Scientific Practice, Conceptual Change, and the Nature of Concepts

Ingo Brigandt

Department of Philosophy
University of Alberta
4-115 Humanities Centre
Edmonton, AB T6G 2E5
Canada

E-mail: brigandt@ualberta.ca

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Abstract

The theory of concepts advanced in the present discussion aims at accounting for a) how a concept makes successful practice possible, and b) how a scientific concept can be subject to rational change in the course of history. To this end, I suggest that each scientific concept consists of three components of content: 1) the concept's reference, 2) its inferential role, and 3) the epistemic goal pursued with the concept's use. In the course of history a concept can change in any of these three components, and change in one component — including change of reference — can be accounted for as being rational relative to other components, in particular a concept's epistemic goal. This framework is motivated and spelled out based on a concrete case: the history of the homology concept in biology.

The task of this paper is to develop a theory of scientific concepts that is intended to account for a) how a concept makes successful scientific practice possible, and b) how a scientific concept can be subject to rational change in the course of history. To this end, I shall suggest that each scientific concept consists of three components of content: 1) the concept's reference, 2) its inferential role, and 3) the epistemic goal pursued with the concept's use. Thus, my tenet will be that an adequate semantic account of scientific terms has to acknowledge *several* semantic properties. Let me give a brief preliminary sketch of my account by comparing and contrasting it with existing accounts of concepts.

I distinguish between two basic types of approaches: causal accounts of concepts and descriptive accounts of concepts. Unlike causal accounts, descriptive accounts assume that a person can possess a concept and refer with a term only if she has certain epistemic abilities or beliefs (so that causal accounts favor a causal theory of reference, while descriptive accounts favor a descriptive theory of reference in one way or another). A *causal account of concepts* construes a concept in terms of reference only (acknowledges reference as the only semantic property of a term), and maintains that possessing a concept consists in standing in a certain causal relationship to the referent, while assuming that a person need not have any epistemic abilities (such as beliefs about the referent) to possess the concept. Causal approaches have been prominent in the *philosophy of science*. Debates about conceptual change in science have typically centered on the incommensurability problem, and the standard reply has been to focus on the reference of scientific terms. Using a causal theory of reference, the idea is that even though scientists favoring different approaches (or scientists from different historical episodes) may endorse incompatible theories, they can still count as referring to the same entity with a given term.[1] Thus, in virtue of the causal theory of reference, a scientist can possess a concept (construed as referring to the term's referent) independent of having beliefs.[2] In the philosophy of mind, *semantic atomism* as prominently defended by Jerry Fodor (1990, 1994, 1998a) is a clear-cut instance of what I call a causal account of concepts. On Fodor's atomism, a person possesses a concept in virtue of standing in a specific causal-nomological relation to the referent. Fodor explicitly denies that possessing a concept presupposes having any epistemic abilities; concept possessing involves neither recognitional abilities, nor beliefs about the referent (Fodor 1998b, 2001, 2004).[3]

Another type of approach can be termed *descriptive accounts of concepts*. Such an approach assumes that in addition to reference/extension, a term has another semantic property, typically called meaning or intension. The various accounts falling in this category differ as to how this 'meaning' is to be construed, but it always includes the idea that meaning involves in one way or another explicit or implicit knowledge, in particular some beliefs about the term's referent. As a result, possessing a concept presupposes having certain beliefs or other epistemic abilities (such as the ability to recognize the referent). Most accounts of concepts in the philosophy of mind and language are what I call descriptive accounts. One traditional idea is that a term's meaning is given by an explicit *definition* or by *analytic statements* (involving the term), so that a person possesses a concept to the extent that she has certain beliefs about the concept's referent, namely those beliefs expressed by analytic statements. A related approach is *inferential role semantics*, which is sometimes construed as the tenet that a term's meaning is given by the theory (set of inferences) in which it figures. A more precise characterization is that inferential role semantics (also called conceptual role semantics or functional role semantics) maintains that the content of linguistic expressions or mental representations is at least partially determined by the cognitive or inferential role they have for a thinker or a language community. A person possesses a concept if she has the disposition to carry out certain inferences in which a term figures, or if her mental representations enter certain causal or functional relations.[4] Some versions of conceptual role semantics assume that all inferences in which a term figures are meaning-constitutive — leading to semantic holism — others maintain that only some (analytic) inferences are meaning-constitutive. Finally, a currently popular approach is *two-dimensional semantics* as used by such metaphysicians and philosophers of mind as David Chalmers (2002a, 2002b) and Frank Jackson (1998a, 1998b). 2D-semantics is a sophisticated version of possible worlds semantics and construes a term's intension as consisting in a two-dimensional matrix. One part of this matrix is the so-called A-intension, which as a function from possible worlds to extensions specifies for any possible world to which objects in that world the term applies. Thereby concept possession is construed as a person's ability to pass a judgment for every possible scenario as to which objects in that scenario fall under the concept. Thus like other descriptive approaches to concepts 2D-semantics assumes that concept possession involves having certain beliefs.

As already mentioned, my approach assumes that each scientific concept consists of three components of content: 1) the concept's reference, 2) its inferential role, and 3) the epistemic goal pursued with the concept's use. Reference is acknowledged by virtually all contemporary accounts as a semantic property, including causal and descriptive approaches. By maintaining that *inferential role* is a component of a concept, I depart from causal accounts and side with descriptive accounts, in that I assume that a person possessing a concept presupposes having certain epistemic abilities (recognitional abilities or explicit knowledge). My motivation for including this component in addition to reference is to meet my first constraint on a theory of concepts, namely, to account for a) how a concept makes successful scientific practice possible. My second constraints is to account for b) how a scientific concept can be subject to rational change in the course of history. To this end, I introduce a novel notion that goes beyond existing accounts of concepts (causal as well as descriptive accounts, accounts in the philosophy of mind and language as well as in the philosophy of science). This is the idea that a further component of a scientific concept is the *epistemic goal* pursued with the concept's use. While it is well-known that the overall activity of research programs and individual scientists is directed at meeting certain scientific and explanatory goals, my point here is that *individual concepts* may be used by a scientific community to pursue specific epistemic goals (that are characteristic of this concept's use). I introduce the epistemic goal associated with a concept's use as a genuine component of a concept as it accounts for the rationality of conceptual change, the idea being that a term's epistemic goal sets the standards for which semantic changes of that term can count as rational.

In what follows, I shall motivate and develop my account of concepts based on a concrete example from biology: the *homology concept*. This case study is relevant as the homology concept is a central concept from comparative and evolutionary biology. Furthermore, the homology concept has a rich history, in that in certain respect the concept underwent significant semantic change.

