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Chapter Author(s): ALAN C. LOVE and WILLIAM C. WIMSATT

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Book Editor(s): ALAN C. LOVE and WILLIAM C. WIMSATT

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EXPLAINING CULTURAL EVOLUTION

An Interdisciplinary Endeavor

ALAN C. LOVE AND WILLIAM C. WIMSATT

A CONTESTED EXPLANANDUM

Scholars are prone to dispute. However, two words in particular can provoke a full-scale brawl across the humanities and various sciences: *cultural evolution*. For some, the phrase conjures up shadows of an older anthropological tradition in which diverse peoples, groups, and societies were fitted—in procrustean fashion—onto a template of evolutionary progress with Western categories and social organization presumed as the apotheosis of cultural development. For others, it sounds like a route designed to eliminate thick, narrative-focused studies of variation in human groups at different times and places with abstract modeling from the natural sciences, which reduces cultural heterogeneity to a small set of idealized biological factors. Perhaps the most infamous poster child for this latter strategy is the meme, a purportedly basic unit of culture claimed to be analogous to the gene. Problems with meme-based approaches include their lack of structural detail to account for why specific entities might acquire particular memes, how they do so (e.g., acquisition order), and how memetic dynamics in aggregate illuminate the complex architecture of culture and its changes through time (Wimsatt 2010; see also Lewens 2015). However, apart from these particular deficiencies (discussed further below), there are still genuine concerns about the very idea of cultural evolution; it is, at least, a contested explanandum.

Cultural evolution's status as a contested explanandum has two dimensions. The first is whether it is even a single thing in need of explanation. Worries about whether "culture" is being reified in problematic ways in order to be explained might encourage a different strategy altogether: giving up trying to explain cultural evolution because there is no such process. Here, the concern about colonial impulses to conceptualize culture or its essential traits is palpable. To advance a model of cultural evolution seemingly requires smuggling in a host of assumptions about the nature of culture that we should be suspicious of based on a checkered history of past attempts. A less strident version of this dimension simply emphasizes that there is not sufficient commonality among items frequently referred to under the rubric of culture and therefore little rationale to offer a more unified account of its supposed dynamics. One might try to individually explain the origin and proliferation of gasoline-powered engines, the manual skill involved in crafting stone tools, or specific variations in cooking, dialect, or marriage practices, but nothing is gained, on this complaint, by shoving them underneath a common theoretical blanket labeled "cultural evolution."

The second dimension of cultural evolution's contested explanandum status emerges from a less skeptical posture. Assuming that cultural evolution is something in need of explanation, how should we proceed? What kinds of disciplinary approaches are needed or should be emphasized in offering explanations (Lewens 2015)? Here, what is contested are the criteria of adequacy because the standards for what counts as a genuine explanatory account differ across disciplines. Is there some reason to privilege a perspective that focuses on biological factors rather than social factors? If so, in what contexts, and for what kinds of factors? If not, how do we build integrated models that articulate both biological and social factors? Should we even look to biology for analogical inspiration for modes of cultural change? And if so, is an evolutionary approach to culture mere analogy, or can it provide something more? Are there interpretive issues involved in deciphering cultural formats that outstrip the analytical capacities found in abstract modeling? Does an evolutionary approach to culture necessarily exclude social science disciplines, as many investigators have assumed? To some degree, answers to these questions of methodological or disciplinary appropriateness and priority depend on answers to another question: What *is* culture? Needless to say, opinions differ. However, it is instructive to pause for a moment over the diversity of answers available.

