Conceptual Change

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Abstract

The topic of conceptual change is a natural target for integrated history and philosophy of science. Scholars working in this tradition have investigated concepts from many different sciences, often supplementing familiar historical and philosophical methods with tools from ethnography, cognitive science, and the digital humanities. After reviewing the literature, we single out two themes that seem especially promising targets for future work. First, as we point out, many &HPS analyses of conceptual change lean on metaphors likening concepts to biological species or artifacts. Drawing on previous studies of metaphors in science, we encourage more attention to the substantive impact of metaphor choice. Second, &HPS scholarship has often moved beyond describing and explaining conceptual change to address normative questions. This agenda is echoed by the recent trend of conceptual engineering in analytic philosophy. Though the two bodies of research have hardly interacted so far, we point out several opportunities for fruitful mutual contribution.

Keywords: conceptual change, conceptual engineering, integrated history and philosophy of science, metaphor, scientific concepts

1 Introduction

Thomas Kuhn's *The Structure of Scientific Revolutions* (1962) was a major catalyst in promoting discussions of conceptual change in science. The book itself is a clear case of integrated history and philosophy of science (&HPS), given its reliance on the history of astronomy to motivate such philosophical notions as paradigms and incommensurability. Yet some responses to *Structure* lost touch with the kinds of historical data that inspired its argument in the first place. Consider the use of the causal theory of reference to ensure referential stability across radical theory change. This project was neither inspired nor defended by the history of changing concepts, but instead by more abstract commitments to scientific realism. In contrast, in this chapter we focus on studies of conceptual change that integrate philosophical concerns with the dynamics of actual scientific concepts, both past and present.

Such studies do not merely investigate theory change, but rather emphasize the unique role that concepts play in organizing and guiding scientific practice (e.g., Feest and Steinle 2012). Concept transformation *across* historical periods is often continuous with concept variation *among* scientists working simultaneously. In this chapter, we use the term 'conceptual complexity' to capture how concepts vary between users, and may even bear multiple meanings for a single scientist. Addressing this complexity matters for understanding how and why concepts change over time. It is also important to note that scholars can fruitfully investigate the behavior of specific concepts without committing to any particular view about what a concept *really is* or what determines the identity of a concept. In particular, the focus on concept *use* (Kindi 2012) does not necessarily presuppose that a concept (or its content) is a separate entity from its various uses—or that a concept merely *is* its use.[1]

[1] Support for this pragmatic approach comes from arguments that philosophers of mind and

In the next section, we present some examples of &HPS work on conceptual change, illustrating how it has engaged with various scientific disciplines, while also employing diverse perspectives and tools. The following two sections offer novel analyses of recent trends in this body of work. It has often been noted that metaphors play an important role in scientific practice, but in Section 3 we examine how &HPS researchers themselves rely on metaphors to characterize conceptual complexity and conceptual change, and how their choices shape ongoing research. &HPS work has not just described conceptual change but also made critical recommendations about scientific concept use. These efforts are analogous to recent conceptual engineering work within philosophy, as Section 4 points out. But since these two bodies of literature have been developing separately from each other, we conclude by suggesting that conceptual engineering work in philosophy and &HPS research on conceptual change have the potential to contribute to each other.

2 Varieties of Work at the Intersection of &HPS and Conceptual Change

&HPS research on conceptual change varies along several significant dimensions. First and most simply, concepts from many scientific disciplines have been subject to &HPS work. In physics and chemistry, these concepts target fundamental components of matter, such as electron, atom, and chemical element (Arabatzis 2006, Chang 2004, Hendry 2005, Kragh 2000), as well as basic properties like temperature (Chang 2012) and acid (Hacking 1983, Stanford and Kitcher 2000). In biology, studies of conceptual change focus on important categories, including virus (Bloch-Mullins 2012), gene (Falk 1986), and species (Wilkins 2018), as well as key relations like homology (Brigandt 2006, 2012, Gouvêa 2021, 2023) and genetic dominance (Shan 2020).

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psychologists tend to ask different but legitimate questions about the concept of ‘concept’ and endorse different goals for an account of its nature (Machery 2009).

Within neuroscience, &HPS scholars have traced researchers' concepts of synapse (Bloch-Mullins 2020) and cortical column (Haueis 2021). Biomedical concepts of sex (Richardson 2013) and psychiatric concepts of multiple personality (Hacking 1995) have likewise been subject to &HPS investigations. Some concepts are also interdisciplinary by nature. Replication (Schickore 2011) is fundamental to the experimental sciences, while the notion of magnetic pole (Steinle 2012) proved useful in understanding objects as diverse as electrified wires and the earth itself.