Homology in pre-Darwinian biology

Two morphological structures in different species are *homologous* if they are the same or corresponding structures. For instance, the human arm, the wing of bats, and the flipper of whales are homologous (they are all mammalian forelimbs). In fact, as Figure 1 shows, even the individual bones that make up the forelimb in these different species neatly correspond to each other. Forelimbs across a larger taxonomic group such as mammals have a common topology. The structures that are mutually homologous to each other are called *homologues* (homology is an equivalence relation). Homologous structures are considered the 'same' structures in different species; and homologues are usually given the same name (see Fig. 1). Various types of structures can be homologous: bones, organs, muscles, nerves, blood vessels, and tissues.

The modern explanation for the presence of homologous structures in different species is that they are derived from an ancestral structure. Figure 1 also illustrates that homologous

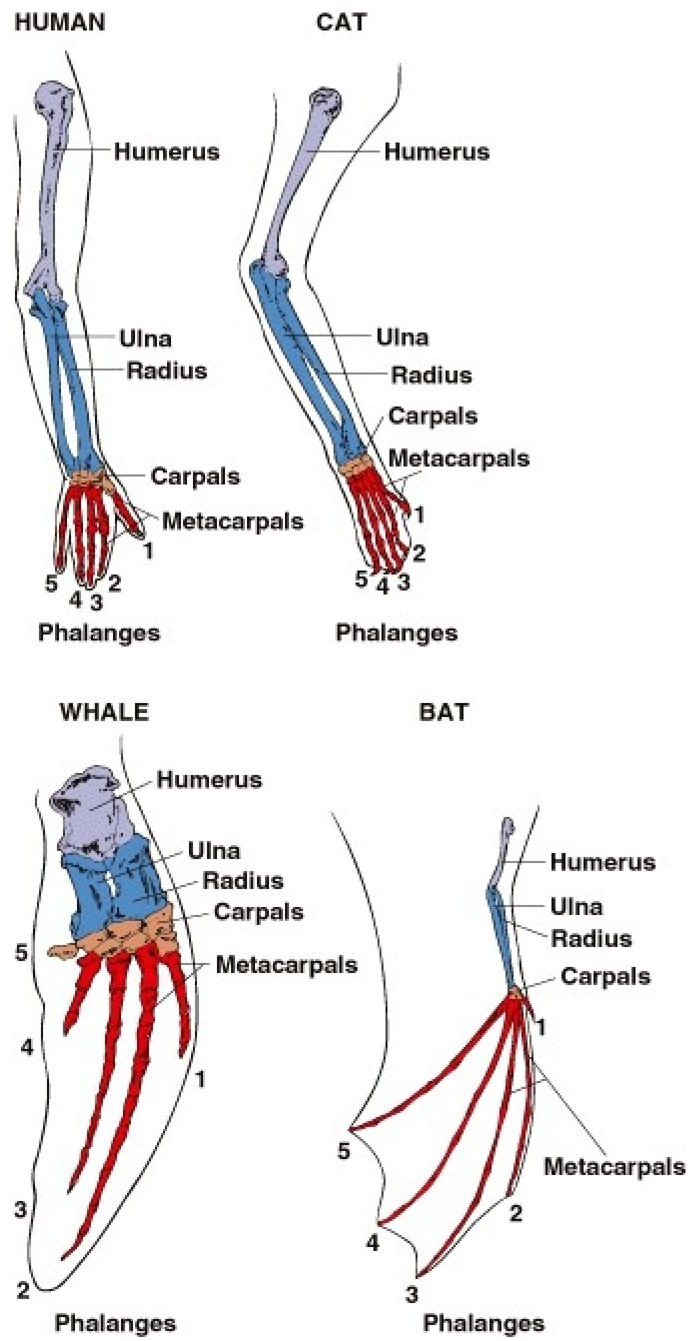

Figure 1: Homologies of the Mammalian Forelimb

structures in different species may differ in their form (shape) and function. The reason is that while an ancestral structure is inherited over generations and species (so that the ancestral and descendant structures are homologous), this structure may undergo evolutionary change in its form and function. For instance, the stapes (one of the ear ossicles) as we find it in mammals is homologous to the amphibian quadrate (a part of the jaw). In the course of evolution this structure shifted and changed in shape and finally adopted a radically different function, without forfeiting homology. Homology breaks an organism down into different morphological units: an individual's body consists of many structures, and what makes a part of the body a genuine morphological unit is the fact that it can be re-identified in other species. The homology concept as picking out an organism's natural units is a *natural kind concept*, with each homologue being a natural kind. Furthermore, an individual homologue is a unit of morphological evolution, as it can undergo change independently of the other homologues making up an organism. As homology individuates biological characters (morphological units), the homology concept is the central notion from comparative biology, including comparative anatomy and embryology, systematics, and evolutionary biology.

With the advent of Darwinian evolutionary theory, homology came to be defined in terms of common ancestry: two structures in different species are homologous if they are derived from one and the same structure in the common ancestor. However, the homology concept was introduced long before advent of evolutionary theory, namely at the beginning of the 19th century. Pre-Darwinian accounts assumed that what makes structures in different species homologous is that they are governed by the same developmental laws, or that they are instantiations of an abstract morphological-geometric blueprint, which may reside in the mind of God (Fig. 3 shows such a blueprint for the vertebrate skeleton, covering such different vertebrates as in Fig. 2). In the rest of this section, I describe how the homology concept was successfully used in pre-Darwinian biology despite a non-evolutionary understanding of homology.

