

Niches and Niche Construction in Biology and Scientific Practice

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Abstract

Concepts of an organism's biological environment and of niche construction as how organisms alter their environment and that of other organisms now play prominent roles in multiple sub-fields of biology, including ecology, evolution, and development. Some philosophers now use these concepts to understand the dynamics of scientific research. Others note divergences among the concepts of niche and niche construction employed in these biological fields, with implications for their possible conceptual integration. My (Rouse 2015) account of scientific research as niche constructive and of laws and lawful invariance in scientific practice illuminates these conceptual differences and their implications for integrating those domains of biological research in two ways. First, it accounts for the partial autonomy of these domains and their concepts as characteristic of scientific conceptual development. Second, it provides a more complex understanding of how research domains can be integrated, which shows how those different conceptions of niches and niche construction do not block their appropriate integration. The conclusion situates my account and its application to niche concepts both amid other philosophical uses of niche concepts to understand research environments and as exemplifying Rouse's revisionist conception of philosophical naturalism.

Keywords: niche; niche construction; scientific practice; ecology; evolution; developmental biology; scientific unification; naturalism

1. Introduction

Some philosophers analyzing scientific understanding in practice have appealed to

biological accounts of organisms' niches and their niche constructive activities as models for understanding the dynamics of scientific research (MacLeod and Nersessian 2008, Griffiths and Stotz 2008, Rouse 2015, Linquist 2019, Trappes and Leonelli forthcoming). Despite each appealing to biological concepts, these analyses differ in their accounts of how research practices are understood as niche-responsive and/or niche constructive. Moreover, philosophers of biology have recently raised concerns about divergent conceptions of organismic niches and niche construction in various sub-fields, suggesting that these concepts may lack clear, univocal sense.

I draw on my (Rouse 2015) account of scientific research as niche constructive to understand these divergent conceptions of an organismic niche and to show why their differences are not debilitating. This analysis in turn highlights how my approach differs from other ways of modeling scientific research practices in biological terms. Finally, I briefly differentiate my account of scientific niche construction from other biologically based accounts of research environments, and indicate how my diffractive reading of biological and philosophical conceptualizations through one another exemplifies a revisionist approach to philosophical naturalism.¹

This analysis proceeds in four parts. The first part explores philosophical concerns about

¹ Scholars in science studies more commonly speak of the “reflexive” implications of their analyses of scientific understanding for their own practices and concepts. Karen Barad (2007, ch. 2) argues that diffraction, which emphasizes the material interaction of light and matter, is more appropriate than the geometry of reflection as a conceptual model for these relations. Discussion below indicates why Rouse appropriates Barad’s appeal to diffraction patterns rather than accepting more familiar appeals to reflective mirroring.

different conceptions of niches and niche construction in biology. I then introduce relevant aspects of my account of scientific research as niche constructive, focusing primarily on how I developed and modified an account of laws and lawful invariance that originated with Marc Lange (2000, 2007) and John Haugeland (1998, 2013). The third section shows how this account of research as niche constructive both illuminates and vindicates the different accounts and uses of niche concepts in the life sciences. A final, concluding section indicates the broader significance of my analysis as a revisionist conception of philosophical naturalism.

2. Divergent Conceptions of Niches and Niche Construction in the Life Sciences

Concepts of an organism's biological environment or niche and of niche construction as how organisms alter that environment and those of other organisms now play prominent roles in multiple sub-fields of biology, including ecology, evolution, and development. The concept of an organismic niche originated in ecology, where it has a complex history (Pocheville 2015; Justus 2019; Griesemer 1992). More recently, recognition of the environmental mediation of many developmental processes and of the many ways in which the life processes and behavior of organisms affect their own environments and those of their descendants have raised hopes for greater conceptual integration among these biological sub-fields. This aspiration has animated the emergence of new, integrative research programs in evolutionary developmental biology or developmental evolution (Carroll et al. 2004, Wagner 2000, 2001), ecological developmental biology (Sultan 2007, Gilbert 2016), and developmental systems theory (Oyama, Griffiths, and Gray 2001), and of intense debates over the possible need for an extended evolutionary synthesis to accomplish such integration (Laland et al. 2014; Wray et al. 2014). Niche construction theory (NCT) (Odling-Smee, Laland, and Feldman 2003) has played a prominent role in each of these

integrative proposals. In the face of these aspirations and programs, however, some philosophers have called attention to divergences among the concepts of niche and niche construction employed in these sub-disciplines and integrative projects (Pontarotti, Dussault, and Merlin 2022; Trappes 2021; Stotz 2017; Linquist 2019). Their critical examinations of these biological conceptions of an organismic niche or of niche constructive activities have mostly focused on the extension of the concepts, the extent to which those extensions overlap, and their implications for the possible conceptual integration of these research fields.

Rose Trappes (2021) recently identified multiple differences between ecological and evolutionary niche concepts. Niche conceptions in ecology are both historically varied and currently contested (Justus 2019, Hubbell 2001). Against that background, Trappes proposes a , conjoined conception of ecological niches with four distinct features. Ecological niches 1) are the environmental conditions that permit the continued existence of the relevant biological unit, including both its requisite and merely tolerable conditions; 2) incorporate both biotic and abiotic conditions; 3) are specifiable at multiple levels, respectively for individual organisms, populations, or species; and 4) can be differentiated between fundamental and realized niches (Hutchinson 1957) at each of these levels. Fundamental ecological niches encompass the full set of conditions, actual or possible, within which the relevant biological unit could persist, whereas realized niches are the subset of those conditions that the organism, population, or species actually inhabits.

Selective niches are initially defined within niche construction theory (NCT) in evolution at one remove from the ecological conception. Odling-Smee, Laland, and Feldman (2003) specify the selective niche of a population as the selection pressures that those environmental

features exert on a population, or as Stotz put it, “the selective niche is defined by the environmental parameters which have a causal influence on the differential survival and reproduction rate of organisms” (2017, 2). So specified, the evolutionary and ecological niche concepts differ significantly in their extensions, since not all factors ecologically relevant to an organism’s or population’s persistence exert selection pressures on that population. In the other direction, environmental conditions that undercut the viability of a population evidently belong to its selective niche but not to its ecological niche when the latter is understood as the conjoined factors that enable the persistence of that population. Trappes notes that these selective and ecological niche concepts also vary modally— selective niches incorporate actual environmental effects and tolerances, whereas fundamental ecological niches extend to include the possible ecological variations still conducive to that population’s continued existence. They differ further in their levels of application: selective niches only apply to populations, whereas ecological niches can also be defined for individual organisms or as what is typical for a species. The concepts also differ in their temporality. Among ecological niche concepts, the notion of a realized niche is closest to the selective niche in evolution, but the former is indexed to a particular time and only hypothetically extended to the persistence of that niche and its occupants over time, whereas selection pressures are defined in relation to possible effects over time and only applied to particular times as derivatives of the function specifying the changes those pressures would normally bring about.