Second, &HPS scholars have selected different aspects of concept use for closer study. For instance, they have examined different stages in the life cycle of a concept, from the first steps of concept formation, when scientific knowledge about a phenomenon is sparse (e.g., Bloch-Mullins 2012, Feest 2012), to the significant transformation of well-established concepts and their roles (e.g., Brigandt 2012), and from historical change in one scientific field to the advent of conceptual variation across several fields (Brigandt 2003). Moreover, some studies have focused on the internal structure of concepts (Brigandt 2010, Haueis 2021), while others have emphasized the influence of surrounding factors, from experimental innovations (Bloch-Mullins 2012, Feest 2012, Schickore 2011) to theoretical perspectives (Brigandt 2015, Love 2007).

Third, different scholars use different portions of the &HPS toolbox to motivate their research. One important *historical motivation* is the desire to understand the causes of change in a concept, rather than merely chronicling its shifts; an early example is the work of Raphael Falk (1986) on the causes of fragmentation in the gene concept (see also Falk 2010). Other scholars are motivated by particular historiographical commitments. For instance, Jutta Schickore (2011) argues that past science serves the 'heuristic function' of reshaping scholars' analytic categories, rather than simply providing data to test established metascientific theories. Her study of early modern snake venom research reveals many nuances in the concept of experimental 'replication.' Meanwhile, Friedrich Steinle (2005/2016) exemplifies the patient interpretation of

archival sources in his work on 19th-century electromagnetism research. He shows that experimentation often served to establish new conceptual frameworks, rather than to test existing theories. Historically motivated work has often generated payoffs for scholars pursuing other questions. For example, the notion of 'exploratory experimentation' pioneered by Steinle (1997) together with Richard Burian (1997) has stimulated significant ongoing research in the philosophy of science. Falk (1986, p. 173) used his historical work to urge "a more reflective mood among the investigators themselves about the meaning of their concepts." Other historical analyses have offered normative recommendations about how scientists might update the gene concept in light of recent developments (Portin 2009, Portin and Wilkins 2017).

Many studies on conceptual change are driven by *philosophical questions*; here, we mention just one example, the work by Philipp Haueis on the norms of scientific concept revision. While combined with historical studies on the changing concept of 'cortical column' (Haueis 2021; see also Haueis and Novick in press), the motivating philosophical issue is the normative question of when and how a scientific concept should be revised. What are the legitimate alternatives to discarding a concept that turns out to have multiple meanings (Haueis 2022)? As a stepping stone toward assessing this issue, Haueis (2024b) articulates the structure of complex concepts based on the notion of a 'patchwork'—on which we elaborate in the following sections.

Finally, &HPS work on conceptual change is sometimes motivated by *perspectives from contemporary science*. A case in point is Alan Love's work on 'evolutionary innovation' and 'novelty.' Love (2003, p. 309) singles out a "foundational question in contemporary biology," namely, "how to 'rejoin' evolution and development." He complicates the standard backstory of their separation, in which the Modern Synthesis excluded embryology. Love shows that comparative morphology and paleontology were also relatively marginalized, the latter despite the prominence of paleontologist G. G. Simpson within the Modern Synthesis. All three of these

fields offer important resources for understanding the central phenomenon of evolutionary novelty. In later work, Love (2006, 2007) details D. Dwight Davis's application of functional morphology to evolutionary questions and William K. Gregory's paleontological investigation of vertebrate evolutionary novelties. He also develops the analytic category of a 'problem agenda' to capture the role of the concept of novelty in coordinating several biological fields and setting the standards for explanatory success (Brigandt and Love 2012, Love 2008). As with the historically motivated research above, this scientifically motivated project has contributed to the other two fields in &HPS.

As we wrap up our survey of researchers' motivations, two forms of integration (represented by the & preceding HPS) deserve special emphasis. Just as questions associated with each discipline tend to prompt those associated with the others, the supposedly distinct projects of 'descriptive' and 'normative' analysis turn out to interact frequently. Attempts to characterize or explain conceptual complexity often lead researchers to evaluate and even intervene upon that complexity—and vice versa. We return to the normative end of this spectrum in Section 4.

Fourth and finally, &HPS scholars have creatively used various tools beyond standard textual analysis to understand conceptual change. One example is *methods from the cognitive sciences*, including the psychology of concepts and child development. Paul Thagard's *Conceptual Revolutions* (1992) hypothesizes that conceptual innovation involves recombining previous concepts and develops a computational model of theory evaluation, which among other things assesses explanatory scope and unification across episodes of conceptual change (see also Thagard 1990, 2008). Thagard (1992) applies this model to historical cases of conceptual revolution in evolutionary biology, geology, physics, and psychology; he also evaluates the analogy between conceptual change in children and conceptual change in science. Nancy Nersessian (1984) likewise applies ideas about concept formation from psychology and linguistics to the emergence of the modern 'field' concept, including the formation of 'line of