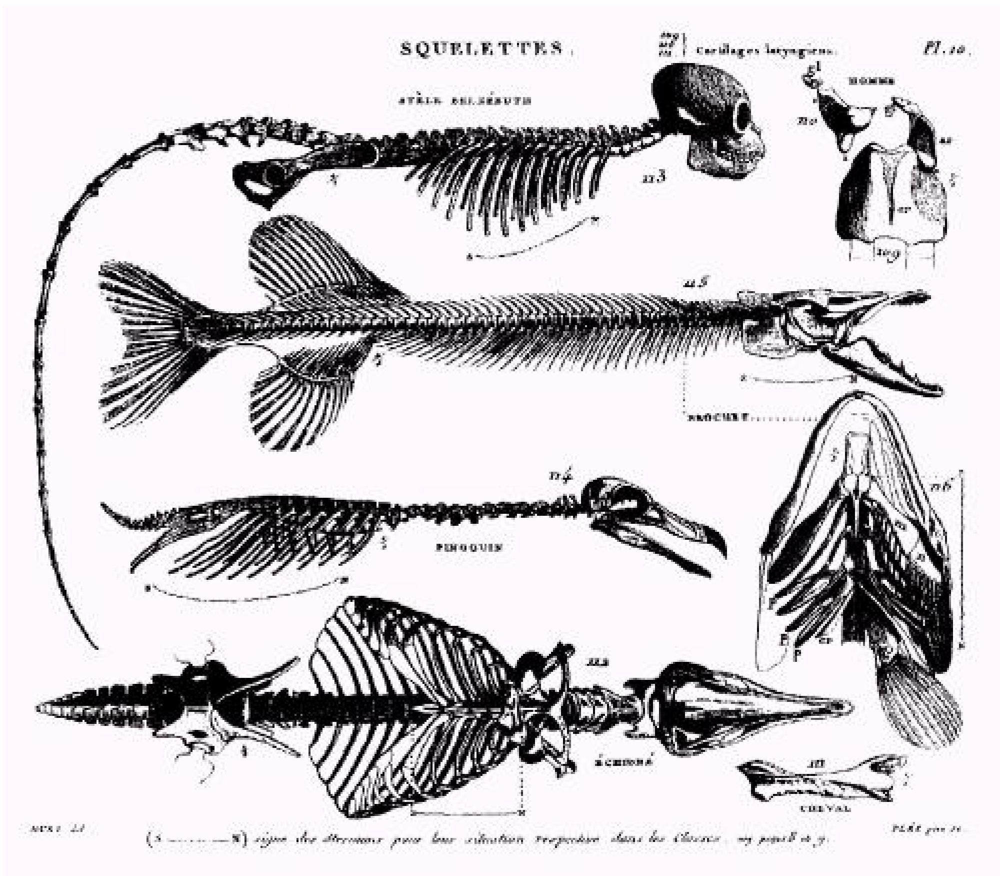

Figure 2: Table from Geoffroy Saint-Hilaire's *Philosophie anatomique* (1818)

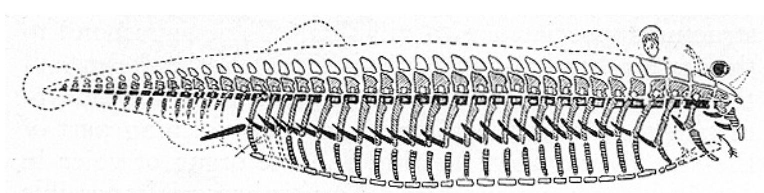

Figure 3: Richard Owen's Archetype of the Vertebrate Skeleton (from Owen 1848)

Two related changes mark the origin of the homology concept in comparative anatomy and embryology at the beginning of the 19th century: first, a change in the way in which biological structures were *individuated*; second, a shift from a more *implicit* way of structure individuation to an individuation in terms of an *explicitly* spelled out notion of homology (including explicit criteria of homology, and later a standardized terminology). Prior to the advent of the homology concept, 18th century comparative anatomists had typically given the same name to structures in different species if these structures were similar in form (shape and internal features) and function. As a result, only structures of more closely related species (different mammals, or different birds, or different fish species) had been viewed as the same structures. In the first decades of the 19th century anatomists came to realize that the individuation of morphological structures is independent of their form and function. This started with anatomists such as Etienne Geoffroy Saint-Hilaire (1807, 1818) arguing that the same structure can be found across reptiles, birds, and mammals. Even fish and other vertebrates share structures, despite a structure having a different function and form in these animal groups. A basis for this tenet was the recognition of morphological sameness across species in terms of the relative position of structures (rather than the internal form or function of structures). Figure 1 illustrates that the different bones making up a limb retain their relative position in different species despite differences in function and shape. Another example is the fact that a muscle is innervated by (and thus connected to) the same nerve across species. Later this came to be called the *positional criterion* of homology: homologous structures retain their topological relations (relative positions) across species. Closely related was the notion of shared body plans among species, i.e., the idea that species belonging to the same taxonomic group (such as different vertebrates) share the same set of morphological structure (see Figs. 2 and 3). Thus, if a certain structure is present in one species, one can expect that a homologous structure is present in other species belonging to the same type (taxonomic group).

In addition to the positional criterion of homology, the *embryological criterion* came to be an important and widely used way of recognizing homologies. According to this criterion, homologous structures in different species develop out of the same precursor structures (von Baer 1828). This idea from comparative embryology greatly enhanced the establishment of homologies, as the embryos of different species are more similar than the developed adults. Once adult structures have been traced back to their embryonic precursors, the corresponding precursors can be more easily identified in different species. These explicit ideas — the two criteria of homology and the assumption that taxonomically related species share the same structures — proved to have an enormous heuristic impact, as they triggered the search for and identification of new structures (Appel 1987). Apart from identifying structures in species that had not been previously studied (subsequently homologizing them with structures in known species), even in well-known species new structures — which had not previously been recognized as independent morphological units — were discovered. For instance, the bones of the human skull are fused together, and the fact that an overall skeletal element actually consists of two distinct structures only becomes clear from the fact that these structures are separated in other species (or are still separated in the human embryo). Thus, the homology concept was an important *tool of discovery.*

There are further reasons why the homology concept supported a successful scientific practice in pre-Darwinian biology. As homology individuates biological characters, it is the basis of effective morphological comparison of different species. Once homologous structures in different species are identified, these structures can be described and compared in detail. The improvement over the 18^{th} century practice (biological practice before the introduction of the homology concept) consists in the recognition that taxonomically relatively unrelated species can have the same morphological structures and therefore compared. Furthermore, in contrast to previous individuation practices, homology breaks an organism down into its natural units, where each such homologue is unit of morphological (phenotypic) variation across species: a homologue can vary in its internal form and function relatively independently of other homologues. One significant consequence for comparative anatomy and embryology was that the novel way of character individuation in terms of homology yields more *unified structural descriptions* of groups of organisms. For homologous structures in related species share many properties. For example, take the cerebrum, a part of the brain, which is present in all vertebrates. Neurobiological textbooks simply talk about 'the' cerebrum, actually referring to individual homologues present in species from a taxon as large and diverse as the vertebrates. Talk about 'the' cerebrum is possible as many biological descriptions apply to any concrete cerebrum. This includes morphological and histological descriptions such as the internal structure of the cerebrum and out of which smaller structures it is composed and how it is connected to other structures. And it also includes how the cerebrum develops. Thus, basing biological descriptions on structures individuated by homology permits statements that apply to large classes of organisms, thereby yielding — despite between-species differences — unified comparative knowledge.

