claim, 'it's working.' Crucially, functional success is neither self-defining nor everywhere equal. It is contingent on people, places and practices, much as epistemic validity is situated (Haraway 1988; Harding 2001).

Finally, 'functionality' conveys value. An artefact's function and its current capacity to exercise it—its functionality—increase an artefact's worth. An artefact's incapacity to accomplish its function—its *lack* of functionality—diminishes that worth. A pen that cannot put ink onto a surface has little immediate value for someone trying to write on a page. Franssen demonstrates that artefacts' functionality is necessarily normative and that evaluations of functionality shape artefacts' value (2006). Houkes and Vermaas convincingly argue that malfunctions have devaluing effects (2010).

An understanding of functionality as character, state and value captures elaborates my conceptualisation of 'function.' First, functionality qualifies an artefact in different ways. It serves to describe what an artefact is and what it can do. We use functionality to characterise *who* uses the artefact, *why* it forms part of certain activities, and *how* it should be used (Houkes 2006). We use functionality to make value characterisations, such as of an artefact's worth or a person's skill with it (Franssen 2006). Second, functionality is active. It constitutes and shapes traits only because people bring it into action (Schyfter 2016). Third, functionality is situated. It exists and has meaning in relation to what surrounds and interacts with it (Preston 2006). As I noted, the analyst shapes that meaning. In her work, she gives certain functionality precedence: transferring ink or writing a poem. Studies of functionality should examine its ability to shape things, its context-dependence and its activeness. My research does so with social scientific methods and an empirical case study.

Mutually-enabling and mutually-sustaining

I will demonstrate that knowledge and function are 'mutually-enabling' and 'mutually-sustaining.' I begin with conceptualisations of the two terms.

Four relationships constitute 'mutually-enabling.' First, two things are mutually-enabling insofar as each helps make the other possible. Second, they endow each other with specific capacities. Third, they bring each other into operation. Finally, each provides justification for the other; they confer or contribute to each other's legitimacy.

Three relations constitute 'mutually-sustaining.' These ensure the continuation of that which is mutually-enabled. Two things are mutually-sustaining if they keep each other in existence. They are mutually-sustaining if they keep each other in working order. Last, two things are mutually-sustaining if they offer each other support. Support includes upkeep:

fixing flaws and correcting poor performance. It also involves ongoing advocacy and protection of mutually-enabled legitimacy.

As is characteristic of social theory, these conceptualisations present issues to explore and pose questions to answer. They serve as tools for empirical methodology and research.

Synthetic biology: A synopsis

Synthetic biology is a useful case study with which to examine how knowledge and its functions are 'mutually-enabling' and 'mutually-sustaining.' The field has developed over the past two decades, though it still lacks clear boundaries and identities. Some claim that it has introduced novel perspectives, practices and products (e.g. Andrianantoandro *et al.* 2006; Heinemann and Panke 2006); others question whether it is an independent field. Even those who argue that synthetic biology is distinct disagree on what makes it so. Nonetheless, the field has enjoyed much attention[4] and institutional and financial support.

The place of engineering and the roles of functionality

Many practitioners and observers distinguish synthetic biology by its multifaceted engagement with engineering. Early texts portrayed the field as innovative due to an ardent commitment to established engineering (Andrianantoandro *et al.* 2006; Brent 2004; Endy 2005; Heinemann and Panke 2006). Today, engineering forms an inescapable part of synthetic biology's identity, discourse and practices (Calvert 2010). As Simons notes, 'engineering' in synthetic biology escapes simple characterisation (2020). Nonetheless, its many forms all affect what synthetic biologists say, do and *know*.

Practitioners have incorporated conventional engineering principles and practices into their work. Their writings and research have focused on topics like standardisation of modular parts (Anderson *et al.* 2010; Arkin 2008; Canton, Labno and Endy 2008; Frow 2013), design-build-test workflows, computer modelling and predictable functionality (Dougherty and Arnold 2009). Synthetic biologists have not embraced these with uniform conviction, nor do they practice in accordance with a single fixed understanding of engineering (O'Malley 2009; Simons 2020). Even so, practitioners navigate a field busy with engineering discourse and practices. These are put to many uses, such as building biological technologies and expanding scientific understanding (O'Malley *et al.* 2007; Schyfter 2013a).