Niche construction theory introduces a further difference between ecological and selective niches. Ecological niches are only defined for a single species, population, or individual. Other species whose lifeways or behaviors affect that unit are conjoined with abiotic

components to comprise its ecological niche, with the implicit assumption that the persistence of the analyzed unit is a straightforward consequence of the presence of those conjoined components. Although NCT models the evolutionary significance of niche construction for specific populations, it conceives niche construction as an inherently multi-species phenomenon. Selective niche construction is not limited to the effects of organisms' processes and behavior on their own environment, but include their transformative effects on the environments of other populations. The evolved similarity of organisms comprising a population or species typically contributes to cumulative niche-transformative effects. Laland, Odling-Smee, and Gilbert remind us that, "collectively, developing niche-constructing organisms in a population act as unidirectional 'biological pumps' in their environments, provided that they constantly do the same things, to the same environmental components, generation after generation" (2008, 557). Taken by themselves, such cumulative processes would normally have negative evolutionary effects on the population's own limiting resources. Niche construction instead typically involves reciprocally transformative effects produced by multiple populations that can compensate for one another's cumulative environmental impact. Recognizing the evolutionary significance of organisms' niche constructive effects changes the linear differential equations that traditionally modeled evolutionary relations between organisms and environments into pairs of coupled, non-linear differential equations: $dO/dt = f(O,E)$ and $dE/dt = g(O,E)$ (Odling-Smee, Laland and Feldman 2003, 18). NCT implicitly recognizes that the niche of any single population is thereby coupled with those of other populations in reciprocally dependent ways that cannot be factored into discrete selective niches for each population.

Karola Stotz (2017) in turn distinguished developmental from selective niches, where a

developmental niche is defined by the parameters that affect the developmental reconstruction of an organism's evolved life cycle. Despite often considerable overlap, these two niche concepts also differ in their extension. One aspect of that difference is that developmental niches extend beyond the external environment that exerts selection pressures on populations to incorporate an organism's internal epigenetic and cognitive environment that mediates its ongoing development. A more subtle extensional difference is that selective niches incorporate the environmental factors that have causal effects on the organism's survival and reproduction. In many cases, however, those selective factors are not directly part of the organism's developmental niche. The relevant developmental cues are instead provided by indirect markers or indicators of the presence or absence of those selective factors. The developmental niche includes those features to which the developing organism is directly responsive, whereas the selective niche includes the causal influences on a population's survival and reproduction that those proximate developmental cues merely indicate.

Tim Ingold (2022) highlights another key difference between selective and developmental niches, which responds to the role that NCT ascribes to selective niches as a complementary inheritance system alongside genetic inheritance. NCT models selective niches and the effects of niche construction with reference to discrete successive generations. Evolutionary niche construction is thereby conceived as how earlier generations modify the selective environments inherited by their successors. Development and developmental niche construction, however, are not so readily parsed into intra-generational activities that produce an inter-generational inheritance. The extensive interactive overlap among generations in enabling development highlights the fact that developmental niche construction is not a product of one

generation making an environment for another, but a joint construction of overlapping generations. Ingold thus argues for understanding developmental niche construction in terms of co-generational perdurance rather than inter-generational inheritance:

It is not as though each generation, having built a niche for itself, or modified one in which it has set up its abode, hands on to its successor a construction that is already complete. Rather, in production, generations labor *together* in fashioning an environment that is never complete, always work-in-progress. And what perdures is the fashioning, not the finished form. (2022, S36)

Developing organisms and their developmental environments that include earlier generations of conspecifics are interactively intertwined in shaping the process of organismic development.²

For Stotz, however, the primary difference between developmental and selective niches is the different evolutionary roles they play, and consequently the different epistemic roles these concepts play in response to different scientific questions. Developmental niches facilitate the reliable developmental reproduction of species-typical traits, but they also enable the variation on which selection occurs. Hence, an important issue for understanding the interactive relations between individual organisms and their developmental niche is the balance achieved between developmental stability and the phenotypic plasticity that produces and maintains variation. Stotz concludes that “DNC [developmental niche construction] is concerned with the origin of

² Ingold argues against modeling *any* aspects of evolution in terms of inheritance because of the co-constructive activities of multiple generations. In section 4, I indicate why NCT might still need to talk about ecological inheritance for the purpose of understanding evolution even if Ingold is right to criticize models that treat generations as discrete and successive.

potentially adaptive, heritable, phenotypic variation ... that can account for the creation of [potential] adaptations without invoking selection” (2017, 3).³ Selection can only operate on traits that are constructed by organisms’ interactions with a developmental niche. She thereby argues that the importance of recognizing the difference between developmental and selective niche construction is to integrate the various extragenetic contributions to organismic development and their role in the regulated expression of genes that enables the reliable but flexible reproduction of organismic life cycles. Selection can gradually change the distribution of life cycles within a population only if developmental niche construction enables an appropriate balance between reliable reproduction and heritable variation.

3. Laws and Modalities in Scientific Research as Niche Constructive

My (Rouse 2015, Part Two) account of scientific research as niche constructive is one of two components of a revisionist conception of philosophical naturalism. The first component, comprising Part One of the book, draws on recent work in evolutionary biology and niche construction theory (NCT) to provide a naturalistic account of human conceptual capacities and their discursive deployment in an evolved, practice-differentiated way of life. The second part, my primary focus here, analyzes scientific research as itself a form of biological niche construction. The significance of bringing these two components together is that the second

³ I insert ‘potential’ to respond to a referee’s concern that adaptation is not a coherent concept without reference to selection. The insertion clarifies a contextual implication in Stotz’s paper that the issue is how potentially adaptive variation arises through developmental processes, including developmental niche construction, and not solely and determinately through genetic mutation.

part's analysis of scientific research both *exemplifies* the analysis of conceptual understanding in the first part, and also *incorporates* the evolutionary biological basis of the first part as itself a form of scientific niche constructive development and evolution. In the concluding section, I will briefly indicate why such a diffractive reading of scientific and philosophical analyses through one another is obligatory for an adequate philosophical naturalism.