Apart from anatomy and embryology, the homology concept also gained some relevance for taxonomy. Taxonomy (systematics) classifies species by comparing various characters, and the similarity or dissimilarity of characters is a guide as to how closely related two species are (whether they belong to the same genus or only to the same order). In the first half of the 19^{th} century, it became accepted that functional similarities between species are poor guides to taxonomic relations. Using the explicit terminological distinction introduced by Richard Owen (1843), while *homologous* structures are the same structures in different species, *analogous* structures are structures in different species that have the same function (the distinction between 'homology' and 'analogy' is still used). In this terminology, pre-Darwinian biologists came to accept (if not explicitly then at least implicitly in taxonomic practice) that classifications are not to be based on analogies between species, but on homologies. For instance, a rudimentary organ (a structure in another species that is homologous yet non-functional and thus non-analogous) is a good indicator that a close taxonomic relation between two species obtains. The increasing recognition that the characters to be compared (whose similarity in different species informs about their taxonomic relatedness) must be homologous, not analogous features promoted more *stable classifications*.

Finally, by the 1850s an enormous number of homologies had been identified and it had been demonstrated that the same structures exist in quite unrelated species (such as different vertebrates). This fact proved to be one of the main reasons why the idea of the *common ancestry* of species was accepted once evolutionary theory had been explicitly defended by Darwin (see Chap. 13 of the *Origin of Species* for how Darwin relied on the previous work in anatomy, embryology, and taxonomy based on the homology concept). In sum, even though pre-Darwinian biologists worked with a non-evolutionary understanding of homology (offering developmental, geometric, and sometimes theistic accounts of what makes structures in different species homologous), the introduction of the homology concept in pre-Darwinian biology marked the advent of a highly successful biological practice. The homology concept was a tool of discovery and it supported the establishment of unified descriptions of larger groups of organisms and effective classifications.

Problems with causal accounts: Successful scientific practice

The case of the homology concept (as already used in pre-Darwinian biology) illustrates that scientific concepts support a largely *successful scientific practice*. I view it as one constraint on a theory of concepts to account for how concept can do so. My complaint about what I called above *causal accounts of concepts* is that they do not meet this desideratum. Recall that a causal account acknowledges reference as the only semantic property of a term (in the case of semantic atomism), or at least studies scientific terms only in terms of reference (in the case of many accounts of conceptual change in the philosophy of science). Concept possession is construed as a person standing in a certain causal relation to the concept's referent, while having beliefs or certain epistemic abilities (such as recognitional capacities) is not necessary for concept possession. This holds for accounts in the philosophy of science relying on the causal theory of reference to address the incommensurability problem; and Fodor as a proponent of semantic atomism explicitly argues that beliefs and epistemic abilities are not constitutive of concept possession. Yet we saw in the previous section that what accounted for how the homology concept supported a successful practice were certain beliefs and epistemic abilities, such as the use of homology criteria and the idea that morphological description and taxonomic classifications are to be based on the comparison of homologous structures. By ignoring the epistemic abilities scientists have in virtue of possessing a concept, a causal theory of concept cannot account for how concepts support successful practice.

In this respect, I side with what I called *descriptive accounts of concepts*, which acknowledge another semantic property of terms in addition to reference (intension or meaning). A descriptive account assumes that a person counts as possessing a concept to the extent to which she has certain beliefs (about the concept's referent) or epistemic abilities (the ability to recognize the referent). Furthermore, these epistemic features are necessary for this person to count as referring to objects in the world in the first place (the traditional idea being that meaning plus the world determine reference). In contrast to traditional descriptive accounts, I do not assume that a concept's content is fully or always given by explicit definitions or theoretical accounts and that an individual must endorse such a definition (a set of analytic statements, or an explicit theory) to possess a concept. While several pre-Darwinian anatomists had theoretical accounts about the nature of homology (which turned out to be largely false), these theoretical accounts or explicit definitions were actually peripheral for how the homology concept was used in actual practice, and for the practical success based on the concept's usage. What was (and still is) more central to the homology concept's content are the criteria of homology (used to establish homologies), and how knowledge about homologies was subsequently employed in morphological and taxonomic practice.

I call those basic aspects of a term's use that account for its successful employment in research practice its *inferential role*. Thereby I use a term from inferential role semantics (conceptual role semantics), which assumes that a term obtains its content by figuring in inference. On my account, a concept's inferential role is another component of a concept in addition to the concept's reference. While inferential role semantics often construes inference as an intra-linguistic relation (a relation between linguistic expressions),[5] I construe inference more broadly as including language-world relations (mind-world relations), in particular how external states of the world lead to mental contents (as in perception) and how mental contents lead to behavior (as in intentional action). In the case of the homology concept, a central aspect of its successful use is how biologists are able to recognize homologies, and how the comparison of homologous structures in different species leads to morphological generalizations and taxonomic classifications. In sum, on my account a term's inferential role is determined by how the term figures in linguistic and world-engaged practice.[6]

Let me briefly illustrate how scientific concepts support discovery, inference, and explanation in virtue of their inferential role. Above we saw that the homology concept is relevant for *discovery*, as it enables the detection of new structures and morphological units in previously unknown but also in known species. This is due to the fact that the homology concept's inferential role includes criteria of homology (the positional and the embryological criterion)[7] and the idea that species belonging to the same taxonomic group have the same set of morphological units (so that for a given structure in one species a corresponding homologue in another species is to be expected). The homology concept also supports scientific *inference*, as it is a natural kind concept. Natural kinds are often considered to have projectable properties: if one instance of a kind has a certain property, then other instances are like to have the same property (Goodman 1955). A related idea is that natural kinds are homeostatic property clusters: if one instance of a kind has a certain property, then it is likely that it has other properties as well (Boyd 1991). Homologues are natural kinds in precisely this sense, which is the basis of the above mentioned fact that individuating biological characters in terms of homology and attaching morphological descriptions to names of characters thusly individuated yields unified descriptions (covering large groups of organisms). This is achieved by the use of the homology concept as the concept's inferential role includes the idea that characters are to be individuated in terms of homology (rather than, say, analogy), beliefs as to how to recognize homologies (what the homology criteria are), and the idea that homologues share many morphological and developmental properties across the group of species in which a particular homologue is present. Thus, the homology concept supports inductive inferences: from one instance of a homologue to another instance in a different species, and from the presence of one property to the presence of another property.[8]

While the homology concept itself does not directly support *explanations*, other scientific concepts do so.[9] The concept of natural selection, for instance, supports explanations of why adaptive evolutionary change occurred. The gene concept permits molecular biologist to explain why molecular entities such as RNAs and polypeptides are produced in individual cells. A concept's inferential role may support such explanations by specifying the causal capacities of the entities picked out by the concept, or the laws that govern the concept's referent. For this reason, my notion of inferential role (conceptual role) is construed broadly, as it does not just include inference as traditionally construed, but also covers discovery and explanation.[10]