Work to develop standard biological parts has produced objects such as BioBricks. Ostensibly, these serve as stock 'nuts and bolts' with which to build functional constructs (Decoene *et al.* 2018). They also represent material instantiations of engineering ideals. Synthetic biologists design and build 'circuits' using genetic components, such as the famed 'repressilator' (Elowitz and Liebler 2000). Those projects involve designs, practices, tools, language and imagery taken from disciplines like electronic engineering (Ajo-Franklin *et al.* 2007; Gardner, Cantor, and Collins 2000; Tamsir, Tabor, and Voigt 2011). Practitioners measure parts' performance, such as promoters' 'strength,' and compile quantitative data similar to those that engineers routinely employ (Mutalik *et al.* 2013).

Synthetic biology's many engagements with engineering help explain functionality's many roles in the field. Standardised parts are built to satisfy specific functions, such as triggering or halting genetic transcription. Synthetic biologists assemble parts into constructs in order to enable higher-level functions, such as producing specified chemicals. Defining components by their function and building constructs to enable functionality are fundamental aspects of established engineering. In synthetic biology, those aspects serve technological and epistemic ends.

Functionality is vital to synthetic biology processes. Synthetic biologists organise their work in accordance with functional ends. What resources practitioners gather, people they enrol, workflows they prepare and tools they ready reflect functions they hope to produce. Building a biological AND gate may require finding and adapting promoter genes, gaining insights from electronic engineers and testing input and output dynamics. Enabling other functions will demand different materials, processes *and knowledge*.

More broadly, synthetic biologists engage with many different understandings of function and functionality. Technological function is something to create. Biological functions are phenomena to understand and qualities to harness. And as I will demonstrate, synthetic biologists build and evaluate knowledge as something functional.

Knowledge at work in synthetic biology

Synthetic biologists design and build in accordance with their conceptions of engineering. They make and use knowledge in the same manner (O'Malley *et al.* 2007; Schyfter 2013b). While synthetic biologists rarely foreground knowledge-making in their field, epistemic work and products are vital to their efforts. One cannot reduce synthetic biology to artefact-building or its knowledge to technical proficiency.

Synthetic biologists survey and source knowledge from different fields. They adjust and employ that knowledge to multiple ends, and produce different kinds of epistemic functionality. But whether they are making technologies or expanding scientific understanding, practitioners subscribe to a functional understanding of knowledge.

Synthetic biologists engage with knowledge as an instrument. Function and use shape its content and form, perceived worth and relationship to truth. My empirical research evidences these claims and substantiates my contention that synthetic biology knowledge and its functions are mutually-enabling and mutually-sustaining. Empirical studies of other fields might demonstrate similar relationships between their distinct knowledge and its particular functions.

Knowledge is brought into existence purposely, with a function in mind

Function first concerns that for which people planned and built something; they specify needs to fulfil and direct their work accordingly. Those responsible for knowledge-making practices seek to satisfy functional needs, which motivate and shape epistemic work.

New types of work pursue new, as yet unsatisfied needs, or approach existing needs in novel ways. Synthetic biology does both. Its practitioners describe the field and its ambitions in many different ways. These have changed over time, but certain ideas have persisted. John, a principal investigator (PI) in a US public university, has sought to understand how unicellular organisms determine and adjust their spatial orientation. He defined synthetic biology as trying to take 'biological modules and use them as tools to build novel, or different, or tuned biological cells, that show different biological behaviour.' John uses those techniques to expand scientific understanding. Other synthetic biologists, he argued, aim to design and build new biological entities with specific capacities. Doing so requires new knowledge.

Those I interviewed described this need in many ways. Thomas' doctoral work at a leading laboratory focused on network-scale metabolic engineering: cellular populations and processes for producing desired chemicals. Like John, Thomas argued that many synthetic biologists seek new forms of biological design and construction. Those new pursuits require new knowledge, as 'the biology that we know isn't totally useful for the engineering we want to do.' Robert, who uses control engineering tools and techniques to develop synthetic biology constructs, argued that 'one of the challenges is lack of knowledge.' Epistemic gaps prevent synthetic biology from satisfying needs. Once practitioners ‘get that knowledge, we will be able to address some of the other things,’ which include technological design and construction. Like Thomas, Robert described how specific needs motivate knowledge-making in their service.