My analysis in the second part of the book has three primary elements. The first element (Rouse 2015, ch. 6) is to show that the relevant conception of scientific understanding for a naturalistic account exceeds and revises what is codified in established scientific knowledge. Scientific understanding is instead embedded in the ongoing practice of research. In Sellarsian terms, a scientific conception of the world (“the Scientific Image”) is not a unified position *in* the space of reasons, but an ongoing reconfiguration *of* that space as oriented toward further research. Scientific understanding in practice encompasses a collective but partially contested grasp of what could be intelligible and significant projects, defensible positions, reasons for or against those positions and projects, and possibilities for extending or revising them. The sciences offer not a single synchronic “image” of the world, but a temporally extended field of research opportunities, intelligible disagreements, outstanding problems, and the conceptual and practical capabilities that guide them.

The second element of my account (Rouse 2015, ch. 7) emphasizes that scientific understanding incorporates experimental systems, field practices, observational setups, or clinical interactions with patients as integral to its discursive articulation in words, mathematical structures, images, or diagrams. Scientific understanding arises from conjoined material-discursive practices that articulate aspects of the world conceptually and thereby bring them into

the space of reasons. The third element, however, is most crucial for understanding the differences among biological conceptions of organisms' niches and their niche constructive activities. This third element (Rouse 2015, ch. 8-10) indicates how scientific concepts belong to distinct research domains, how those domains are related to one another, and how their concepts and practices thereby acquire scientific significance. In the remainder of this section, I introduce this third element of my analysis.

My account of how the conceptual articulation of scientific research domains is a form of niche construction starts from an extension and modification of revisionist accounts of laws or lawfulness initially developed by Marc Lange (2002, 2007) and John Haugeland (1998, 2013). This conjoined conception (hereafter referred to as LHR) emphasizes the domain-specificity of lawful invariance and of the concepts involved in those patterns of invariance.⁴ Biological domains provide an especially striking example for the LHR conception of laws and lawfulness. The contingency, complexity, and variability of most biological phenomena have seemed to block any role for laws or necessity in the life sciences (Beatty 1995; Brandon 1997; Mitchell 2003; Lange 2007). Philosophy of biology has consequently played a prominent role in criticisms of the centrality or importance of laws for scientific understanding. The LHR approach attributes that line of criticism to an infelicitous strategy for understanding lawful invariance. Most accounts of scientific laws or laws of nature start from some presumed exemplary cases in

⁴ Lange and Haugeland were not aware of one another's work and made no references to one another. My discussion of their work (2015, ch. 8) shows both their common ground and how each develops points that usefully complement and strengthen the other's account. My treatment in turn adds further aspects to a conjoined account that builds on their important work.

the physical sciences, e.g., Newton's Laws, Maxwell's Laws, the laws of thermodynamics, or the Boyle-Charles and van der Waals Laws. They develop accounts of what laws are based on these or other comparable examples, and then ask which sciences discern or appeal to laws so conceived (Hempel 1965; Lewis 1973; Dretske 1977; Armstrong 1982, Swoyer 1982). The LHR approach proceeds in the opposite direction, starting from the roles that lawful invariance and counterfactual or subjunctive reasoning play in scientific research before asking how those roles are undertaken in various disciplines or research domains.

Consideration of the roles of lawful invariance in scientific understanding starts with Nelson Goodman's (1954) new riddle of induction, which showed that scientific hypotheses are only empirically testable if their concepts are projectible. Phenomena falling under a concept must have sufficient commonality or invariance for one instance of that concept to have evidential bearing on others. Well-known difficulties in distinguishing lawlike invariance from merely accidental correlations might suggest a skeptical concern that one cannot even assess evidence for or against a hypothesis unless one already knows that the concepts involved have sufficient projectibility to be testable. Lange, Haugeland, and I argue that this concern is circumvented by the role of lawful invariance in scientific research. Empiricists were long suspicious of empirically grounded modal concepts because the subjunctive or counterfactual application of a concept outruns any presently available evidence. From the prospective orientation of scientific research, however, one needn't already *know* whether concepts are projectible in order to develop and assess empirical claims using those concepts. Research instead implicitly invokes a prospective, defeasible *commitment* to the modal invariance of the phenomena studied and the concepts used.

On this conception, the lawfulness of a pattern in the world concerns its reliability or robustness under counterfactual or subjunctive suppositions. My extension of the LHR conception initiates a shift from laws as statements or equations to laws as invariant patterns in the world. Lange and Haugeland usually speak of laws as invariant truths, even though Lange primarily considers their role as norms of inference that guide inductive strategies and Haugeland emphasizes a relevant interdependence between real patterns in the world and associated capacities for pattern recognition (Haugeland 1998, ch. 11). I explicitly extend their conception of lawfulness beyond verbally or mathematically expressed laws to include both the lawful invariance of phenomena or patterns in the world and that of theoretical modeling of those patterns. Explicitly articulated laws are then a special case of the more general phenomenon of lawful invariance.

Lawful invariance and contingent variability are not all or nothing matters, however. Contingent patterns still hold under many counterfactual suppositions; most experimental results would hold even if an experimenter had worn different shoes or had done an experiment on Tuesday instead of Wednesday, among many other more or less relevant contingencies. Meanwhile, even genuinely lawful patterns may not hold under some intelligible suppositions. Lange (2000, 2007) notes that if it is a law of materials science that copper is electrically conductive, that law would not still hold on the supposition that copper had no outer shell electrons. As a result, the notion of lawful invariance depends on having a basis for distinguishing the more limited invariance of accidental patterns that only hold under some subjunctive or counterfactual contingencies but not others from lawful patterns that have a more encompassing counterfactual reliability.

The need to reconceive the difference between laws and accidents is addressed by the first of three central points in LHR accounts of lawfulness. LHR distinguishes lawful patterns from accidental generalities not one by one, but only collectively. Lawful patterns and the concepts that articulate them mark out conceptual domains for research as interrelated patterns that are understood to display *maximal* counterfactual invariance together. Specifically, these patterns would hold under any counterfactual suppositions consistent with the other lawful patterns that together constitute that domain. The underlying idea is that these patterns and the concepts that express them have a kind of collective counterfactual stability, such that each pattern holds under all relevant counterfactual or subjunctive *contingencies*. Any hypothetical violation of a lawful pattern in that domain would thereby have invoked a *counternomic* supposition that would violate another of the domain's lawful patterns. This criterion is hard to visualize abstractly, but easier to recognize in examples. Consider adding the fact of my arrival at my office this morning to the group composed of the lawful patterns of fundamental physics, whatever they are. That enlarged group would clearly lose the counterfactual invariance exhibited by the original set of laws. It would not have violated any laws of physics had I had a fatal accident on the way to the office, but under that supposition, I would not have arrived at the office. Contingencies do hold under many counterfactual or subjunctive suppositions, but they always remain dependent on *some* other contingent occurrences that fall outside of any group of patterns that display such collective counterfactual stability .