Problems with descriptive accounts: Rational conceptual change

Now I turn to the question of conceptual change, which raises issues not only for causal, but also for descriptive accounts of concepts. Pre-Darwinian biologists pre-dominantly had a non-evolutionary understanding of homology, and offered various non-phylogenetic accounts of what makes structures in two species homologous (including geometric, morphological, and developmental accounts). With the advent of evolutionary theory, homologies between species came to be understood as being due to inheritance from a common ancestor. As a result, most post-Darwinian definitions of homology came to include reference to common ancestry. Traditional descriptive accounts of concepts construe a concept's content as being given by certain definitions or analytic statements. Therefore, due to the introduction of a novel definition of homology, a descriptive account is likely to view the term 'homology' as being used in pre- and post-Darwinian biology as corresponding to two distinct concepts.[11] Yet why should the use of a novel, post-Darwinian definition of homology amount to a distinct concept? In any case, the pre- and post-Darwinian usages are far from incommensurable. There is in fact a large continuity in the way in which the homology concept was used in actual biological practice. For as discussed above, the concept's successful use by pre-Darwinian biologists hardly depended on theoretical views about the nature of homology, but on other features such as the homology criteria employed and the way in which knowledge of homologies was used for morphological and taxonomic purposes. (These were the features that my semantic interpretation therefore included in the concept's inferential role.) Post-Darwinian biologists continued to rely on these aspects of the homology concept (due to their significance for comparative practice), but they enriched it by viewing homology from an evolutionary point of view. In my semantic terminology, the concept's inferential role did change with the advent of evolutionary theory, but only moderately in that a phylogenetic understanding of homology was added to the previous inferential role (rather then an old definition being replaced with a distinct definition).

Apart from the question of whether a particular theory is committed to postulate a pre- as opposed to a distinct post-Darwinian homology concept (and whether one may do so), a more pertinent question is how to account for the rationality of this instance of semantic change. Given that not every change in beliefs about a phenomenon leads to a novel definition, why was it in the case of the homology concept rational for biologists to adopt a phylogenetic definition? How can it be epistemically or semantically warranted to change the 'meaning' of a term, or on my approach, to change a concept's inferential role? Referential accounts of concepts fail to account for semantic change on two counts. First, philosophers of science have focussed on the reference of scientific terms (arguing for referential stability to address the incommensurability problem) and avoided to talk about meaning, meaning differences, or meaning change — without actually denying that terms have a meaning. Yet pointing to stability of reference does not explain why change in a term's meaning / definition / inferential role can be rational.[12] Second, reference as a semantic property of a term may also change in the course of scientific history, and change in reference can be rational as well, so that it has to be philosophically accounted for.[13]

But also descriptive accounts of concepts have not offered ways of accounting for the rationality of semantic change. While usually the question has not bee addressed, two-dimensional semantics is in fact a descriptive approach to concepts that explicitly denies the possibility of rational conceptual change. According to this account, either a concept (a term's intension) does not change at all, or if a term's intension changes, then this is a 'change of topic'. David Chalmers (1996) prominently maintained that consciousness cannot be physically reduced. His argument proceeds from analyzing our current (partially folk) notion of consciousness, which permits imagining zombies that are physically like us but do not have consciousness, so that consciousness cannot be equivalent to any physical property. Chalmers is aware of the fact that future scientists may put forward a naturalistic definition or concept of consciousness that prohibits the possibility of zombies. Yet he replies that in this case scientists would simply have changed the topic and started to talk about something else when using the term 'consciousness'. Two-dimensional semantics conceives of concepts as *a priori* (defending conceptual truths and *a priori* conceptual analysis), and change in a term's meaning or intention is seen as switching from one concept to another one and thereby as philosophically illegitimate.[14]

My framework of concepts accounts for the rationality of semantic change by introducing the *epistemic goal pursued with a concept's use* as a third and independent component of a concept, in addition to the concept's reference and inferential role. It is well-known that overall scientific activity is directed at meeting certain scientific and explanatory goals. It is also not controversial that certain epistemic goals are characteristic of a particular research approach or scientific field, in that this scientific field attempts to work towards one set of epistemic goals, whereas another scientific field focuses on other research aims. The point here is that *individual concepts* are used by a scientific community to pursue specific epistemic goals, in that one epistemic goal may be characteristic of one particular concept's usage, while other epistemic goals pertinent for the scientific community are pursued by using other concepts. Scientists pursue certain epistemic goals when introducing a novel term, and they attempt to achieve certain things with the continued use of a term. A scientific concept may be used to explain certain phenomena, to support certain inferences and justify certain kinds of knowledge, or to guide experimental research so as to lead to discoveries of a certain type. Neither do I assume that already at the very introduction of a novel term this term acquires a clearly articulated epistemic goal, nor is it the case that the epistemic goal is determined by the term usage of a single scientist. Rather, the epistemic goal pursued by a term's use is determined by the term's continued usage within an overall scientific community — and in the course of history the epistemic goal pursued may change.

This notion accounts for the rationality of semantic change as a concept's epistemic goal sets the standards for which of the novel acquired empirical beliefs may rationally lead to a revision of the concept's semantic properties, such as a change in the concept's definition (inferential role on my account). A concept may be used to pursue an epistemic goal such as putting forward an explanation of a particular phenomenon, even if at this point the explanation cannot be given yet (i.e., the concept's inferential role currently does not support this explanation while the epistemic goal demands it). Assuming that a concept's epistemic goal is stable, a change in the concept's inferential role is rational provided that the new inferential role permits scientists to achieve the epistemic goal to a higher degree than the old inferential role. If the concept's reference changes as a consequence of a rational change in inferential role, then this change in reference is epistemically warranted as well. Thus, a change in a concept's reference and inferential role can be accounted for as rational relative to the concept's stable epistemic goal. The novel notion of a concept's epistemic goal can be illustrated by comparing my account to descriptive accounts of concepts. Traditional accounts have construed concepts in terms of certain *beliefs about the concept's referent* (definitions, analytic statements), which may change over time. My approach acknowledges this as one aspect of a concept (inferential role), but emphasizes that another central question is what scientists *try to achieve by having those beliefs*. This last feature (which I call the epistemic goal pursued by a concept's use) accounts for the rationality of semantic change, which is my reason for viewing it as a genuine *semantic* property of a term, or in other words, as a genuine component of the concept itself.