In their magisterial book, *Culture: A Critical Review of Concepts and Definitions* (1952), A. L. Kroeber and Clyde Kluckhohn documented six thematic groupings of definitions of culture: (1) descriptive, (2) historical, (3) normative, (4) psychological, (5) structural, and (6) genetic. Descriptive definitions emphasize the enumeration of specific content types, such as social customs, property systems, and artistic expression, including the norms that govern each of these, which comprise the "whole" or "sum" of culture. Historical definitions focus on social heritage, such as items, forms, or institutions inherited from earlier generations, either through explicit teaching or implicit exemplars. Normative definitions isolate rules or sanctioned ways of living that are typical of different communities and constitute membership identity. Psychological definitions revolve around capacities of problem solving or adjustment to environments of different kinds—how culture is a means to different ends. These capacities can be learned through formal or informal education, be instilled by habit, or be present in common attitudinal orientations. Structural definitions concentrate on predominant patterns of organization in a society that play particular functional roles. Genetic definitions conceptualize culture as a created product or artifact of recurrent human activities, including central ideas, sacred rituals, or ubiquitous symbols. Treated more abstractly, culture (from this vantage point) can be seen as a type of information (for discussion, see Lewens 2015). For each of these definitions, change over time will be conceptualized differently, both in terms of the relevant units (e.g., rules, material artifacts, or problem-solving strategies) and their dynamics, which will range over their origination, diversification, and (sometimes) extinction. At a minimum, talk of the "nature" of culture and its evolution is strained in light of this definitional diversity.

A more recent and focused discussion subdivides senses of culture that have been relevant to evolutionary analyses (Driscoll 2017; cf. Lewens 2015). Driscoll identifies five different groupings: (1) behaviors or artifacts used by individuals that are typically acquired by social learning in a particular community environment or population; (2) behaviors or artifacts used by nonhuman individuals, especially primates, that require trial-and-error learning on the part of an individual in emulation of achieving a particular goal and shed light on homologous capacities or traits that might underlie corresponding or allied human traits; (3) the environmental features that are modified to transform selective forces transgenerationally (e.g., in terms of niche construction); (4) properties of groups (e.g., traditions) that yield differential survival and reproduction of these higher level units over time; and, (5) the origin of social learning mechanisms that yield cumulative effects on particular features in a society, such as a socially learned trait, or the processes from which these mechanisms, and hence capacities for culture, originated. Driscoll then resists two divergent interpretations of these groupings. First, she argues that these are not five separate approaches or inquiries. In fact, standard theoretical perspectives (e.g., dual inheritance or multilevel selection) overlap in addressing different conceptions of culture and deal with various facets of these conceptions in their models and explanations. This is a nuanced reply to the less strident form of the first dimension of cultural evolution's contested status. Although there is not a single endeavor or project in view, there is sufficient commonality among these items to talk of accounting for the dynamics of cultural change: "The current single definitions of culture . . . seem to refer to different levels or parts of cultural evolutionary phenomena" (36).

The second interpretation Driscoll resists is that sufficient analytic fiddling will permit collecting the diversity of cultural phenomena under a single definitional umbrella. Through a survey of literature in which culture is treated as information and phenotypic traits, it is clear that what counts as either of these is variable (e.g., mental representations versus socially learned behaviors). We agree: culture is a complex beast. Although its many facets evolve, moving beyond the truism ("culture changes") requires dealing specifically with the facets of this complexity and their many interconnections. In teasing apart the individual level from the group level or environmental culture from cultural psychology, we have circled back to the insights of Kroeber and Kluckhohn: culture, in virtue of its complexity, admits of many characterizations. Although we have found at least one way to address the less strident form of the skeptical dimension for cultural evolution being a contested explanandum—there are significant, overlapping connections within the complexity of items referred to as "culture"—we still must face the second dimension of cultural evolution's contested status: how should investigation, modeling, and explanation proceed?