This conception thus defines a *scientific* lawfulness that guides ongoing research rather than laws of nature independent of how the world becomes scientifically intelligible. Scientists never discern a complete set of lawful patterns displaying such collective maximal counterfactual

invariance, or rather, if they were to do so, the domain defined by their interdependence could no longer be an active research field.⁵ Researchers aim instead to work out concepts and patterns that together *would* form a coherent and counterfactually invariant domain. They often do confront phenomena that may seem to undermine the lawful invariance of the conceptualized patterns making up their field of inquiry. In those cases, however, they must then revise or augment those previously accepted patterns and concepts to accommodate the recalcitrant phenomena while restoring the collective counterfactual invariance of the field's conceptual relations. Nomological invariance is thus a practical commitment that guides exploration and revision of putatively coherent domains of inquiry.

LHR's second core claim concerns the interdependence between the *modal* invariance of the concepts marking out a research domain and the *normative* commitments governing work in that domain. Many lawful patterns only hold *ceteris paribus*, such that their counterfactual invariance is reliable only as a default commitment in the absence of relevant information to the contrary. These default commitments need not be fully specifiable in advance, but the difference between a *ceteris paribus* condition and a violation of a supposed law needs to be scientifically

⁵ Kuhn (1970) cites geometrical optics to exemplify research fields that cease to be focused on their own conceptual development and instead become stabilized as conceptual tools used for other research purposes. Other aspects of optics (the fringes of shadows or the diffractive interaction of light and matter) remain open to further articulation, but the older concepts no longer articulate a domain of research. Rheinberger (1997) generalizes this transition from research targets ("epistemic things") to conceptual tools ("technical objects") as integral to the research process at multiple levels.

intelligible (Lange 2002). The segmented body plans of insects are an example of a lawful pattern in entomology, which holds so long as various homeotic mutations or developmental anomalies have not occurred. Theoretical models likewise only incorporate some components of the phenomena modeled, and an understanding of their range of application is limited by recognition of the kinds of circumstances in which the factors omitted are understandable as having non-negligible effects. What counts as lawful pattern and what is tolerable background noise also differs across fields. Here too, the normative standards for pattern recognition and the modal determination of the nomological invariance of domain-constitutive patterns work together.

A different kind of example arises from a research domain's own constitutive goals. Evolutionary biology considers patterns of descent and variation within the geological history of the earth. How those patterns would have evolved had the earth had twice its actual mass and hence a larger gravitational force is not within evolutionary theory's relevant counterfactual range. Lange (2000, 229) similarly notes that medical cardiology need not consider how epinephrine would affect people's hearts had the human heart evolved differently. As Lange puts the point, those patterns still retain their counterfactual stability on those excluded suppositions because *any* answer to such questions is trivially consistent with the lawful invariance of the domain's conceptualized patterns (2000, ch. 8). The answer does not matter for what is at issue and at stake normatively in the conceptualization of that domain of scientific practice, and so any answer is accurate enough for the purposes of that domain of inquiry. Finally, although this issue is less central to the conceptual variation among biological conceptions of niches and niche construction, the norms of experimental or observational

practice in a research field shape whether a lawful pattern actually holds in a particular case.

Norms of proper performance, relevant conditions, accessible evidence, and attainable precision work together to determine whether a purported lawful pattern actually does hold under specific circumstances, and thus also help define the modal invariance of a scientific domain.

The counterfactual range of many domain-constitutive lawful patterns nevertheless extends beyond those in other research domains. R.A. Fisher's (1958) evolutionary explanation of the ratio of female to male births in sexually reproducing species is a salient example of the nomological autonomy of so-called "special sciences." The selection pressures to produce a one-to-one ratio among male and female animals at sexual maturity would remain even if the biochemistry of sex determination were different. Natural selection actually occurs within the confines of the biochemistry of sex determination, but the constitutive *counterfactual* invariance of those evolutionary patterns exceeds the nomic invariance of their biochemical realization. Lange (2007) similarly notes that the lawful patterns of island biogeography relating species distributions to the size of an isolated region and its distance from mainland species reservoirs would still hold under some violations of the laws of physics, such as if migratory birds had evolved modest anti-gravity assistance on takeoffs.

Lange and Haugeland only discuss conceptual development within scientific domains that have distinct ranges of counterfactual invariance, and hence their discussions by themselves would be consistent with a strong form of nomological disunity among the sciences. My extension contributes a third key feature of the conjoined LHR conception by arguing that conceptual development in scientific research has two complementary aspects. Borrowing terms from Donald Davidson (1980), I characterize as "homonomic" the forms of conceptual

development which Lange and Haugeland also describe, namely those circumscribed by the commitment to maintain the counterfactual stability of a research domain.⁶ Homonomic conceptual relationships do comprise the primary locus of scientific conceptual development. The sciences gain conceptual clarity and empirical coherence within particular research domains defined by the collective counterfactual stability of the conceptualized patterns they articulate. Within such research domains, scientists develop concepts and display conceptualized patterns both in controlled experimental, observational, or clinical settings and in theoretical modeling, and they deploy those concepts in counterfactual and subjunctive reasoning. Their experimental systems and theoretical modeling are then mutually tailored to sustain their collective counterfactual invariance.⁷ A broader “heteronomic” accountability nevertheless accompanies conceptual and empirical refinements within particular research domains. An entirely self-enclosed, self-referential domain might well be an artifact, and in any case would lack

⁶ While I borrow Davidson’s terminology, my conception of homonomic and heteronomic conceptual relations differs in important ways from Davidson’s use of the terms (Rouse 2015, 331-332).

⁷ Ian Hacking (1992) characterizes this mutual tailoring of experimental practices and theoretical modeling as the “self-vindication” of the experimental sciences. I argue (2015, 228-29) that this understanding of the conceptual autonomy of the resulting homonomic domains would render them empty of conceptual content and empirical accountability. The dual character of homo- and heteronomic development is thus essential to scientific understanding, and I discuss it further in section 4 below for its importance in understanding the relations among the different disciplinary conceptions of organismic niches and niche constructive activities.

broader scientific significance. Nomologically distinct scientific fields are thus mutually accountable in at least two ways. First, they cannot license *conflicting* accounts of what actually happens even though they situate and describe those phenomena using different concepts with different counterfactual range. Second, however, they also enable less systematic, heteronomic interconnections across domains, whether in borrowing techniques, using specific results, collaborating on joint projects, or developing more localized “interfield” models of phenomena that cut across their respective domains. Those heteronomic relations can nevertheless also sometimes reconfigure those conceptual domains.