This account applies to the 19th century history of the homology concept as follows. With the advent of evolutionary theory, a phylogenetic definition of homology came to be used (which defines two structures in different species as homologous in case they are derived from an ancestral structure). This is on my account a change in the homology concept's inferential role, which is in need of explanation. Independent of my particular semantic approach, any philosophical study of this case has to address the following question: Given that one could have accepted evolutionary theory while still using a traditional homology definition (as Darwin did in the *Origin*), why was it rational for biologists to adopt a revised definition of homology? My account appeals to the concept's stable epistemic goal. The previous discussion of the concept's use in pre-Darwinian biology has actually mentioned for which epistemic purposes the concept was used. The homology concept was used to pursue two basic epistemic goals: 1) the morphological comparison of the structures of different species (so as to arrive at anatomical generalizations covering larger groups of organisms), and 2) the classification of species into taxa. The important historical feature is that while the advent of evolutionary theory led to a revised homology definition (apart from other theoretical changes in biology), it did not change what comparative biologists were attempting to achieve when using the homology concept. Biologists continued using the homology concept for the epistemic goal of morphological comparison and taxonomic classification (biological taxa simply came to be understood as genealogical groups, and morphological relations between species as being due to common descent).

Post-Darwinian biologists came to accept the phylogenetic definition of homology as they realized that it improved their previous practice and permitted them to pursue the traditional morphological and taxonomic goals in a more effective way. A case in point is Carl Gegenbaur, the most eminent anatomist in the second half of the 19^{th} century and one of the founders of what was called evolutionary morphology. Gegenbaur actually started out with a largely non-phylogenetic understanding of morphology (Gegenbaur 1859), but then came to adopt and promote a consistently phylogenetic approach to morphology (Gegenbaur 1870).

The historian of biology William Coleman (1976) documented how easily Gegenbaur moved from a non-phylogenetic to a phylogenetic approach in his actual practice. The reason is that Gegenbaur and others realized that the phylogenetic interpretation of homology and of taxonomic and morphological relations provided a more sophisticated way to assess homologies, to interpret morphological findings and scrutinize morphological hypotheses (e.g. about the nature and origin of the vertebrate limb), and to establish and revise classifications in the light of genealogy. Post-Darwinian biologists did not just assent to a phylogenetic definition of homology, but the homology concept's inferential role changed in that biologists came to actively rely on a phylogenetic approach to comparative biology, thereby making *active use* of the novel phylogenetic definition. This change in conceptually guided practice occurred because the phylogenetic approach permitted biologists to meet the traditional morphological and taxonomic goals in a more effective way, so that the change in the concept's inferential role can be accounted for as rational relative to its epistemic goal.[15]

Change in the epistemic goal pursued by a term's use

So far I have focussed on how to account for the rationality of change in a concept's reference and inferential role, assuming that the concept's epistemic goal is historically stable. Yet the epistemic goal pursued by a scientific term's use may be subject to change as well. It is well-known that scientific disciplines come to set new items on their research agenda, and also may shift their focus away from epistemic goals that used to be explicitly addressed in the past. The same may happen with the set of epistemic goals tied to a particular concept. Adding a new explanatory task to a concept's epistemic goals is rational if there is some evidence that actual progress can be made on this novel task. Deemphasizing or abandoning a previous epistemic goal is epistemically warranted if this scientific question has been sufficiently solved or if solving it is not manageable or pertinent any longer. In this way, the epistemic goal pursued by a scientific term's use may rationally shift from one issue that used to be primarily addressed to a different issue that is the focus of the current research agenda in which the concept figures. Such a shift from an old to a new epistemic goal being pursued with a particular term's use may constitute a novel concept becoming associated with this term, where this new concept grew out of the old concept that used to be expressed by the term. My assumption is that typical cases from science show that in the case of a term's epistemic goal changing, a change in the term's inferential role (definition) and reference can be accounted for as rational after all, provided that these semantic changes, in particular the change in epistemic goal, proceeded in a continuous and gradual fashion (including that the requirement that the epistemic goals pursued at different times are different, but empirically compatible). For instance, novel empirical findings may among other things lead to a change in a concept's inferential role, a semantic change that is rational if it is in accordance with the concept's previous epistemic goal; yet at the same time this new empirical situation may also bring about a gradual modification of the very epistemic goal pursued by the concept's use.[16]

This paper is not the place to discuss this issue in detail. Still, I want to sketch one example: the development of the homology concept in the 20^{th} century. Above I maintained that throughout the 19^{th} century the term 'homology' was used for the same basic epistemic goals — which is a basis for my assumption that evolutionary theory did not introduce a novel homology concept in the 19^{th} century. Yet I do assume that novel homology concepts emerged in the 20^{th} century, which are used for different epistemic goals, and are used in different biological subdisciplines (Brigandt 2003). In a nutshell, what I call the *phylogenetic homology concept* is used in contemporary evolutionary biology and systematics. This concept is used for the purposes of establishing phylogenetic scenarios and for the classification of species strictly according to their genealogy. Due to being tied to a strongly phylogenetic approach, a definition of homology in terms of common ancestry is characteristic for this homology concept.

The *developmental homology concept* is used in evolutionary developmental biology (evo-devo). While evo-devo biologists view homology as a phylogenetic phenomenon, they primarily pursue questions about the development and morphological organization of organisms with the use of their homology concept (which bears on the developmental basis of morphological evolution). The epistemic goal pursued is to understand why the same structures (homologues) reliably develop over many generations, which makes it necessary to address developmental processes taking place within individuals (while phylogenetic approaches are interested in relations between different species). The phylogenetic and the developmental homology concept differ in reference, in that the latter has a larger extension. Developmental approaches acknowledge what is called serial homology, i.e., the repeated occurrence of the same structure in an individual. For instance, the different vertebrae of one vertebrate are serially homologous. Developmental accounts view these as *bona fide* homologues as serial homologues are assumed to be governed by the same developmental features as homologies between different individuals (the developmental homology concept being about the processes generating morphological order between and also within individuals). Phylogenetic approaches, in contrast, reject the very idea of serial homology, as comparing structures within an organism (rather than structures of different species) is of no concern for them. Many developmental accounts of homology view common ancestry as a sufficient, but not as necessary condition for homology. In sum, while the phylogenetic homology concept is a tool of inference (establishing phylogenetic trees and scenarios), the developmental homology concept is a tool of causal-mechanistic explanation.

Finally, most branches of molecular biology (those that do not deal with phylogenetic issues) use what I call the *molecular homology concept*. It is an operational concept in that it uses similarity of gene and protein sequences — which other approaches regard as a mere criterion of homology — as the definition of molecular homology. The molecular homology concept does not support phylogenetic inferences, and it is rather used as an effective tool for discovery in molecular biology, the idea being that if two molecular systems are sufficiently similar ('homologous'), experimental strategies that proved to be successful in one case are likely to be promising for investigating a new case.