force' (Michael Faraday) and Newtonian and non-Newtonian 'aether-field' (James Clerk Maxwell and Hendrik Lorentz, respectively), up to the transition to Albert Einstein's field concept (see also Nersessian 1992). Nersessian's more recent book *Creating Scientific Concepts* (2008) combines empirical cognitive science with historical analysis to show how novel concepts emerge through model-based reasoning, including mental modeling. In *The Cognitive Structure of Scientific Revolutions* (2006), Hanne Andersen, Peter Barker, and Xiang Chen rely on the notion of 'frames' used in psychology to represent the content of concepts. They develop it further to 'dynamic frames,' arguing that these can capture clear-cut concept change without running into Kuhnian incommensurability, applying it to the concept of planetary orbit, among others (see also Chen et al. 2006).

Another relevant tool is *ethnographic methodology*, as employed by MacLeod and Nersessian (2013). Their study of integrative systems biology involves the ethnographic observation of two systems biology laboratories, including interviews with the lab members, to understand the factors that foster the integration of concepts and methods in systems biology. A further example of the use of diverse methods is Laura Nuño de la Rosa's &HPS research on 'evolvability.' Prior to the introduction of this concept around 1990, the evolutionary capacity of organisms and populations had been taken for granted by evolutionary theory, but it is now seen as a phenomenon in need of explanation. To some extent, the concept of evolvability has even united ongoing investigations in different biological fields, including quantitative genetics, evolutionary developmental biology, and paleontology (Hansen et al. 2023). Going beyond standard &HPS work using textual sources (Brigandt 2015), Nuño de la Rosa (2023) conducted many interviews with biologists who were historically instrumental in getting the concept of evolvability on the map, while also interviewing more junior researchers. This provides insights into the (multiple) origins of evolvability research and changes in research agendas and conceptual tools transforming the research landscape on evolvability. Notably, Nuño de la Rosa

(2017, 2023) adds *digital humanities methods* to her historical investigation, using bibliometric tools to track how the relative prominence of various terms has changed and to conduct co-citation analysis. The latter quantifies how often two articles are cited together in a given period, which reveals clusters of research (e.g., complex network research and quantitative genetics work on the G-matrix as different clusters) and their transformation across time.

3 Metaphors as Tools for Understanding Conceptual Change

In the last section, we surveyed the wide range of methods used by &HPS studies of conceptual change. Now we focus on one notable interpretative technique. It is widely known that scientists use metaphors as part of their accounts (e.g., Kuhn 1979, Montuschi 2000). But here we explore how metaphors have been used by &HPS scholars to understand conceptual change. In recent work, we find concept variants undergoing 'adaptive radiation' (Brigandt 2003) and occupying 'ecological niches' (Stotz and Griffiths 2004)—but also 'evolving neutrally' rather than adaptively (Novick 2023). We also see researchers assembling 'patchworks' of domain-specific concept uses (Haueis 2021) and erecting entire 'conceptual neighborhoods' in pursuit of challenging explanatory goals (Love 2005). What should we make of such figurative language? What role should it play in ongoing attempts to understand conceptual change?

To address these questions, we borrow ideas from the study of metaphors in science itself. After all, one recent paper calls biologists to recognize metaphors as "powerful tools as much a part of science as microscopes, pipettes, and mathematical models" (Olson et al. 2019, p. 606) and the same message appears in recent books intended for lay audiences (Brown 2003, Kampourakis 2020, Reynolds 2022). The key source for this message is the philosopher Max Black (1955, 1962), who challenged the prevailing idea that metaphors are shorthand for literal

speech.[2] Instead, he argued, they are "cognitive instruments" that change users' perceptions of their subject matter (Black 1979, p. 39). Mary Hesse (1966, 1980) developed these ideals in her own influential work on scientific models and scientific realism, while Evelyn Fox Keller (1995, 2002) applied ideas from both Hesse and Black to the history of genetics in the 20th century.

In identifying one thing with another, argued Black, the metaphor invokes an entire system of associated beliefs about each thing. The implication-complex generated by the source of the metaphor *interacts* with its counterpart from the target to produce a single meaning.[3] In the process, the user of the metaphor "selects, emphasizes, suppresses, and organizes" her beliefs about its subject to enhance the correspondence between the two domains (Black 1979, p. 29). When applying these ideas to science, it is helpful to distinguish two broad functions of metaphor. (a) Key epistemic tasks like explanation and prediction may be accomplished by formulating or refining a metaphor rather than by constructing propositions in literal language, whether natural or mathematical (Hesse 1966, Rentetzi 2005). (b) Metaphors play a more pragmatic role in supporting the process of inquiry, for instance, by weaving disparate "experimental systems" and "research programs" into a "coherent scientific agenda" (Keller 2002, p. 120). As we show later in this section, both these functions also characterize interpretative metaphors for conceptual change in science.