4. Understanding the Divergences Among Niche Concepts

With this brief summary of the LHR account of lawful invariance in scientific research practice in hand as a component of my account of scientific research as niche constructive, I can now return to the divergent conceptions of organismic niches and niche constructive activities in ecology, evolutionary theory, and developmental biology. Trappes’s review of different conceptions of organismic niches and niche construction in ecology and evolution is premised by a concern, shared by many biologists, for constructing a more unified understanding of ecological, evolutionary, and developmental phenomena. She notes that, “[a]ccording to its proponents, NCT will not only transform evolutionary theory, but may also help to integrate evolutionary biology and ecology (Odling-Smee et al. 2003, 26). This unifying potential is jeopardized by the use of ecological terms in non-standard ways” (2021, 31). Stotz also aspires to an integrative understanding of evolution and development. She nevertheless argues that to fulfill that aim, biologists and philosophers need to distinguish selective and developmental niche construction in ways that the proponents of NCT often overlook, even though she

recognizes that these conceptions have considerable overlap. Linquist (2019) similarly argues for keeping ecological and evolutionary explanations mostly distinct, even under conditions of relatively rapid evolution by natural selection, while also acknowledging that under some conditions, one does need to consider the evolutionary relevance of the “gory details” of ecological explanations, or vice versa.

The LHR conception of domain-constitutive patterns of lawful invariance provides considerable insight into these questions concerning conceptual divergence and the unification of scientific disciplines or their conceptual domains. Most discussions of the aspiration to integrate these biological sub-fields and the conceptual differences that might be obstacles to their integration take for granted that there are such domains of inquiry and that the only question is how they relate to one another. It is worth remembering, however, that both evolutionary biology and developmental biology as a successor to embryology had periods of relative eclipse as research fields in the 20th Century (Smocovitis 1996; Amundson 2005, ch. 9; Gilbert 1998). Drawing on the LHR conception of how research domains are constituted by a practical commitment to the collective counterfactual stability of their concepts and conceptualized patterns requires a different approach. We cannot understand the similarities, divergences, and connections among the concepts of ecological, selective, and developmental niches, and of the niche constructive activities of organisms in each of those domains, without at least an overview of how these domains are constituted by commitment to patterns of collective counterfactual invariance among a group of phenomena and the concepts that express and demarcate that collective invariance. Moreover, those domains typically invoke both explanatory aspirations that govern the relations among those phenomena and scientific practices and normative

concerns that guide the discernment and assessment of conceptualized patterns within the domain.

Consider first the emergence and efflorescence of developmental biology. Among the key conceptual relationships involved were the recognition of epigenetic regulation of gene expression and the molecular biological patterns involved; the connections between these biochemical cascades and both the timing of cellular differentiation and the spatiality of cellular migration in eukaryotic embryos; the role of extra-cellular cues in triggering these molecular processes and tissue movements; and correlations between these molecular or embryological phenomena and large-scale patterns in body plans or organismic behavior. Moreover, as developmental phenomena, these relationships were not only identified primarily as species-typical patterns for which intra-specific variation was noise; they were mostly discerned in model organisms whose developmental patterns were projected as the basis for understanding these functional relationships in larger taxa (Bolker 1995).

Where developmental biology was primarily concerned with patterns that are relatively robust and often conserved across species and larger taxa, evolutionary biology has long been concerned with patterns of variation within populations and changes in that variation over time. That variation has classically been discerned and correlated at two distinct levels, however. Patterns of genetic variation and phenotypic trait distribution within populations were correlated through accounts of random mutations as the source of that initial variation and environmentally-adaptive natural selection or genetic drift as driving changes in both patterns of variation. At least three considerations played especially prominent roles in prompting a partial rapprochement between development and evolution. First was recognition of the role of

epigenetic processes in development and the resulting forms of phenotypic plasticity in producing the variation on which selection could take place. Second was the recognition that evolutionary change might be effected not only by small-scale mutations in coding regions of DNA, but also by more consequential shifts in the timing and regulation of gene expression in development, thereby at times dramatically affecting the tempo and mode of evolution. Third was the recognition that the genes and epigenetic markers involved in these processes were also subject to natural selection. The evolution of developmental patterns led to recognizable homologies among highly conserved developmental mechanisms both within and across taxa, alongside the more dramatic evolutionary shifts produced by duplication and differentiation of genome segments and regulatory patterns and relationships.

Ecology and evolution were of course long related by the role of environments in natural selection, but ecological and evolutionary accounts of organism-environment relations have often been differentiated in two broad ways. First, ecologists were primarily concerned to understand how organismic life patterns were enabled by their dependence on environmental relationships, whereas evolutionists were more concerned with how environments constrained populations of organisms so as to change their distributions of traits and sometimes lead to their extinction. Second, ecological and evolutionary phenomena are typically discernible on different time scales, as ecological relationships and their patterns are operative in the relatively short run, whereas evolutionary change takes place over more extended periods of time. Linquist (2019) nevertheless argues that even for traits that exhibit strong directional selection over relatively short time spans, explanations of the organism's ecological dynamics typically do not depend on the factors driving selection, while evolutionary explanations could benefit from detailed

analysis of ecological dynamics only within a limited range of empirical conditions. As Linquist notes,

Environments must be changing to some degree, otherwise it is unlikely that traits would be evolving rapidly in response to ecological selection in the first place. On the other hand, if environments change too rapidly, then at some point it becomes difficult or impossible to track the effects of specific ecological factors on evolutionary outcomes. (2019, 148-49)

Under conditions outside that narrow range between ecological stability and ecological change too rapid for selection to track, evolutionary analysis would do better to estimate dispositional fitness directly by counting offspring of phenotypically different individuals (Brandon and Beatty 1984) without seeking an ecological basis for those fitness values. Linquist then produces a range of further considerations that would lead to maintaining a separation between the research practices and explanatory strategies of evolutionary biology and ecology. The relative autonomy of evolutionary from ecological analyses is encouraged by the empirical difficulties in distinguishing selection from genetic drift and by the role of sexual selection that is often relatively detached from ecological dynamics. In the other direction, the relative autonomy of ecological analyses is supported by the possibility that evolutionary change could stabilize rather than change ecological dynamics, the possibility of non-mechanistic explanations in ecology that do not depend on the causal details of how those ecological patterns are produced, and above all, the difficulty of shifting ecological explanations from discerning species-typical ecological patterns to ones that incorporate variation within populations and the heritability of and strength of selection on specific traits.

The LHR account of domain-constitutive patterns of collective lawful invariance makes two primary contributions to understanding the variation among disciplinary conceptions of organismic environments and organisms' niche constructive effects on those environments. First, it provides a more general basis for understanding why these conceptual *differences* play a constructive role for biological understanding in each of these research domains. Second, it provides a more specific conception of what it would mean to "integrate" or "unify" scientific domains, which enables assessment of whether their conceptual differences would block their integration.