FROM CONTESTED EXPLANANDUM TO AN INTERDISCIPLINARY RESEARCH AGENDA

Culture is not unique as a concept in admitting of different characterizations. Philosophers of biology have wrestled with a number of concepts that fit this description: gene, species, individual, and homology (inter alia). Driscoll (2017) explicitly recognizes this relationship: "It seems the absence of a single definition of culture . . . is a feature of other important scientific concepts and exists because of the increasing understanding of cultural evolutionary processes in the cultural evolutionary sciences" (52). For concepts like gene or individual, the complexity of processes and entities involved suggests that seeking a single "correct" concept is methodologically ill-advised. In fact, a variety of relevant and related conceptions can emerge from scientific success (i.e., having learned more about features of the phenomenon), such as in the case of genes (Griffiths and Stotz 2013). The epistemic response of proliferating distinct but allied senses of culture (or genes, or individuals) can be taken as a positive signal of a different methodology. Researchers use divergent characterizations of a concept that represents a complex phenomenon because they have different explanatory aims. These characterizations are then justified by reasons related to those aims. An account of those reasons starts with the identification and rejection of an implicit premise in the search for a single correct concept: that the primary task of a concept is to categorize phenomena or provide a classification of objects or processes that fall under the concept.

Conceptual Roles: Representing Structured Research Agendas

Debates over gene concepts or species concepts can frustrate many scientists. They are often dismissed as "merely semantic." This frustration arises naturally from the implicit premise of a single-concept methodology. If the primary task of a concept is to identify a single, correct definition, then multiple characterizations are a kind of failure. They do not univocally tell you what is in the category and what falls outside of it. However, one way forward is to shift from finding the definition of a concept, where the goal is to formulate criteria for delineating the set of entities a term classifies or categorizes, to characterizing the explanatory agenda associated with a concept (Brigandt and Love 2012), where the goal is to map out a space of explanatory expectations for the study of diverse features of a complex phenomenon. Mapping this problem space promotes the construction of theory and an understanding of the processes of change. Different conceptions of culture (or genes, or species) involve different commitments to what counts as an adequate explanation for the particular features of a complex entity. For example, consider the emergence of interchangeable parts in what came to be characterized as the "American system of manufacture." A full account would need to address: (1) the motivations of the U.S. Bureau of Ordinance interested in the benefits of repairing arms in the field; (2) the development of machine tools allowing for the adjustability that contributes to different functions and high precision in reproducible manufacture; (3) the practice of using sets of templates to give precision in assessments of dimensions; (4) the change in labor practices from the production of individual muskets by craftsmen to the piecemeal production of "lock, stock, and barrel" parts that could be produced and assembled by relatively untrained labor (with consequent labor unrest); and (5) the spread of the method of manufacture as "mechanics," who were expert in the use of the new tools and methods, migrated into other manufacturing industries.

Different disciplinary approaches are relevant for addressing these distinct facets of the complex phenomenon, such as sociological aspects of changes in labor organization, technological aspects of templates and machine tools, and historical aspects of the development and spread of manufacturing practices (see Smith 1977; Hounshell 1984; Wimsatt 2013). These differential commitments structure the investigative and explanatory efforts of researchers and provide criteria for how to address distinct scientific questions associated with the different conceptions. As a consequence, different models and theories with distinct causal factors represented in various fashions become more or less germane to different characterizations. These models and theories derive from a range of disciplinary approaches and therefore not only speak to the fact that interdisciplinary explanations are needed but also inform how interdisciplinary contributions should be coordinated to meet the criteria of explanatory adequacy.

Several corollaries follow from adopting this perspective of concepts as markers of structured explanatory agendas (Brigandt and Love 2012; Love 2014). The first is that there are different sources for the structure manifested in these explanatory agendas. One of these is historical debate, which has carved out dominant theoretical positions in the landscape of questions related to the complex phenomenon. This debate includes controversy over how to characterize culture and the manner in which particular characterizations, such as group properties or social learning mechanisms, have crystallized over time. Another is epistemic heterogeneity: different kinds of questions are being asked about cultural change. Some of these are empirical. *Has the rate of technological change increased with the onset of more rapid diffusion of innovations? Does it depend more on the rate of transmission or the size of the cultural breeding population?* Some research questions are theoretical. *How can we characterize cultural heredity with multiple parents making contributions of different sizes at different stages in the developmental processes of enculturation?* Other questions are conceptual. *Can the dependency structure of knowledge and skills acquired in ontogeny provide structure analogous to genetic architecture in population genetics?*