Functional needs guide and shape knowledge-making. Dylan’s research involves enabling biological data storage by using genetic switches. To satisfy his functional ambitions, he requires ‘more understanding of the fundamental processes which are driving biological systems.’ Practitioners like him aim to ‘use this knowledge to try [their] application,’ and so those applications help set the direction for knowledge-making. Others made similar claims. Hannah worked in the biotechnology industry and is now a leading researcher at a prominent US institution. Her work focuses on designing organisms to produce desired chemicals at scale. She argued that many synthetic biologist try to understand ‘the basics of what can be done? How can it be done? How can it be done most efficiently?’ She described such knowledge as tools and argued that answers to those questions are ‘things that will facilitate the design process.’ Dylan and Hannah suggested that needs are specific; as a result, the knowledge-making that they spur is particular.

Sharon, who studied alongside Thomas, expressed a similar view. ‘To do engineering instead of just like, messing [around],’ synthetic biology requires specific forms of new knowledge. She described the need to understand the structure and working of gene networks, rather than focusing on single genes. John agreed. Synthetic biologists have sought to use standardised components to build larger operational constructs. John argued that synthetic biologists try to ‘understand those rules of how parts, simpler parts are put together to build the next, higher level of complexity.’ The need to enable technological functions explains synthetic biologists’ particular concerns and ways for understanding genetic networks. Others study networks with different end-goals; their epistemic approaches differ accordingly. Sylvia, one of John's students, tried to understand how 'biological process can be built' and sought to produce 'a blueprint or a guidebook for it.' She guided and shaped her knowledge-making following what she saw as the field's engineering needs. She meant her epistemic products to be usable instruments.

In summary: *functional needs contribute to the start of knowledge-making, and they affect the directions taken by knowledge-makers*. The two points evidence knowledge functionality and the mutually-enabling relationship between knowledge and function. In this case, functional needs enabled knowledge-making, brought it into operation and provided it with specific capacities.

Knowledge exists through use

A technological artefact's function exists as that for which user communities employ it, not as an inherent, immutable essence established by makers (Schyfter 2009). Similarly, knowledge claims operate as active components of encompassing activities. Epistemic functions are contingent on those activities and change with them. Their utility is established and given form by the collective. Moreover, knowledge remains valid by remaining functional: usable and used as the community specifies.

Synthetic biologists explained that knowledge is born and exists only within their field's activities. Its function reflects that situatedness. Elizabeth, a postdoctoral researcher working to develop a 'minimal cell' to house synthetic constructs, argued that 'it's one thing to say that you're going to make this or that you can make this.' However, 'the real learning process, like the real valuable information is going to come from the exercise of actually trying to do it.' Functional aims motivate the start of knowledge-making and practitioners deliver new knowledge through efforts to realise those aims. They create knowledge in the process of realising an intended function. By building a 'minimal cell,' synthetic biologists will create knowledge for making biological technologies and for expanding scientific understanding of what constitutes life.

Practitioners employ knowledge to carry out their work and its character shapes that work. Hannah argued that synthetic biology could benefit from ‘a better understanding of how different elements of biology work.’ For Hannah, that knowledge could function to ‘facilitate the design process.’ For others, it could serve to expand understanding of biological phenomena. Its place in the field reflects its function and its functionality shapes the field’s work.

Once synthetic biologists produce and accept knowledge, it becomes employable. That is, established knowledge is *usable* knowledge. For instance, Hannah described synthetic biology’s concern for ‘abstraction.’ The field hopes to produce component that practitioners can use without knowing their details (Endy 2005). Synthetic biologist would only need to know what a part does (its function) and its operating parameters (its requirements for functionality). Hannah argued that her team ‘can’t abstract because we don’t know enough yet about the system.’ With the necessary knowledge:

> … we can specify parameters and say, ‘if you want to get the same phenomenon that we observe, here’s how you do it.’ And the next person doesn’t actually have to understand those details anymore.

Hannah viewed successful knowledge as something that her colleagues can employ for their work. Epistemic success follows functional success, which is defined by local aims. Sylvia described successful experimental results as tools for designing and producing working technologies. ‘It would be lovely’ if her work could serve others as ‘a starting guide to how people build circuits with function.’ Like Hannah, she views accepted knowledge as usable knowledge[5].

In summary: *knowledge exists through its functional operation and established knowledge is usable knowledge*. Practitioners produce knowledge by trying to make it satisfy functional needs. Established knowledge is kept in place by its functionality, such as technological applicability and expanded scientific understanding. At the same time, established knowledge keeps its functionality in existence and in working order. The two support and maintain each other.