Keller's work is particularly fruitful for our purposes because the situation of philosophers studying conceptual change today is reminiscent of that facing geneticists in the early 20th

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[2] Other philosophical approaches to metaphor emerged during this period in both the analytic and continental traditions (Hills 2022, Theodorou n.d.).

[3] There has been considerable debate over how exactly the two domains involved in the metaphor interact to produce its meaning. Black (1979) and Soskice (1985) are two helpful entry points.

century. They wanted to understand how genes affect heredity and development, but they lacked knowledge of their material form, let alone their physiological properties. Our own discussion proceeds without any settled philosophical or psychological account of what concepts are, beyond loose agreement that they enable certain cognitive functions (Machery 2009, Margolis and Laurence 2019, Weiskopf 2009). A closer look at biologists' metaphor of 'gene action' will set the stage for our analysis of HPS scholars' metaphors. When this metaphor arose in the 1930s, Keller (2002) argues, it simultaneously filled two gaps in biological understanding. "What is a gene, and what does it do?" A gene is simply "an entity embodying the capacity to act (in whatever ways are required) within its own being" (pp. 129–130).

This particular metaphor gained power from the "latent ambiguity" belonging to the word 'action' in the biochemical lexicon of that time. In addition to the purposive movement of persons and animals, this word also evoked the chemical properties of enzymes. The metaphor effectively endowed genes with the "disparate properties of atom and organism" (Keller 2002, pp. 130–131). Rather than discrediting early geneticists' research, Keller argues, this metaphorical 'incoherence' actually demonstrates their creativity and resourcefulness.

> Not only did it permit researchers to get on with their work—resolving the problems they *were* able to address, without having to worry about those they could not—but it also provided them with an explanatory framework, albeit a provisional one, with which they could make sense of the progress they were making in their day-to-day research, both to themselves and to others. (Keller 2002, p. 132)

Here we see Keller invoking both functions of metaphor mentioned above—the epistemic function (a) of explaining development, and the pragmatic function (b) of coordinating research. Of course, the incoherence could only be contained for so long, and biologists eventually replaced 'gene action' with 'genetic program' and (later) 'gene regulation' to more precisely describe the differential causal impact of various stretches of DNA at various places and times during the life of an organism. While it lasted, each metaphor helped to coordinate the thought

and the activity of a large and diverse group of researchers tackling the complexities of development.

Now we turn our attention to &HPS scholars toiling over the complexities of conceptual change in science. In order to make sense of their target, they have drawn on *structures* and *processes* belonging to *nature* as well as *human society*. Once again, Kuhn (1962) provides a helpful starting point. His central metaphor—revolution—belongs to the political domain, but he also appealed to evolutionary biology to argue (controversially) that science does not advance towards "one full, objective account of nature" (p. 171).

Biological evolution has remained an enduringly popular source domain for analyses of conceptual change employing analogies and metaphors. Toulmin (1972) and Hull (1988) both developed detailed theories of conceptual evolution, though in different ways and for different purposes. Toulmin wanted to vindicate scientific rationality by reconceiving it historically, but this intervention remained highly theoretical. By contrast, Hull offered "an empirical account of empirical science" (1988, p. 9) and emphasized his desire to understand rather than justify conceptual evolution. His account was therefore heavily informed by the details of his focal case, theoretical change in systematics.[4] Nevertheless, Hull (1988, p. 522) saw his own work as "the fulfillment of Toulmin and Kuhn's suggestions." Toulmin analyzed the trajectory of individual scientific disciplines, which he took as analogous to biological species, as the outcome of selection acting on their intellectual components (particularly concepts, methods, and theories). Using his own earlier analysis of biological selection (Hull 1980), Hull treated scientists as 'interactors' determining the differential survival of such disparate 'replicators' as "beliefs about

[4] Hull not only chronicled but also participated in these debates; other participants (e.g., Farris 2018) and historians (e.g., Gouvêa 2023, fn. 25) have since contested matters of fact and interpretation.

the goals of science, proper ways to go about realizing these goals, problems and their possible solutions, modes of representation, accumulated data, and so on" (1988, p. 434). As in biological evolution, these conceptual replicators "exist in nested systems of increasingly more inclusive units" (p. 449). Hull identified social credit as the key determinant of conceptual fitness, but also allows (contrary to Kuhn) that science is modestly progressive. Scientists search for regularities in nature and assign credit at least in part on their assessment of success in identifying those regularities.