A further source of structure results from relationships between research questions, sometimes as nested, component hierarchies (e.g., research questions divided into subproblems) and sometimes as functional, control hierarchies (e.g., answers to one research question are presupposed in another question). Consider again the question of how interchangeable machine parts emerged in the early nineteenth century. It subdivides into a question about the origin of motivations to do so, a question of what technological innovations were necessary to support the increased precision of manufacture, and a question of how the requisite conditions of production were put into place. The question about conditions of production can be subdivided further into the relevant changes in labor, the organization of parts manufacture and assembly, and the support tools that facilitated this production, such as lathes and templates. An example of functional hierarchies in problem structure can be seen in the research question of how to create autonomous vehicles that operate in standard (and nonstandard) traffic situations. In order to address this question, different levels of autonomy need to be distinguished. Once this is done, the requirements for creating a control system for a particular level of autonomy can be specified appropriately, such as the degree of reliance on computational analysis of multimodal sensory information versus accumulated information about road conditions. Combinations of different disciplinary approaches and methods will be required to address these structured sets of research questions in the problem agenda. The focus of one discipline on some questions rather than others creates a fruitful division of labor and organizes different lines of investigation in terms of the kinds of questions they tackle, such as different teams working on different aspects of the problem of autonomous vehicles in the same company.

Structure that derives from history, heterogeneity, or hierarchy is significant because of how criteria of explanatory adequacy are embedded within them. For example, heterogeneous questions have distinct standards for what counts as an adequate answer. An acceptable explanation of how and when the rate of technological change depends more on the rate of transmission than on the size of the cultural breeding population will differ from an acceptable explanation of how the dependency structure of skills acquired through a developmental sequence is analogous to genetic architecture in population genetics. Relevant criteria of adequacy are localized to different types of questions and different hierarchical levels, as well as conditioned on trajectories of historical debates. However, this localization facilitates systematic understanding as a consequence of the problem structure. Explanations of what changes in labor were relevant to the conditions of production for interchangeable machine parts will differ from explanations of how support tools facilitated this production. However, both explanations jointly increase our knowledge of this nineteenth-century episode of cultural evolution. At a more theoretical level, criteria of adequacy for the problem agenda of cultural evolution will include attention to what transmissible elements are relevant, what kinds of biological individuals are involved, what developmental sequences are germane for the transmission and expression of cultural traits, what types of social organizations and societal institutions are involved, what kinds of material artifacts are manifested, and what forms of scaffolding relationships obtain between these various items (see chapter 1). Once these criteria of adequacy are made explicit, they comprise a strong rationale for an interdisciplinary approach to cultural evolution. No single discipline or approach will be sufficient to fulfill these criteria. As a result, tendencies to ignore or selectively eliminate aspects of the complex phenomenon not amenable to particular disciplinary approaches are lessened (a perennial complaint about abstract modeling that reduces cultural heterogeneity to a small set of idealized factors). The criteria of adequacy embedded in the structured problem agenda not only speak to what disciplines or approaches are required but show exactly where they need to make their contributions.