These three contemporary homology concepts emerged when the original (19^{th} century) homology concept became in the second half of the 20^{th} century integrated into newly developed, specialized subdisciplines. Each of these disciplines came to use the homology concept for its particular purposes — epistemic goals that are more specific than the epistemic goal of the original concept. This led to conceptual diversification and ultimately to the emergence of three distinct homology concepts, which differ in their epistemic goal, inferential role, and also reference. This semantic change, including the change in inferential role (meaning, 'definition'), occurred in a rational fashion, as each of these concepts is an effective conceptual tool given the scientific demands of the field in which it is used (the variation in inferential role across biology as a whole is conducive to biological practice as the inferential role of each particular homology concept permits the biological subcommunity using it to largely meet the particular epistemic goal). Even though there are three different contemporary homology concepts, these are no incommensurable concepts. For the three contemporary homology concepts overlap in their epistemic goals (they are used for a generic epistemic goal in spite of different disciplines focusing on a more specific goal). There is also an overlap in inferential role (e.g. the same criteria of homology are used, homologies in different species are viewed as being due to common ancestry), so that communication across biological subdisciplines is possible in many (though not all) contexts.[17]

Summary

In this paper, I worked towards a framework of scientific concepts that is intended to account for a) how a concept makes successful scientific practice possible, and b) how a scientific concept can be subject to rational change in the course of history. To this end, I suggested that each scientific concept consists of three components of content: 1) the concept's reference, 2) its inferential role, and 3) the epistemic goal pursued with the concept's use. Different such components of a concept (or several semantic properties of a scientific term) are to be acknowledged as they fulfill different philosophical functions: The notions of reference and in particular inferential role are necessary to account for how a concept underwrites successful practice, while the notion of a concept's epistemic goal accounts for the rationality of conceptual change.

Due to the inclusion of inferential role as a component of a concept, concept possession involves a person having certain epistemic abilities that are characteristic of possessing that concept. This may include the ability to recognize objects, conduct scientific investigation, carry out inferences, give explanations, and communicate with other scientists. The discussion of my case study illustrated how the homology concept in virtue of its inferential role supports discovery in comparative biology, the establishment of unified descriptions of animal groups in comparative anatomy and embryology, and the establishment of classifications in taxonomy.

Because of my assumption that a scientific term obtains its reference, inferential role, and epistemic goal due to the term's use by an overall scientific community, historical change in one of a term's semantic properties is sometimes correlated with change in another semantic property. Yet in other cases a concept may change in one component of content without change in other components, so that the three components are independent dimensions of semantic change. The epistemic goal pursued by a concept's use sets the standards for which changes in a concept's inferential role or reference count as rational. A change in a concept's inferential role is epistemically warranted if the revised inferential role (the new 'concept') meets the epistemic goal to a higher degree than the previous inferential role (the old 'concept'). If a term's reference changes as a result of a rational change in inferential role, this change in reference is rational as well. While a concept's stable epistemic goal accounts for rational change in reference and inferential role, the epistemic goal pursued with a term's use may change as well (which can be used as the basis for postulating a different concept being associated with the term). Change in epistemic goal can be epistemically warranted as well — at least in typical scientific cases. My study briefly mentioned how the original, 19$^{\text{th}}$ century homology concept gave rise to three contemporary homology concepts that differ in the epistemic goal pursued by their use. These contemporary homology concepts originated when the traditional concept became integrated into newly developed specialized subfields of biology, which came to use the concept for their specific epistemic purposes, leading to conceptual diversification. In each of the three cases, the change in epistemic goal pursued with the term 'homology' occurred in a rational fashion, as a generic epistemic goal was replaced with a more specific epistemic goal (or was replaced with a novel epistemic goal that had not been addressed before in the case of the molecular homology concept).

Notes

[1]Putnam 1975; Martin 1971; Fine 1975; Devitt 1979; Leplin 1979; Levin 1979; Newton-Smith 1981; Kitcher 1978; Hacking 1983; Burian 1985; Sankey 1994; Psillos 1999; Boyd 2002.

[2]More precisely, philosophers of science have not actually argued that reference is the only semantic property a scientific term can have, and that there is no such thing as 'meaning' (as a genuine causal account of concepts would have it). Rather, philosophers of science have focussed on reference and *avoided to talk* about meaning. They are thereby committed to the fact that a term's meaning may vary across scientists or historical episodes. Yet avoiding addressing meaning and the extent of differences in meaning does not solve the fundamental epistemic challenges stemming from the incommensurability problem: how scientists endorsing different theories can successfully communicate with each other and rationally choose between different theories. In fact, despite the popular focus on reference, the notion of reference alone cannot solve these epistemic issues.

[3]The approach is called atomism because it is metaphysically possible that a person possesses one concept without possessing any other concept (which is denied by rival approaches that assume that possessing any concept involves having beliefs and thus some other concepts).

[4]Conceptual role semantics is a broad framework that encompasses various different theories, see e.g., Block 1986; Brandom 1994; Field 1977; Harman 1973; Horwich 1994; McGinn 1982; Peacocke 1992; Sellars 1974.

[5]In the philosophy of mind this idea is popular under the label of 'narrow content'. Many versions of conceptual role semantics define the conceptual role of a mental symbol as the set of causal or functional connections it has with other mental symbols, so that content is purely inside the head.

[6]Furthermore, in contrast to some traditional accounts I do not assume that every person possessing a concept has grasped the same definition (makes use of the same inferential role). The division of scientific labor implies that different scientists have different abilities, and the epistemic abilities accounting for a concept's successful communal use may be spread out over a whole research community. For instance, some biologists may engage in the comparative anatomy of adult organisms (using the positional criterion of homology), other researchers are specialized in comparative embryology (using the embryological criterion to establish homologies). Thus, I assume that it is a term's communal use — possibly reflecting between-person variation in usage — that constitutes the term's inferential role (the latter thereby accounting for the successful communal use of a concept).

[7]More precisely, possession of the homology concept includes the ability to recognize and establish homologies (implicit knowledge or an ability that a biologist may have without necessarily being able to explicitly defend each posited instance of homology in all its detail), where this implicit usage is individually guided as well as communicated and intersubjectively defended by the available homology criteria.

[8]An explanation of *why* the inference from a structure in one species to its homologue in another species is sound makes it necessary to recognize that homologues are derived from a common ancestor. Yet even pre-Darwinian biologists knew *that* the inference is a good one as a matter of fact.

While the idea that natural *kinds* have projectable properties and are homeostatic property clusters is widespread in the philosophy of science, natural kind *concepts* have often been discussed in terms of their reference only (using the causal theory of reference). My point here is that in addition to the ability to refer to a kind, scientists possessing a natural kind concept also have the epistemically significant ability to make inferences.