More recent work on conceptual 'evolution' is much more modest in scope. It tends to focus on individual concepts, rather than theories, disciplines, or research programs, and to steer clear of comprehensive evolutionary theories. For example, Ingo Brigandt (2003) argues that the homology concept underwent an 'adaptive radiation' in the 20th century, spreading from comparative anatomy into the new biological fields of evolutionary theory, systematics, evolutionary developmental biology, and molecular biology (see also Richard 2019 on meanings as 'species'). In a similar vein, but with a different metaphor, Karola Stotz and Paul Griffiths (2004, p. 6) describe the 'diversification' of the gene concept to support molecular biologists' diverse research goals. In both these cases, the authors use metaphors to check the prescriptive impulses of previous philosophical work. "If scientific concepts are evolving tools," argue Stotz and Griffiths, "it should not be the aim of philosophers to identify the one correct conception associated with a word" or to manage polysemy within a community (2004, p. 6). Instead, Brigandt maintains, "the project is to try to understand the way in which a particular variant … is adapted to the biological field in which it is used" (2003, p. 9; see also Brigandt 2012).

Despite its more modest scope, this recent work follows Toulmin and Hull in treating

conceptual evolution as analogous to natural selection.[5] In response, Rose Novick (2023) cautions against the implicit assumption that either the origin or the persistence of conceptual complexity is adaptive. Even when philosophers of science have shown that conceptual complexity currently provides a benefit to researchers, they have generally failed to show that it provides a *net* benefit, or that it exists *because* it provides that benefit. It is more plausible, argues Novick, that conceptual complexity arises as a byproduct of other processes and persists because eliminating it would be more trouble than it is worth. It arises because scientists often apply a concept to a given domain of nature "before it is known exactly how the concept will behave in that domain" (2023, p. 1026). Scientists often realize that the original domain is heterogeneous or subdivide it into smaller domains. Either way, they end up with a fragmented concept that covers multiple domains, such as genes and body parts as instances of 'homology,' or definitions pertaining to microbes as well as metazoans for the concept of species. However, this fragmentation is generally only a minor nuisance (at worst), because the concepts are familiar tools for the community and because humans are already such "competent navigators of polysemy," able to reliably "determine relevant uses from context" (2023, p. 1027).

It is important to recognize that Novick's (2023) 'neutral theory' of conceptual complexity invokes a second major metaphor, Haueis's (2021, 2024b) model of *patchwork* concepts mentioned in Section 2. The domain in which a conceptual variant applies is part of what differentiates it from other related uses. As Haueis sums up this theory (which is inspired by

[5] In his cultural evolution account of how different cultures come to sometimes have the same number of basic color concepts but sometimes also very different numbers of color concepts, Decock (2021) takes a more balanced approach by arguing that it is a combination of 'conceptual adaptation' and 'conceptual drift'— also relying on two metaphors. He also makes room for conceptual reform and conceptual engineering, which, unlike conceptual adaptation, are planned.

Mark Wilson 2006),[6] scientific concepts often have "multiple scale-dependent, technique-involving, domain-specific, and property-targeting uses (patches)" (Haueis 2024b, p. 741). Continuing the metaphor, there are general reasoning strategies that supply "instructions on how to assemble patches of a patchwork concept" (p. 746). Examples include the strategy to identify transformation series of diverse biological entities descended from a common ancestor in the case of the homology concept (Novick and Haueis 2023) or to measure the resistance of various materials to different mechanical interventions for the concept of hardness (Haueis 2024b). Patches also sometimes involve overlapping domains or shared techniques, creating an additional form of local relationship.

With just two source domains for metaphors on the table—biological evolution and patchwork quilting—we can draw two important lessons from the theories of scientific metaphor. *First*, these metaphors perform both the epistemic function (a) and the pragmatic function (b) for the &HPS community. The comprehensive evolutionary theories of Toulmin and Hull are especially obvious attempts to explain via "metaphoric redescription" (Hesse 1966, p. 157), but the more modest metaphors in recent work are also doing important *epistemic* work. The choice between adaptationist and neutralist metaphors turns on genuine disagreements about the causes of conceptual complexity. These explanatory differences also have predictive consequences. By analogy to the neutral theory of biological evolution, the neutral theory of conceptual evolution predicts that the continued usage of any given complex concept "may be slightly beneficial or slightly deleterious, compared with other ways of conceptualizing a

[6] Cartwright (1999) previously used the 'patchwork' metaphor by arguing that nature, including the domain of physics, is governed by a patchwork of laws. Conceptual patchwork structures have also been analyzed using the tools of formal semantics (De Benedetto 2021, De Benedetto and La Rosa 2024).

domain" and that scientists will therefore deliberately clean up their language "only where complexity is causing significant, demonstrable confusion" (Novick 2023, pp. 13–14).