Combining Thick and Thin Descriptions of Cultural Phenomena

An often-discussed locus of controversy related to the selective elimination of aspects of complex, heterogeneous cultural phenomena is the methodological distinction between "thick" and "thin" descriptions (Geertz 1973). The former, exemplified in the practices of disciplines like cultural anthropology or natural history, involves descriptions that embody details about intentions, history, context, and related cultural practices or analogous details for natural history. Thin description, exemplified in the practices of disciplines like population genetics, involves descriptions keyed to traditional mathematical modeling that adopt only a few variables in the equations used to model the dynamics of phenomena. Those disciplines that value thick description are most skeptical about evolutionary approaches to culture because they assume thin description is constitutive of these approaches. They argue that thin descriptions treat cultural phenomena too abstractly and therefore fail to engage its multilayered character. However, those disciplines that value thin description complain that the rich detail of thick descriptions sacrifices quantitative prediction, generalizability, and explanation. But the methodological distinction between thick and thin description is not a dichotomy. Because of the complexity of cultural change over time, both are often necessary at multiple levels of detail and from multiple perspectives. Which perspective and what level of detail is needed will depend on the question being addressed. Often, thick descriptions will be involved in analyzing how to operationalize the variables of thin models. Moreover, the need to combine thick and thin descriptions in various ways for different questions points us to methods of intermediate or heterogeneous *viscosity* (Wimsatt and Griesemer 2007). These methods generate characterizations that can provide explanations of intermediate grain and varying textures, which help to capture real-world detail while still utilizing general mathematical theories and quantitative predictions. Incorporating development and culturally induced population structure to study cultural evolution brings us into this domain (see chapter 1).

A lovely example that involves integrating multiple thin models with thick descriptions and methods of intermediate viscosity is William Durham's complex narrative for the maintenance of sickle cell anemia through heterozygote superiority driven by malaria resistance (Durham 1991, 103–53). Although the spread through West Africa of three different HbS mutations, which cause sickle cell anemia when in homozygous genotypes, can be modeled abstractly within population genetics, a complete explanation of the relevant phenomena must deal with spatially structured migrations, different degrees and patterns of rainfall, the cultivation of different crops that differentially favor mosquitoes (and exposure to them), and various cultures and language groups that affect interbreeding and cultural practices related to mosquito control. Templeton's (1982) analysis of the interactions between the HbA, HbS, and HbC loci, as well as the effects of inbreeding, further complements Durham's analysis by suggesting an explanation for the relationships between the distribution of the HbS and HbC alleles. Combining Templeton's abstract population genetic model of the temporal evolution of the phenomena with Durham's descriptions of environmental heterogeneity shows how the complementary application of multiple thin models of different types yields a thicker overarching narrative. The parameters of abstract mathematical theory are calibrated with the spatially and temporally variable patterns of rainfall and the complexities of migration, including population flow and linguistic group structure, affecting the degree of interbreeding. This calibration modulates our expectations for how close populations should be in relation to predicted equilibrium frequencies.

Regularities emerge from the data but curve fits are noisy at best; deviations from quantitative expectations are sometimes explained by thick descriptions of the characteristics of local, individual populations.

Despite the fact that Durham's analysis serves as an exemplar of combining thick and thin descriptions in different ways to achieve a rich explanatory tapestry that is also generalizable, it is an ongoing effort to address the variegated structure of this problem by articulating different approaches. Even with a "thin" mathematical model only containing a few explicit variables, the complexity of cultural phenomena can make it difficult to determine which specific causes are relevant to a modeling result. Although it may be experimentally tractable in principle, the specificity of complex causal relationships might resist generalization. The only reasonable response in these situations—common to the study of cultural evolution—is to practice multiple approaches simultaneously at different grains of analysis appropriate to different questions and then integrate the answers in a piecewise fashion to better comprehend such multifaceted and multidimensional phenomena.

Beyond Partitioning Theoretical Approaches

Once we have adopted the perspective that there is a structured problem agenda with diverse explanatory questions about the evolution of culture construed as a complex phenomenon, it becomes clear why partitioning the research landscape in terms of broad theoretical approaches alone might be less fruitful. For example, Lewens (2015) offers a tripartite division of approaches to cultural evolution: historical (scrutinizing facets of culture as products of historical processes), selectionist (analyzing cultural change in terms of selective dynamics operating on individual behaviors or group-level units as replicators and interactors), and kinetic (emphasizing the capacity for learning to modulate cultural change over time). These different approaches are not mutually exclusive but tend to have clusters of shared theoretical commitments. Selectionist approaches are sometimes motivated by the aim of offering a fully general account of selection; kinetic approaches are often focused on generating increased understanding of the mechanisms of learning. While Lewens is fully aware that this taxonomy does not capture everything relevant in studies of cultural evolution (e.g., cultural phylogenetics), a more important concern from our perspective is that it does not offer enough structure for answering the key methodological question: How should investigation, modeling, and explanation proceed?