Three considerations work together in constituting these disciplinary domains and the extent of their autonomy from one another. The first consideration is which concepts figure in the *collective* counterfactual stability of the domain that marks a "real pattern" in the world (Dennett 1991). A pattern is lawfully invariant within that domain (i.e., having "developmental necessity" or "evolutionary necessity") if it would hold under any counterfactual or subjunctive suppositions that do not violate other invariant patterns in that domain, in which cases those suppositions would instead be counternomic suppositions that consequently do not challenge the domain's counterfactual stability. These collectively lawful patterns contrast to other patterns that would serve as contingencies in that domain, in the sense that the former patterns would still have held even had the latter varied. A second, related consideration comes from the empirical practices, procedures, and norms that determine *whether* the domain-constitutive patterns hold in any particular case, which consequently form the discipline's capacities for *recognition* of its constitutive patterns (Haugeland 1998, ch. 11). These include which considerations serve as background noise against which the domain's characteristic patterns still stand out. The LHR

account shows why these normative concerns are not independent criteria of assessment of lawful invariance, but are instead *components* of the lawful invariance that constitutes the domain. Conceptual relations *articulate* scientific domains from within rather than representing them from without.⁸ The third consideration in sustaining the collective counterfactual stability of a scientific domain and its concepts is which considerations are relevant to the discipline's concerns, since the domain's patterns are trivially sustained under counterfactual suppositions that do not matter to what it aims to understand.

The various considerations that Linquist (2019) invoked for the mutual conceptual autonomy of most ecological and evolutionary explanations provide good examples of how these joint determinations of collective counterfactual stability constitute research domains and the empirical accountability of their concepts. A primary point of his arguments, construed in LHR's terms, is that the dynamic relationships that figure in ecological understanding are mostly independent of whether and how those relationships are undergoing selection: ecological relationships are largely impervious to whether the population in question is undergoing selection or drift, some selective factors (notably most sexual selection) are not ecologically

⁸ Haugeland (1998, ch. 13) indicates an especially telling aspect of the integral character of lawfully invariant patterns and scientific pattern recognition. The lawful invariance of a conceptual domain incorporates the *resilience* of scientific practice, as “a kind of perseverance born simultaneously of adaptability and self-assurance ...[of] an expert who ‘knows full well’ that he or she can do something— and so is not turned aside or discouraged at the first, or even the second, sign of recalcitrance” (1998, 322). Without such practical resilience, lawful patterns in the sciences would not *remain* invariant in the face of apparent anomalies.

relevant, and selection on species traits can stabilize as well as shift ecological relationships. Those points work in conjunction with the recognition that taking account of phenotypic variation within a population and whether that variation is undergoing ecologically relevant selection would enormously complicate the empirical work of ecologists without sufficiently compensatory benefits in *ecological* insight. Similarly, he argues in the other direction that the “gory details” of fluctuating ecological relationships serve as evolutionary contingencies against which more persistent patterns in fitness variations stand out, and which can be measured directly without reference to ecological relationships. Moreover, as Trappes rightly indicated, these two domains have different explanatory interests: ecology is concerned to discern the environmental dependencies and tolerances that do or would enable the population’s *persistence* as a whole, whereas evolutionary biologists seek to understand the dynamics of *change* within that population.

Stotz’s discussion of the different orientations of developmental and selective niches and the role of organismic (re-)construction of those niches also illustrates the considerations invoked by the LHR account of lawful invariance. She begins with a primary difference in the aspects of evolution which analyses of developmental or selective niche construction address.

Developmental niche construction contributes to understanding how a balance is achieved between stable reproduction of successful traits and phenotypic variation on which selection can act. Selective niche construction instead concerns relations between selection pressures that reshape phenotypic traits and how organismic ways of life reconfigure those pressures. One consequence of this difference in interests is that both the internal milieu of a developing organism and its external environmental circumstances belong to its developmental niche, since

the internal milieu often determines genetic regulation and cellular differentiation and movement that produces phenotypic variation. By contrast, those internal components are of interest to evolution not as environmental factors that play a selective role, but only as traits possibly undergoing selection. Meanwhile, the difference between evolutionary interest in causal factors affecting reproduction and survival and developmental interest in the proximate and partial indicators of those factors reflects different patterns of collective counterfactual stability. Those factors would be selectively relevant even if the developmental signals of those factors were different, but the developmental pattern and the kinds of variation it enables are often sensitive to those different sources of environmental information and have to incorporate those signaling mechanisms in its conceptual domain.

A centerpiece of Trappes's paper on the differences between ecological and evolutionary niches and the relevant conceptions of niche construction was three prominent phenomena that are treated differently in the two disciplines. Habitat degradation (including loss of reciprocal, multi-species forms of niche construction) is of central evolutionary interest because of its selective relevance, but it does not figure in ecological investigation of the conditions that (would) enable the persistence of the population in its current configuration. Commensal relationships belong to the selective niche of the population benefitting from that relationship, but not to that of the host population. The relationship nevertheless belongs to both ecological environments, as requisite or tolerable conditions for the population's persistence. Meanwhile, even some requisite conditions for a population's persistence are not part of its selective environment if these resources are not limited in ways that would have selective effects on population size or internal differentiation. These are all examples of phenomena which are

outside of the explanatory concerns of at least one of ecology or evolution, and hence for which the lawful invariance of the field's niche concept trivially holds for counterfactual suppositions that invoke those phenomena: any answer to those hypothetical variations would be sufficient for the purposes of that field.

Understanding the import of these disciplinary differences among concepts of niches and niche construction for the integration of those disciplines and their insights depends on what kinds of integration are at issue. Philosophical conceptions of the unification of conceptual domains have traditionally focused on theoretical reduction, which incorporates one or more theories and their domains within a more encompassing theory. The LHR model of the partial conceptual autonomy of research domains complicates but does not rule out reductive unification, but it also offers alternative models. These alternatives include less systematic heteronomic unifications along with a more encompassing form of homonomic "reduction." Heteronomic integrations of disciplines can take more or less limited forms. Sometimes they only involve the borrowing and adaptation of instruments, procedures, or results from one field for specific purposes within another. They can also form specific research programs that draw on resources from more than one discipline to understand specific phenomena that fall between their domains but without attempting a more comprehensive reorganization of the contributing disciplines. If those disciplinary borderlands are sufficiently extensive, they might then prompt the development of "interfield" theories which build more substantial bridges between domains (Darden and Maull 1977) without yet establishing their own forms of collective counterfactual stability. Over time, of course, those interfield relations may broaden and deepen in ways that gradually form a new, relatively autonomous, counterfactually stable conceptual domain. Peter