Beyond their explanatory import, these two metaphors serve the *pragmatic* function (b) of coordinating &HPS research on conceptual complexity. As mentioned above, Hull self-consciously elaborated the evolutionary theory of conceptual change suggested by Kuhn and initiated by Toulmin. Evolutionary metaphors have also been used to articulate distinctive &HPS methods. Jim Lennox (2001) argued that reconstructing the history of philosophical problems in contemporary science is essential to tackling those problems. He dubbed this the 'phylogenetic approach,' evoking biologists' use of phylogenetic history to understand the current features of organisms—without appealing to any evolutionary mechanism for understanding the history of science, unlike Hull's reliance on natural selection. Other &HPS scholars subsequently used the notion of phylogeny in their studies of conceptual change (Brigandt 2006, Love 2005, Stotz and Griffiths 2004). Metaphors also coordinate the results of different case studies. This is especially evident for the patchwork approach, which was developed alongside close studies of several different cases and has already been applied to a new case, attention in psychology (Taylor 2023).

Second, these metaphors bear out a central claim of Black's interactionist theory—metaphors shape their users' perceptions of the target domain by emphasizing features that can be matched to the source domain. Here, we emphasize two important features that are differentially represented by evolutionary and patchwork metaphors. The first is the temporality of any given concept. Does the metaphor highlight semantic variation at a given moment, or does it highlight change over time (as seen in adaptive radiation and neutral evolution analogies)? The second is the relationship between concepts. Does the metaphor engage with the internal structure of one concept, or can it also capture relations across several concepts?

Patchwork metaphors highlight the current structure of a single concept by specifying the different variables that define a patch and the different mechanisms that hold patches together. At the same time, they make room for concept change over time; Novick and Haueis (2023) emphasize the process of 'conceptual extension' to a new domain (for more details, see Section 4). But even here, the metaphor suggests the formation of a new stable structure. In that new domain, "the term *settles* on a property that allows for the realization of the reasoning strategy" (p. 15, emphasis ours). By contrast, evolutionary metaphors more naturally present concepts as constantly in flux and focus attention on the causes of such behavior. Stotz and Griffiths (2004) describe their approach to the gene case as 'conceptual ecology' and imply that the diversification of the gene concept may represent 'incipient speciation events.' Devin Gouvêa (2021, pp. 140–144) broadens the scope of the ecological metaphor to emphasize the interaction of a target concept ('homology') with related concepts like 'novelty' and 'character' and also with cognitive and material resources that affect multiple concepts at once (e.g., new theories and techniques).

With these two lessons in mind, we close by presenting two more metaphors that differ from those already mentioned in the properties that they emphasize. Like the patchwork metaphor, the 'conceptual neighborhood' (Love 2005) emphasizes the intricacies of conceptual structure at a given moment in time without entirely neglecting their history. Unlike the patchwork metaphor, it is explicitly designed to capture the relationships between multiple concepts. For example, 'homology' is an "explanatory target concept" at the heart of a neighborhood that also includes concepts designating relations (e.g. 'inheritance'), entities (e.g. 'common ancestor'), and properties (e.g. 'relative position'). Neighborhoods experience 'equilibrium states' of relative stability punctuated by more dramatic "upheavals in the theoretical foundations of a science" which change the set of concepts involved in the explanation and the epistemic relationship

among them (Love 2005, p. 19).

Finally, Friedrich Waismann's (1945) notion of 'open texture' is notable for its unique treatment of the temporality of an individual complex concept. More than just an evocative phrase, open texture is Waismann's English rebranding of a German metaphor—*die Porosität der Begriffe*, the porosity of concepts. The domain here is geological, and the open space within the structure of the concept—embodying a conceptual ambiguity not unlike the metaphor of gene 'action' noted above—can accommodate future discoveries, purposes, scientific hypotheses, and applications (Makovec 2025). Waismann's goal was to capture the way in which even the most precisely defined concept may need revision as science changes. As Makovec (2025) argues, this diachronic focus distinguishes it from Wittgenstein's metaphor of 'family resemblance' between objects that instantiate a concept, or Neurath's use of *Ballung* to evoke an agglomeration of meanings akin to the diverse population of a city center.

In deploying these and other metaphors, scholars of conceptual complexity face choices that shape their understanding of complex concepts. Scientists who use those same concepts face significant choices of their own. What are the normative implications of using a concept in one way rather than another, or choosing one variant over another? In the final section, we will survey the contact points between &HPS work on (complex) scientific concepts and recent work on conceptual engineering.