Knowledge is qualified and situated through its function

Functional needs motivate and shape knowledge-making; later, knowledge exists as something functional. As a result, function shapes knowledge claims' content and their place within a system of work.

Sharon emphasised synthetic biology's knowledge deficit repeatedly. As others did, she described it as problem hampering the field's progress. Sharon suggested that much of the deficit results from the tasks that synthetic biologists want their knowledge to carry out. She argued that synthetic biologists 'still don't really know what happens when you move one gene.' She then qualified her claim: 'don't really know, *at an engineering level*.' Knowledge is missing because that which already exists cannot satisfy specific needs, which reflect her ambitions to design and build *as do engineers*. For others with different ambitions and functional needs, there may be no epistemic deficit. Emily, a PI whose works to enable information and control functions in living systems, also described the field's knowledge as insufficient. To fulfil her design aims, synthetic biology must develop sophisticated understanding of 'how complex biological systems work.' That knowledge will help practitioners to 'build on that complexity,' and help 'synthetic biology to advance.' In this case, epistemic functions include both technological accomplishment and disciplinary development. Similarly, John described his knowledge as serving many synthetic biologists' ambition to practice as ‘a designer or an engineer… starting from scratch.’ Sharon, Emily and John described knowledge content as characterised and situated by its functions, which include technical purposes and encompassing disciplinary aims.

Edward made a similar claim by describing how certain types of work and knowledge *fail* to fit within some pursuits. His work focused on assembling certain genomes that are normally toxic to *E. coli* bacteria, modifying them to be non-toxic and examining what effects the changes have. Edward argued that his experiments are ones that ‘no-one who is doing regular science, and trying to discover things, would probably ever really want to do.’ For such a person, with different functional needs, Edward’s work would ‘[feel] like a side-track.’ In his synthetic biology community, his experiments and knowledge are well situated because they serve aims valued by the group. Edward’s reflections evidence the situatedness of knowledge and the interpretation of its content in relation to its uses. They also suggest that capacity and use affect knowledge worth.

In summary: *function shapes what ‘goes into’ knowledge, and functionality situates knowledge within an encompassing undertaking*. The researchers argued that function influences what must form part of knowledge claims. It affords those claims the capacity to satisfy desired aims. Function also qualifies knowledge insofar as users employ it to serve an encompassing activity. Knowledge relies on its function to keep its place in the activity, and its presence sustains that function. When its functionality becomes irrelevant or unappreciated, knowledge loses its belonging.

Knowledge is evaluated according to its functionality

How practitioners mean to use knowledge motivates its existence, qualifies its content and shapes its place. Functionality also shapes knowledge value. Successful functionality adds to its worth. Functional failure lessens it.

Many synthetic biologists evaluate their knowledge from an engineering perspective, and attribute value in accordance with engineering ambitions. They assess knowledge using parameters that conform to its intended use. Hannah defined engineering success as the ability to 'make a design work the way that you want to work.' Success demands that practitioners know how '[biological components] function individually' and can 'predict how they'll behave in combination.' She viewed current knowledge as inferior because it does not satisfy those criteria. She conceded that previous work has accomplished a great deal using insufficient knowledge. For instance, it has been able to ignore small differences in component workings and rely on population-wide behaviours. However, because she is 'trying to do this sophisticated engineering, those small differences start to matter.' New criteria for epistemic assessment accompany new functional needs. Thomas, who also investigates chemical production, argued that synthetic biologists must 're-evaluate biology from this new perspective.' With an engineering standpoint, they can 'figure out what's useful to know and what's not' for their field's engineering ambitions. Like Hannah, Thomas described engineering parameters as guidelines for making new knowledge and for evaluating existing knowledge.

Practitioners evaluate knowledge and its worth in accordance with its utility. Walt was trained in electrical engineering and computer architecture. As a synthetic biologist, he used circuit design techniques to engineer biological constructs. He argued that synthetic biology and the biological sciences diverge in terms of their aims and their concern for specific forms of knowledge. While biological scientists might seek to 'understand what are the natural functions,' synthetic biologists believe that 'it can do whatever you want it to do, as long as it all fits together… and the inputs lead to the outputs which we predicted.' Understanding and technological applicability are different functions and so establish different parameters for evaluation. For Walt, engineering ambitions and uses cast some knowledge as uninteresting or irrelevant. Knowledge that supports successful device operation is relevant and valuable. Edward argued something similar. He reflected that many biological scientists would consider his work to be ‘tedious experiments, because, you know, you are not really discovering anything.’ Those scientists expect their knowledge to support understanding, whereas he wanted his knowledge to enable technological functionality. As a result, each employs different criteria to assess the worth of knowledge work and products.