Kinetic approaches might concentrate on learning models and their explanatory power, but what these models represent and whether they explain depends on what research question is being asked. And these research questions about the dynamics of cultural change require more than one disciplinary contribution. Without an explicit account of the problem structure (in terms of history, heterogeneity, and hierarchy) and its associated criteria of adequacy, the complexity of the contested explanandum of cultural evolution is elided, and the necessary articulation of diverse explanatory resources—both thick and thin—is elusive. However, embracing the need to flesh out the problem architecture and its evaluative standards yields a broad outline of answers to our earlier questions. An evolutionary approach to culture necessarily *includes* social science disciplines precisely because there are interpretive issues involved in deciphering cultural formats that outstrip the analytical capacities found in abstract modeling. Considerations of thick and thin description indicate that there are sometimes reasons to privilege a perspective that focuses on biological factors (such as the relation between number of mosquitoes at a time and the temporal and spatial distribution of rainfall) and sometimes reasons to privilege a perspective that focuses on social factors (such as cultural practices for rooting out evil spirits that involve waving firebrands at dusk near the roofs inside residences, which happens to be when mosquitoes tend to congregate there). The problem structure and criteria of adequacy govern in what contexts and for what kinds of factors privileging is warranted, while pointing toward the ongoing need to build integrated models that articulate both biological and social factors together. An evolutionary approach to culture (sensu lato) provides far more than mere analogy or inspiration.

The criticisms of how Lewens partitions the research landscape for studying cultural evolution remind us why approaches anchored in memes are woefully inadequate. It is not clear that the central role of finding a unit of heredity in biology should be paralleled in studies of culture. (In chapter 1, Wimsatt suggests not, or at least not directly.) Not only are there concerns about a nontrivial characterization of what memes are and how they can be transmitted or replicated but memetic approaches do not provide any significant structure for coordinating different explanatory resources to account for the complex phenomenon of cultural evolution. The structure in the problem anatomy described above in terms of history, heterogeneity, and hierarchy gives scaffolding to theorizing that articulates the necessary diverse perspectives. It is not enough to assume people can be infected by memes and that there are different rates of infection for different memes. What exactly are the relevant subpopulations, the cultural histories, their connections, and the population dynamics? Is cultural evolution best modeled epidemiologically? Why do some people "catch" the meme in question and others do not? Adequate answers reliant on memetics alone seem unlikely; one disciplinary approach will not be adequate even if it could determine a population dynamics for memes. Instead, we need strategies for articulating diverse perspectives in order to comprehend cultural evolution.

BEYOND THE MEME: ARTICULATING THE EXPLANANS

Although memetic approaches suffer from a variety of irremediable problems, one motivation for their introduction was venerable: start simple. It is a time-honored modeling practice to begin with simple models that involve relatively strong idealizations and appear disconnected from the phenomena of interest. (Recall the humorous jab at theoretical physicists modeling biological phenomena: "Assume a spherical cow in a vacuum . . .") The virtue of starting simple is visible in early population genetics, as well as in dual-inheritance theories of cultural evolution (e.g., Boyd and Richerson 1985). Consider the former. The assumption of panmixia, or random mating, played an important role in developments of neo-Darwinian evolutionary theory. This is marked by its prime location near the beginning of textbooks and alongside accompanying discussions of the Hardy-Weinberg principle in population genetics. Its use as a simplifying assumption nurtured the elaboration of several aspects of the mathematical theory. However, as is true of other simplifying assumptions, there also were drawbacks. For example, we have learned subsequently that population structures that violate the assumptions central to Hardy-Weinberg equilibrium are critical for engendering biological evolution. Population structure like groups, which arise either through selective breeding or localized interaction, can facilitate and elaborate adaptations that could not be supported at the individual level (reviewed in Wade 2016; for culture, see Sterelny 2012). The denial of any population structure in mating at the group level was equivalent to assuming an extremely strong form of blending inheritance, which rendered group selection and local population differentiation difficult or impossible (Wade 1978; Wimsatt 1980, 1981, 2002).