4 From Understanding Conceptual Change to Conducting Conceptual Engineering

As we noted in Section 2, &HPS projects often generate recommendations for improving scientific concepts. Philosophers in particular have reached for engineering metaphors to

describe deliberate conceptual innovations. Carnap (1947, p. 43) likens the selection of variables in a formal language to that of a "suitable motor for a freight airplane." Both are "engineering problems" constrained by the components' properties and intended purposes. Isaac et al. (2022) document independent lineages of this metaphor in Carnap scholarship and metaphilosophy. Brun (2016) notably presents 'conceptual re-engineering' as a generalization of Carnap's (1950) famous method of explication. The process involves replacing an old concept with a new one that is similar but better for some purpose, whether theoretical or practical. Meanwhile, *conceptual engineering* has emerged as a vibrant perspective and practice in analytic philosophy (Burgess et al. 2020, Burgess and Plunkett 2013). Though this literature has developed separately from &HPS work on conceptual change, we see instructive parallels between the two, along with opportunities for productive mutual contribution.

Conceptual engineering has thoroughly *prescriptive* aims: to discard defective or harmful concepts, to revise and improve problematic concepts, and to introduce better concepts. Traditional conceptual analysis in philosophy merely articulated a concept some philosopher possesses, while often erroneously assuming that this concept was widely shared by others and used in the same fashion. Although philosophers made conceptual prescriptions before the advent of the 'conceptual engineering' label, this new perspective is distinctive in coordinating research across very different areas of philosophy, from logic, metaphysics, and epistemology to feminist philosophy and philosophy of race. It has also prompted more reflective metaphilosophical discussions on the aims and proper practice of philosophy. Some conceptual engineering work on individual concepts clearly aims at advancing social justice or environmental and animal ethics (Brigandt and Rosario 2020, Deans 2024, Haslanger 2020, Podosky 2021, 2022). These aims raise questions about how to practically implement concept revision and innovation, given the need to affect larger populations of ordinary speakers. A related question for conceptual engineers is whether to attach a revised or novel concept to an

existing word (inheriting the prior connotations) or to coin a new term. For instance, Philipp Haueis (2024a) argues that 'climate crisis' is a better word to use than 'climate change' or 'global warming' for advancing climate change mitigation.

Even when historians and philosophers of science do not identify themselves as conceptual engineers, they often go beyond describing conceptual change in order to critically evaluate it and even recommend interventions on scientific language. A case in point is Sarah Richardson's (2022) contextualism about the concept of sex, especially in the context of biomedical research. Richardson's main target is the binary sex essentialism implicitly promoted by mandates to include male and female cells and organisms in preclinical research. By considering diverse examples, she shows that 'sex' may apply to cells, organs, or individuals and calls for a construal of sex that captures the within-species variation in sex-related developmental trajectories and is also "sensitive to the ethical implications of claims-making about the biology of sex differences" (given that "concepts and words have political and social implications," p. 9). Richardson (2022, p. 10) argues that this requires "researchers to contextually define sex-related biological variables and to justify their choices in how they operationalize sex," where what counts as 'sex' or a 'sex-related biological variable,' how many different sexes there are, and whether 'sex' is a relevant category at all depend on the research situation.[7] This practical recommendation is both analogous to conceptual engineering and a clear instance of &HPS. It is informed by Richardson's detailed work on the history of research on sex and changing visions about biological sex differences as well as her investigation of contemporary biomedical mandates to include sex as a biological variable (Richardson 2013, Richardson et al. 2015, Zhao et al. 2023).

A step beyond contextualism about sex would consist in eliminating 'sex' "from large swathes of biological practice" and replacing it with more specific terms (Watkins and DiMarco

[7] For a similar position on the concept of disease, see Kukla (2022).

2025, p. 2). More generally, *selective eliminativism* has been endorsed as a general strategy for managing fragmented scientific terms (Taylor and Vickers 2017). A more nuanced approach to conceptual complexity than a pervasive eliminativism has been suggested by Philipp Haueis and Rose Novick using the patchwork account of concept structure (see Section 3). Like Richardson's work, this project can be seen as making &HPS and conceptual engineering germane to each other by using *historical* investigations to motivate *normative* guidelines. Drawing on the cases of 'cortical column' and 'sequence homology' (Haueis 2021, Haueis and Novick in press), under the (metaphorical) labels of 'conceptual housekeeping' and 'conceptual retirement,' Haueis and Novick propose forms of concept revision in addition to concept elimination (Haueis 2022). Their approach articulates a complex concept's change in terms of the addition of new patches (meanings) to the overall set of patches, the modification of an existing patch's scope of application, or the removal of a patch.