Finally, disciplinary needs shape practitioners’ understanding of failure. Carol, a PI who participated in the earliest synthetic biology working groups, explained that an important difference between engineers and biologists is the formers’ concern for the uses of failures. She argued that ‘biologists say, “oh it didn’t work,” and they throw it in the trash can,’ whereas an engineer ‘tries to learn from what didn’t work.’ Dylan agreed:

> … there’s a ton of experiments in biology that people have done and didn’t work, and they didn’t really investigate why, and they didn’t even publish and there’s no record that this stuff didn’t work.

He suggested that for biologists, ‘failure is not enough recognised as information.’ Carol’s and Dylan’s engineering aims and needs give worth to knowledge drawn from failures. It can be used to improve future technological performance. Just as with successes, evaluation parameters and value criteria for knowledge failures concur with the field’s functional needs.

In summary: *function shapes evaluations of knowledge*. Functionality helps confer legitimacy and value upon knowledge. When knowledge lacks functionality, it carries less worth. How synthetic biologists evaluate successful and failed knowledge depends on their capacity to enable or improve functionality. Functionality is situated and changeable; so is its relationship to value, which is neither inherent nor fixed.

Working knowledge

I have shown that function forms a vital part of what constitutes synthetic biology knowledge, why and how it exists, and how people perceive and engage with it. Synthetic biology knowledge and its functions are mutually-enabling and mutually-sustaining. My argument contributes to the broader study of scientific and technological fields, knowledge and practices. It offers lessons and potential topics to explore.

Knowledge is a mechanism

Synthetic biology knowledge exists both as end-results of work, and as active instruments in work. The two forms are interdependent, though not selfsame. As a result, understanding such knowledge requires studying it in both forms.

I noted that scientific and technological knowledge remain under-explored as functional mechanisms. Conceptualisations of scientific and technological truth offer one opportunity to explore epistemic functionality. Epistemologists and sociologists of knowledge have produced countless conceptualisations of 'truth.' Their breath and complexity betray the difficulty of analysing truth and should encourage intellectual humility. My understanding—based on functionality—is neither definitive nor unprecedented. For instance, pragmatist epistemology identifies truth with usefulness (Dewey [1929] 2008, Dewey and Bentley [1949] 1989; James [1910] 2011). However, my contributions are particularly effective for studying scientific and technological knowledge.

Science studies does not have one sole conceptualisation of knowledge or of its relationships to beliefs and truths. However, its traditions share some fundamentals. First, science studies describes established knowledge claims—those considered true—as socially-endorsed beliefs (Bloor 1997). Without collective support, scientific and technological knowledge loses its legitimacy as truth (Collins 1981). Support includes endorsing epistemic functionality and certifying functional success. Second, because truths are social accomplishments, they reflect the particularities of the collective, including the group's functional aims and its understanding of utility. The collective establishes what constitutes epistemic functions and decides if its knowledge fulfils its functionality. Third, establishing social endorsement for scientific and technological truths often requires resolving disputes and building consensus. Negotiation and compromise are important and necessary for knowledge making. Defining epistemic functions and evaluating functionality are also subject to disagreement and require collective consensus.

Function and functionality contribute an understanding of scientific and technological truths as 'working knowledge,' capable of fulfilling what people designed and built it to do. Function depends on people and their collective endorsement to exist as a valid function, rather than as simply a type of use. Function is neither inherent nor immutable. People impart and modify functions (Houkes and Vermaas 2010; Schyfter 2009). Those actions reflect the particularities of their context, just as scientific and technological knowledge do (Preston 1998, 2006). Such contingency calls for empirical investigation. Last, attributing new functions or abandoning existing ones can give rise to debate. Designers and users may disagree about an artefact's effectiveness for a particular task. They may have to compromise about when and how a certain use is properly a function.

If knowledge and function are mutually-enabling and mutually-sustaining, then collective endorsement of one enables and sustains endorsement of the other. SSK controversy studies examine how epistemic endorsement is produced in scientific knowledge making (e.g. Collins 1981, 2001). Similar studies about epistemic functions can examine knowledge use as a vital kind of collective endorsement.