[9]The homology concept, as used in pre-Darwinian biology, permits the establishment of phylogenetic trees and theories as to how individual characters (homologues) have changed in the course of evolution. Yet an explanation of why a homologue underwent change in its form and function is given using other concepts (such as the notions of phenotypic variation and natural selection).

[10]Against my approach the semantic atomist Fodor would object that accounting for how concepts figure in successful practice is an *epistemological*, but not a *semantic* issue, so that accounting for successful practice is not a constraint on a theory of *concepts* at all (and therefore my reason for viewing inferential role as a component of a concept's content is irrelevant). I reject a contrast of epistemological vs. semantic issues, if the implication is that epistemic issues can be philosophically ignored (as Fodor does). In my view, semantics is fundamentally about understanding successful term use, an issue with epistemological relevance that includes the possibility of communication between scientists, and the rationality of conceptual change. Semantic atomists acknowledge that concept possession in humans or in this possible world is *causally correlated* with having epistemic and cognitive abilities, but maintain that epistemic abilities are not *metaphysically constitutive* of concept possession (Margolis 1998; Laurence and Margolis 2002). The idea is there are possible worlds with beings that possess a concept in virtue of standing in a causal relation with the referent, yet these beings do not have any epistemic abilities. My reply is that I do not view and defend my account as the right *metaphysical* account of the nature of concepts. Rather, it is intended as a *heuristic tool* for the study of scientific

concept use and its historical change. Thus, my framework of concepts is to be evaluated in terms of what insights it yields about the use of concrete scientific concepts, i.e., the account's fruitfulness for addressing *this* task (whatever else Fodor may try to achieve by developing a theory of 'concepts').

[11]This applies in particular to some versions of inferential role semantics, which assume that a term's meaning is the total set of inferences (or the total theory) in which the term figures. As a result, changes in the beliefs about a term's referent always lead to a change in meaning. Such a semantic approach is one of the reasons for Kuhn's contention that a change in a basic scientific theory leads to incommensurable concepts.

[12]Likewise, the semantic atomist Fodor (2000) denies that concepts change, as on his theory there is nothing more to a concept than reference (the latter being stable). Yet this way of maintaining that there is no need to account for 'conceptual' change as 'concepts' do not change is merely a terminological maneuver, and fails to address the important philosophical challenge as to how to account for the rational change in a concept's use or definition.

[13]One example of rational change in a term's reference is 'gene' as used by classical (Mendelian) and molecular geneticists. There are examples of classical genes that are not molecular genes and vice versa, so that there is a historical change in reference (Weber 2005). Yet the molecular gene concept grew rationally out of the classical gene concept.

[14]2-D semantics construes a term's A-intension (a concept) as a function from possible worlds to the term's extension in that world. Thereby the approach can *prima facie* maintain that concepts (the intensions of term's) do not change while still being able to account for change in the usage of terms or definitions put forward. The idea is that Linnaeus and present taxonomists have grasped the same species concept in that they share the very same *function* from possible worlds to extensions. Linnaeus assumed that he lives in a possible world where species are fixed and therefore offered a non-evolutionary definition of species (though he would have offered a modern definition once he had learned that the actual world is an evolutionary one). Contemporary biologists, in contrast, have different beliefs about which possible world is the actual one and therefore offer an evolutionary definition of species (though they would have used Linnaeus' usage had they had his empirical beliefs). However, my contention is that this theory of concepts does not fit with how actual scientific concepts are used, how they change, and why they change. But such an argument against the *a priori* vision of concepts put forward by 2-D semantics would have to rely on detailed empirical facts about the behavior of scientific concepts that are beyond the scope of the present discussion.

[15]If different scientists or different scientific approaches use a given term to pursue the same epistemic goal, then they are likely to react similarly to novel evidence (by revising the term's inferential role). Thus using a term for a similar epistemic goal ensures successful communication across different scientists, so that the term as used by different persons does not correspond to incommensurable concepts. For this reason, I view a concept's epistemic goal as a particularly significant component of content for the purposes of concept individuation. As a result, I typically consider a term as used by past and present scientists as expressing the same or two distinct concepts depending on whether past and present scientists used it for the same or distinct epistemic purposes. As a result, I assume that a single homology concept was used throughout the 19^{th} century due to stability of the concept's epistemic goal. Thereby the change in inferential role that occurred with the advent of evolutionary theory is a semantic change occurring internal to the homology concept (that does not lead to the origin of a distinct concept). Despite viewing a concept's epistemic goal as particularly salient for concept individuation, I acknowledge that a difference in reference or a difference in inferential role can be philosophically important and therefore the basis for concept individuation. Ultimately, on my account a concept can change in any of its three components; and different philosophical purposes pursued with different studies may lead to regarding different components (or different combinations of semantic components) as salient for concept individuation. In my view, the central task is not so much to decide whether or not historical change led to the advent of a novel concept, but to account

for semantic change — be it change in reference, inferential role, and/or epistemic goal.

[16]Such an example of a term's epistemic goal changing is the term 'gene' from classical (Mendelian) to molecular genetics. The classical and the molecular gene concept differ in inferential role, reference, and epistemic goal, yet the latter rationally grew out of the former. The epistemic goal pursued by the use of the classical gene concept is the explanation of patterns of inheritance. The molecular gene concept, in contrast, is used to account for how genes produce their molecular products (which unlike inheritance between generations is a process taking place in a single individual, even within a single cell). My account of the shift in the epistemic goal pursued by the use of the term 'gene' — marking the transition from the classical to the molecular gene concept — is in a nutshell as follows. In addition to the idea that genes are units of mutation and recombination, one aspect of the classical gene concept was the idea that genes are units of physiological/phenotypic function (otherwise genes could not bring about phenotypic patterns of inheritance). In the 1940s and 50s new discoveries about the molecular function and molecular structure of genes were made. As these findings were relevant for *one aspect* of the *classical* gene concept's epistemic goal — the physiological function of genes — these novel ideas rationally led to a change in the inferential role of the term 'gene'. Ultimately, this rational semantic change led even to a change in the term's reference and epistemic goal (the establishment of the molecular gene concept which focuses solely on the molecular function of genes, and epistemic goal that is a transformed version of what used to be only one aspect of the classical concept).

[17]As in the case of the 19th century history of homology, the primary philosophical question is not whether one should count the term homology (as currently used) as expressing distinct concepts. The primary task is to explain why the change in the semantic properties of the term 'homology' (reference, inferential role, epistemic goal) was rational, i.e., to philosophically account for the development of the current conceptual diversification (no matter whether one views this as change occurring internal to a single homology concept or rather as the advent of different homology concepts).

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