'Cortical column' refers to a vertical band of functionally similar neurons, once seen as the building block of the neocortex. The concept developed a structure of different patches, designating column types at different spatial scales. But over time, several patches have suffered an internal breakdown of the patch. Some key techniques turned out to be unreliable in new brain areas, for instance, when the patch 'hypercolum' was extended from neocortex region V1 to the middle temporal area MT. Some of the properties that supposedly distinguished columns proved either too heterogeneous for this task or not relevant to achieve the researchers' scientific goals. Though it has lost its positive organizing role, 'cortical column' need not be eliminated altogether; instead, it is in *conceptual retirement* and can "provide guidance or a cautionary tale to avoid the errors of past practitioners" (Haueis 2021, p. 110). By contrast, the history of 'sequence homology' illustrates a form of *conceptual housekeeping* in which researchers expel a patch from a previously existing patchwork. For some while, sequence homology as mere sequence similarity among genes was a (new) patch of the overall homology concept. This

became controversial since such similarity does not guarantee the phylogenetic homology of either genes or organisms. Eventually, scientific practice settled on expelling sequence homology from the set of patches making up the homology concept, as a housekeeping measure, though 'sequence homology' is still occasionally used as a separate concept. In line with conceptual engineering, Haueis and Novick (in press) draw two general lessons from these cases. First, the history of scientific practice suggests a tolerance of conceptual complexity and a concomitant *minimalism about conceptual interventions* such as housekeeping. This diverges from taking simplicity and precision as the philosophical default—and recommending concept elimination whenever this standard is not met. Second, housekeeping decisions depend on the particular historical context, and not just the structure of the concept. Scientists have delayed intervening to reduce polysemy until the risks of confusion and error became sufficiently high.

The norm of tolerance is also supported by general philosophy work on the causes of conceptual complexity. Focusing on social notions like art, democracy, and religion, W. B. Gallie (1956, p. 169) proposed that there are "concepts the proper use of which inevitably involves endless disputes about their proper uses on the part of their users." He offered an analysis of his new category, 'essentially contested concept,' which gained traction among political scientists (Collier et al. 2006). More recently, historians and philosophers of science have applied Gallie's ideas to the cases of 'cause' (Godfrey-Smith 2010), 'human nature' (Kronfeldner 2018), 'homology' (Gouvêa 2021), and 'nature' (Hopster et al. 2024). Godfrey-Smith and Gouvêa both propose to soften Gallie's analysis; many complex scientific concepts are merely "essentially dynamic" (Gouvêa 2021, p. 20) and "reliably subject to dispute" (Godfrey-Smith 2010, p. 336) rather than necessarily contested. Gouvêa (2021) also reworks Gallie's semi-formal criteria to produce a flexible model of conceptual change. She begins by arguing that even 'pure science' concepts may be value-laden in a very particular sense—they are taken to designate important research targets, and thus shape scientists' decisions about

where to allocate their limited resources. The shared pursuit of this valuable target creates cohesion among concept users, as does shared recognition of exemplary research efforts guided by the concept. Other factors promote semantic variation, most importantly, the complexity of the target phenomena and the conceptual and material resources required to investigate them. Hopster et al. (2024, p. 419) follow Gallie more closely in their focus on disputed concepts laden with social value. They point out that novel phenomena, such as lab-grown food ingredients, are especially likely to be "conceptually underdetermined" and subject to power struggles over strongly valenced labels like 'natural' (see also Ludlow 2014). We view the practice of 'conceptual appropriation,' as Hopster et al. (2024) dub these novel applications, as an economically and ethically important form of conceptual engineering.

While the recent conceptual engineering literature has developed independently of (and unacquainted with) longstanding &HPS studies of the change of scientific concepts, there are parallels that permit future interactions (see also De Benedetto 2023, Haueis 2024a). Both the &HPS literature (Boon 2012, Brigandt 2003, 2012, Feest 2010, Steinle 2012) and conceptual engineering work (Nado 2021, Podosky 2022) view *concepts as tools*—tools that are used for certain purposes or to pursue certain human aims. In line with this, Jennifer Nado (2021, p. S1524) argues that the key virtue of an engineered concept is not accuracy but efficacy, where efficacy is "relative to a purpose or goal." While &HPS discussions have understood various aspects of concept behavior and conceptual change by appealing to the role, goal, or function of a concept (Brigandt 2010, Haueis 2024, Smith et al. in press, Steinle 2012), conceptual engineers have recently come to scrutinize in detail what a concept function may—or should—actually be (Podosky 2022, Queloz 2022, 2026). This is particularly important since there are different construals of 'function' (Jorem 2022, Riggs 2021). Such conceptual engineering discussions on concept functions may well be relevant to &HPS studies of scientific concepts, especially if a concept such as sex calls for a critical evaluation that has social-political ramifications in view,

as we have seen with Richardson's (2022) advocacy for a contextualism about 'sex.' Conversely, conceptual engineers have started to realize that their practical aims can only be met if they pay more attention to the community-wide use of language, including the social conditions that constrain conceptual change and the history of language use in actual communities (Gibbons 2022, Podosky 2024). &HPS can here be a vital resource for future work, given its longstanding studies of conceptual complexity, conceptual variation, and conceptual change in scientific communities, which even involve negotiations among different visions of the relevant scientific aims and the purposes for which a particular concept is used.

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