Knowledge practice includes knowledge use

Science studies compels scholars to develop causal explanations of knowledge based on empirical studies of knowledge-making practices (Bloor 1976). Functionality expands what causality and practice reveal about scientific and technological knowledge-making.

Studies of practice can explore activities through which practitioners develop, enable and employ epistemic functions. Knowledge use offers insight into what scientific and technological knowledge is once practitioners have accorded it truthfulness. It exists as more than a shared abstraction or as information codified in writings; knowledge exists as a resource for work (Rheinberger 1997). Studies of knowledge use can reveal the particularities of that work, such as the need for knowledge maintenance.

Functional mechanisms require upkeep. Whenever scientific and technological researchers examine something new, they employ their knowledge in a correspondingly new way. Even during routine use, established knowledge may fail. Adjustments to the knowledge might restore its functionality, re-establish collective endorsement, and so sustain its truthfulness. Repair practices—functional maintenance—may lend insight into how scientific and technological knowledge persists through utility and use.

Studies of practice have also contributed to research on what defines and characterises different scientific and technological communities. Studying knowledge use, a form of practice, may so the same. Groups use epistemic functionality to distinguish their work and their knowledge from others, as I demonstrate above with regard to synthetic biology. Studies of different forms of knowledge use can reveal different strategies for consolidating practitioners and producing collective identities.

Faltering knowledge

Understanding functionality requires understanding *failed* functionality. When studying epistemic functions, ‘inadequate,’ ‘malfunctioning’ and ‘broken’ knowledge are rich in analytic potential.

Houkes and Vermaas argue that technological malfunctions take different forms (they are plural) and reflect the particularities of makers and users (they are contingent) (2010). For synthetic biologists, knowledge falters in different ways and its failures reflect the field. As the participants explained, much existing knowledge cannot satisfy their functional needs: it fails when put to their new uses. Knowledge systems also fail because of missing components: epistemic gaps. Like an unsuitable or inadequate instrument can hinder technological work, epistemic inadequacies can limit knowledge practices. Unsatisfactory equipment may motivate technologists to develop new or better tools. Epistemic inadequacies may influence practitioners’ choices about what knowledge to pursue and which epistemic functions to enable. Thus, functional failures offer new opportunities for causal explanation of scientific and technological knowledge and practice.

Franssen discusses criteria used to evaluate functionality and functional failures (2006). Without parameters to define ‘working,’ one cannot label an instrument ‘broken.’ Similarly, knowledge failures are defined using collective criteria. Knowledge that satisfies a community’s functional demands may fail when those demands change. Studies of epistemic function can explore how failure parameters are established and how they influence the making and use of scientific and technological knowledge. Franssen also examines the need to define ‘legitimate expectations’ in order to establish true malfunctioning (2006). Studies of scientific and technological knowledge might explore how practitioners collectively establish which failures constitute acceptable annoyances or expected limitations, and which are meaningful problems needing repair.

Working forward

Knowledge use in synthetic biology offers insights into the field, its work and its people. It demonstrates the mutually-enabling and mutually-sustaining relationship between knowledge and its functions. It also suggests potential for future study.

Social scientists and philosophers have studied scientific and technological functions extensively. Those interested in scientific and technological knowledge should examine epistemic functions just as comprehensively. Doing so requires producing and evaluating different conceptualisations of knowledge function. It demands empirical studies of other scientific and technological knowledge, accompanied by inclusive understandings of what constitutes epistemic function. Studies can investigate the diversity of epistemic functions and knowledge use. They can delve into topics such as practitioners' understanding of knowledge at work, their perceptions of success and failure, their evaluations of epistemic worth, and their upkeep of working knowledge. Case studies from other scientific and technological fields can test my argument's applicability. Most importantly, further study will reveal questions wanting answers and research yet to be done.

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[1] The literature on biological function and teleology is expansive. Examples include: Ayala 1998; Brandon 1998; Buller 1999; Perlman 2009; Ruse 2002.

[2] E.g. Hansson 2006; Houkes 2006; Houkes and Vermaas 2010; Preston 2009; Scheele 2006.

[3] E.g. Schyfter 2009, 2015, 2016.

[4] *The Economist* (Morton 2019), *The New York Times* (Markoff 2014; Pollack 2010), *The Washington Post* (Basulto 2015) and *The Wall Street Journal* (Mack 2019) have all reported on synthetic biology.

[5] Consider Rheinberger's 'epistemic things,' which once established "turn into the technical repertoire of the experimental arrangement." (1997, 29)