Although population structure was initially ignored in evolutionary theory, there were other systematic sources of structure within population genetics that derive from the architecture of the genome. They can be recognized by the fact that these features of genomic structure retard the rate of approach to Hardy-Weinberg equilibrium, causing deviations from random assortment or a maximally mixed distribution of elements. Representations of these sources of genomic structure have played crucial roles in the elaboration of evolutionary genetic theory and contributed new complexities in modeling the dynamics. First among these are linkage relations arising from the location of genes at different distances along the same chromosome. Other aspects of structure that originate in genetic architecture and were incorporated into population genetic models include diploidy (chromosomes in pairs, as in whole genotypes), in contrast with haploidy (single chromosome sets, as found in sperm and egg), haplodiploid mating systems as found in some of the social insects (with diploid queens and haploid sterile castes), and the role of diploid gametic organization in life cycles alternating between haploid gametes and diploid zygotes in sexual reproduction, which imposes a seldom recognized correlation in linkage models (Wimsatt 2007, 287–93). The effects of sex-linkage and age structure act as *segregation analogs* by retarding the rate of mixing and therefore attenuate the approach to a (maximally mixed) Hardy-Weinberg equilibrium of gene frequencies. Any element of population structure can act as a segregation analog with similar effects (Wimsatt 1981, 152–64; 2002, S9).

Evolution is substantially affected by *both* internal and external sources of structure. To emphasize this, Michael Wade coined the terms *endogenetics* (for what we call genetics) and *exogenetics* (for what we call population structure; Wimsatt 2002). We tend to treat genetics as crucial and population structure as a subsidiary complication, but they are equally important in determining evolutionary outcomes. This is nicely illustrated in the population genetics of the system of alleles affecting sickle cell anemia and malaria resistance (HbA, HbS, and HbC; Templeton 1982). The HbS allele causes sickle cell anemia in the homozygote (HbS/HbS) and confers malaria resistance in the heterozygote (HbS/HbA). The HbS allele arose four separate times and increased in frequency in regions of Africa where the incidence of malaria was high (Durham 1991). However, one also finds pockets of the apparently more recent HbC allele. When homozygous (i.e., HbC/HbC), this genotype confers malaria resistance without the ravages of sickle cell disease and is thus higher in fitness than any alternative. In this case, inbreeding (as would occur within small, relatively isolated groups) allows the HbC allele to grow in frequency because it occurs more frequently in the homozygote.

But under conditions of random mating (panmixia), this is not possible (Templeton 1982). In a population at equilibrium with HbA and HbS, HbC cannot invade, even with unusually high fitness, because at low frequencies it would occur primarily in heterozygotes of much lower fitness. Thus, HbC alleles would be eliminated before they could achieve the higher frequencies of homozygotes necessary to become established.