Godfrey-Smith in turn proposed the possibility of a still more encompassing but resolutely heteronomic form of conceptual integration in the form of a philosophy of nature:

[A philosophy of nature] comments on the overall picture of the natural world that science, and perhaps other types of inquiry seems to be giving us.... The claims made by a good philosophy of nature do not have to be the same as those used in the relevant science, and the organization and presentation of information in the two projects can be quite different. (Godfrey-Smith 2001, 284)

Such philosophical unification often stands apart from the more detailed and conceptually integrated applications of scientific concepts to specific phenomena within a research domain. In later work (Rouse 2023b, 2-4), I invoke both Godfrey-Smith's conception of a philosophy of nature and Wilfrid Sellars's conception of philosophy as concerning how "things in the broadest sense of the term hang together in the broadest sense of the term" (1963, 1) to characterize my deployment of niche concepts to understand scientific practice, a point to which I return in the next section.

The cross-disciplinary differences in niche concepts and analyses of their niche constructive dynamics illustrate both homonomic and heteronomic conceptual development. Odling-Smee, Laland, and Feldman's (2003) influential book on niche construction prominently does homonomic work. They are hardly the first to note that organisms change their environments or that such changes may have some evolutionary significance. The book gets its prominence from their efforts to display that significance in canonical population-genetic models while also marshaling evidence for pervasive and cumulative effects of niche constructive activities across taxa. That work shows how to expand the standard conceptual tools of

evolutionary theory to incorporate the feedback effects of niche construction on trait evolution. This role of the book accounts for why Ingold's (2022) criticism of NCT's idealization of ecological "inheritance" between discrete, successive generations partly misses the mark. Even if Ingold is right to emphasize the intertwined, cross-generational work of niche construction, this idealization does important homonomic work to reconfigure the systematic conceptual relations embedded in the population genetic models that play a central role in evolutionary biology. In this respect, the appendices displaying NCT's technical population-genetic models strikingly differ in style and content from their co-authors' other collaborative papers that build more limited, heteronomic bridges to other work in biology and the social sciences. Stotz's paper, meanwhile, distinguishes two different forms of niche constructive dynamics with the presumption that the connections between them are heteronomic. Intra-population variation arises in part via developmental niche construction. Evolutionary niche construction then reconfigures those populations by changing selection pressures. While there is some overlap between their domains, the two invoke different conceptual systematizations relevant to their governing concerns.

Stotz's account of the evolutionary significance of developmental niche construction thus intervenes in contested heteronomic territory between development and evolution. The gradual emergence of the interdisciplinary field variously known as evolutionary-developmental biology ("evo-devo") or developmental evolution ("devo-evo") provides a telling example of how the configuration, direction and significance of heteronomic conceptual integration can be at issue in

its ongoing exploration.⁹ The emergence of a new interdisciplinary research field at the borders of evolutionary genetics and developmental biology was made possible by striking results at the molecular level, notably the discovery of a homeotic gene complex (Lewis 1978) and developmental signaling cascades (Nüsslein-Vollhard and Wieschaus 1980) in *Drosophila*. Yet the significance, direction and even evidential norms of this new field remain very much disputed. At one extreme, evo-devo looks to extend the modern synthesis to incorporate development by displaying the evolution of regulatory, developmental genes as highly conserved patterns with deep homologies across taxa (Carroll et al. 2004). In the other direction, developmental evolution is central to a revisionist project in evolutionary theory that emphasizes genes as relatively plastic resources for epigenetic processes in development that indicate the close interconnections of ontogeny and phylogeny (Laublicher and Maienschein 2007, Wagner 2000, 2001, Wagner and Larsson 2003).

In this respect, the competing conceptions of how to integrate development and evolution illustrate the possibility of a homonomic reduction of one research domain within a more encompassing domain with a different explanatory orientation and an expanded set of counterfactually stable conceptual relations. This distinctive form of domain reduction can be briefly illustrated by the relations between the emergent domain of cell biology and a predecessor domain of cytology. Cell biology subsumed classical cytology in a more

⁹ Similar controversies might eventually emerge between ecological-developmental biology (Sultan 2007; Gilbert 2016) and ecology, although I have not seen any explicit effort at a parallel assimilation of the ecological aspects of organismic development into a developmental ecology.

encompassing way. This unification was not limited to the incorporation of one theory into another. The instruments, techniques, and phenomena of cytological studies were incorporated into a new disciplinary domain with different explanatory interests, which also required new material resources, organizational institutions, and pedagogical regimens (Bechtel 1993; Rheinberger 1995). Cell biology provided not so much a unifying theory as an expansive shift in explanatory concerns and conceptual patterns, from identifying cellular components and structures to understanding how those structural relations enabled or facilitated cellular functioning. Evolutionary-developmental biology and developmental evolution similarly propose alternative expansive incorporations of development within evolution.

Evolutionary-developmental biology aspires to incorporate developmental patterns within the modern evolutionary synthesis by displaying the evolution and conservation of developmental-genetic “toolkits” (Carroll, Grenier and Weatherbee 2004). Developmental evolution and ecological-developmental biology instead aspire to subsume population-genetic models of evolution within an “extended” synthesis that treats them as components of a more encompassing pattern of the evolution of ecologically-mediated developmental life cycles.

I conclude this section with two points about the broader integrative projects within which these questions about concepts of niches and niche construction are situated. I first highlight LHR’s emphasis on the organization of research rather than the retrospective theoretical and explanatory unification of knowledge. The shape of evo-devo/devo-evo as a research field is contested. Whether it is best understood as an interfield domain, as two alternative and possibly competitive homonomic projects within the existing fields of evolution and development to encompass a broader range of phenomena, or something more akin to a

philosophy of nature, is not yet settled.¹⁰ It is too soon to tell whether evo-devo/devo-evo will eventually form a more systematically unified conceptual domain that draws variously from evolutionary genetics, comparative morphology, developmental biology, and systematics, or will instead retain its current heteronomic plurality or split into two fields with different orientations but some common elements differently situated within their conceptual fields.

¹⁰ Stotz (2017) explicitly situates her analysis within developmental systems theory (Oyama et al., 2001), which Godfrey-Smith (2001) in turn proposes as an exemplary case of a philosophy of nature. One might well then argue that the controversies between the modern evolutionary synthesis and proposals for an “extended synthesis” (Wray et al. 2014, Laland et al. 2014) are less focused on the shape of evolutionary biology as a research field than on competing approaches to a broader philosophy of nature that draws on multiple life science disciplines. Indeed, one way to read Smocovitis’s (1996) history of the modern synthesis is that the synthesis itself was less a systematic theoretical unification of multiple biological domains and more an organizing philosophy of nature that connected those domains heteronomically. That philosophical framing emerged from distinct conceptual reorganizations *within* the fields of evolutionary genetics, systematics, paleontology, and botany, each of which retained its conceptual autonomy and commitment to a collective counterfactual stability. That is how I read Smocovitis’s concluding remark about the 1980 conference volume that initially addressed the historiography of the modern synthesis: “The meaning of the synthesis—to a close reader of texts—has always resided in the textbook title: *The Evolutionary Synthesis: Perspectives on the Unification of Biology*” (1996, 188)

The second point I want to emphasize is a key consequence of the LHR model of scientific conceptualization as encompassing both the homonomic articulation of partially autonomous conceptual domains, and less systematic heteronomic connections among them. The conceptual relations among these different accounts of organismic niches and niche construction do not primarily involve disagreements about specific scientific results. Despite differing conceptions of their overall shape, practitioners of ecology, evolution, and development, and proponents of alternative interfield programs of evo-devo or devo-evo and for or against a possible Extended Evolutionary Synthesis can accept most of the claims made within the contexts of one another's constitutive idealizations. That widespread empirical agreement is nevertheless consistent with quite different counterfactual extensions of those claims, amid different visions of where those fields are going, what are their most central concerns and directions of research, and how their achievements and prospects matter to biology generally. The controversies over how to integrate development and evolution, and how best to configure evolutionary theory in light of challenges to the modern evolutionary synthesis thereby illustrate how I position my account between strong claims for the aspirational theoretical unity of the sciences and a contrary insistence on the disciplinary disunity of scientific practices and conceptual domains. The LHR account of conceptual development in the sciences as homonomic seems strongly disunifying, but my version also insists on holding those disunified conceptual domains mutually accountable heteronomically and in their actual empirical determinations. These two considerations together constitute a more limited form of scientific unity, which we can now see also at work in the relations among disparate biological conceptions of niches and niche construction.

5. Conclusion: Scientific Niche Construction as Naturalistic

I conclude by briefly situating my conception of scientific research as niche constructive and its application to conceptual differences among niche concepts in two interconnected ways. First, I explore its relation to other explications of scientific research environments in biological terms as niches. Second, I situate this analysis in its original context as a contribution to a revisionist conception of naturalism.

My account of scientific niche construction differs significantly from other philosophical discussions of research environments in at least four ways. First, as Trappes and Leonelli (forthcoming, sect. 5) also discuss, most philosophical accounts of research environments talk about epistemic, cognitive, or conceptual niches as merely analogical to biological niches or even as metaphorical extensions of the biological concept. I instead focus on scientific research as itself a form of human *biological* niche construction. Second, these various accounts draw on different niche concepts. Whereas other discussions of research environments talk about the epistemic or cognitive niche of particular research projects as analogous to conceptions of ecological niches, I draw on evolutionary accounts of niche construction as a dynamic phenomenon. As I noted above, evolutionary niche construction is a multi-species phenomenon, in which the niche constructive activities of one population changes the selection pressures on others as well as on subsequent generations of its own lineage, and may also reconstruct others' developmental environments. I then make that analysis more fine-grained by discussing the practice-differentiated evolution of human ways of life and emphasizing how different practices,

scientific and non-scientific, transform one another's *developmental* environments.¹¹

A third related difference explains why I have relied on my account of scientific niche construction in this paper. Trappes (2019), Linquist (2019), Stotz (2017), and Stotz and Griffiths (2008) each detail how concepts of organismic niches and niche construction differ in different disciplinary research environments, but their accounts provide no apparent resources for understanding or assessing the relations among these concepts or the conceptual domains to which they belong. My more encompassing conception of homonomic and heteronomic conceptual articulation does provide the basis developed in this paper for understanding and assessing the differentiation and unification of niche concepts from different domains. Finally, while Trappes and Leonelli rightly emphasize that all of these philosophical deployments of niche concepts highlight the heterogeneity and dynamism of scientific research practices, my analysis is “dynamic” in a stronger sense. Both Griffiths and Stotz's (2008) conceptual ecology and MacLeod and Nersessian's cognitive niche construction “examine the way research conditions shape conceptual and theoretical developments in science” (Trappes and Leonelli forthcoming, ms. 9). Their focus on epistemic or cognitive niches thus emphasize the dynamics of knowledge *production*. I instead treat conceptual development as a temporally extended,

¹¹ I (Rouse 2023b) also emphasize how these practice-differentiated forms of niche construction are a multi-*species* phenomenon. That aspect of his account is less central to his (2015) account of scientific niche construction, although not irrelevant. Both the involvement of commensal and domesticated organisms in scientific research and the ways in which research belongs to larger patterns of multi-species interdependence belong within Rouse's overall account of scientific niche construction.

prospectively oriented *process*. Instead of understanding research as the dynamic production of knowledge, I understand efforts to codify scientific knowledge as components of a more extensive process of conceptual articulation in ongoing research. Paralleling Ingold on intra-generational developmental perdurance, my account treats scientific research as “fashioning an environment that is never complete, always work-in-progress [a]nd what perdures is the fashioning, not the finished form” (2022, S36).

I (Rouse 2023a) differentiate naturalism in the philosophy of science from more traditional conceptions of naturalism in philosophy. The latter typically rely on idealized conceptions of scientific understanding as a more or less unified theoretical representation. Naturalistic philosophy of science instead recognizes that a scientific conception of the world is, as Trappes and Leonelli put it, “multi-dimensional, processual, agential, [selective], relational, and normative” (forthcoming, ms. 2), as part of the world that it renders intelligible.¹² I argue that a constitutive criterion for an adequately radical naturalism is that it begins “at home” with a naturalistic conception of scientific understanding. A naturalism that exempts the sciences from naturalistic incorporation within a scientific conception of the world would fail to live up to its own commitments. That is why I “diffractively” interpret the different conceptions of niches and niche construction in biology and my account of scientific practice as a form of biological niche construction through one another. I am not merely “reflexively” applying an account of scientific understanding to itself. Whether one regards my analysis as an integrative philosophy of nature

¹² The quotation is modified in context to turn their nouns into adjectives, and substitutes “selective” for “capability,” since Trappes and Leonelli elaborate the latter as “relying on certain capabilities and not others” (ms. 13)

or as a Sellarsian account of how “things hang together,” it contributes to the heteronomic accountability of scientific and other conceptual domains to one another as interrelated conceptual articulations that are ongoing forms of scientifically intelligible biological niche construction.

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