Michael Wade's distinction between endogenetic and exogenetic structure for population genetics and evolutionary biology is paralleled for cultural evolution by sources of internal and external structure. This volume explores the nature, variety, and impact of features that add structural elements that amplify evolutionary potential, as well as other characteristic features that must be accounted for in formulating an adequate theory of cultural evolution. These elements include the impact of sequential dependencies in the acquisition during development of cultural traits—a prime example of internal structure—and the roles of external structure, such as social institutions, organizations, and technological infrastructure, which scaffold segregation, learning, and cumulative culture in individuals and groups. Including these structures provides resources to deal with cultural traits that satisfy the diverse definitions surveyed by Krober and Kluckhohn (1952) or Driscoll (2017). As a consequence, this allows for more unified and compelling accounts of cultural evolution. The diversity of the kinds of structural elements yields both a more abundant range of phenomena and an increased number of evolutionary possibilities for cultural evolution than for biological evolution. However, many current models of cultural evolution are, for the most part, stuck at the earlier stages of theoretical development where the modeling assumptions do not include or recognize these diverse kinds of structure. One reason for this situation may be that researchers have not yet found good ways of incorporating this structure into their models. Another is that their assumptions hide the relevance of these factors (as with ignoring the role of technology). Regardless, the potential of these structural elements for mediating far more complex forms of adaptive evolution is therefore not usually taken into account.

A crucial structural element for cultural evolution is the fact that different aspects of culture are acquired sequentially throughout the life cycle. As a result, earlier acquisitions can act as necessary precursors that facilitate, inhibit, or transform the reception of later ones. This corresponds to the endogenetic structure provided in biology by the architecture of the genome. For instance, the language an individual learns channels all subsequent cultural additions. Humans acquire many complex skills that show strong sequential dependencies of this kind, especially in societies with robust social institutions. Consider the inculcation of mathematical skills, where arithmetic precedes algebra, which precedes geometry, which precedes calculus. A closer inspection of this standard sequence would reveal multiple intermediate dependencies, such as the pathway from elementary algebra, through intermediate algebra, and on to advanced algebra. Each of these introduces new tools, procedures, and concepts used at later stages. Similar patterns of dependencies are true for most of the sciences and for reading, as well as the modes of thought mediated by them. This is no less true for manual skills and for our social modes of interaction.

Much of culture can be seen as the construction of external structures, like our schools and learning curricula, to support the sequential acquisition of these competencies. Our culturally induced group structures—things like universities, business firms, and religious communities—interact with us and with these institutions, mediating knowledge acquisition and modes of collective action that we could not do individually. Furthermore, our technologies, while often credited with increased powers of production, have also become ubiquitous elements of scaffolding for our cognitive and cultural development. These operate both individually and collectively through an infrastructural generative reconstruction and extension of our cognitive and social niches. The interactive character of this scaffolding makes the articulation of endogenetic and exogenetic factors far more interpenetrating for culture than for biology.

The essays contained herein explore the impact of these structuring elements and their interactions in various elements of culture. These include spoken and written language, the institutional structure and interest groups of science, the evolution and descent relations of technology as reflected in patents, the role of prior theory in scaffolding the development of new theory, the cumulative effects of lithic technology, religion, irrigation practice, and the costs and adaptations required when adopting new technologies that challenge our entrenched practices. These cases begin to illustrate the interdisciplinary combinations required to address the problem agenda of cultural evolution. They document and account for interactive dynamics dependent on multiple structural dimensions and thereby encourage new directions for elaborating theory to explain the diverse possibilities for cultural evolutionary processes. Although the contributions do not always mention cultural evolution per se, they focus on relevant factors from theories in the social sciences. This is as it should be; social structures are of central import for cultural evolution and, from our perspective, should be incorporated into theoretical approaches to adequately account for the complex phenomenon. The evaluative standards for the problem agenda demand an evolutionary approach that genuinely integrates existing social, cultural, and technological theory, not one that trades social science approaches for simplistic genetic models of social structures and practices (cf. Wilson 1975). An evolutionary approach to culture necessarily *includes* social science disciplines. There is far too much of value in existing social science theory and allied analyses of phenomena. Existing attempts at theories of cultural evolution typically lack the intellectual resources to generate stable explanatory combinations incorporating the riches these accounts provide. The contributions to this volume jointly accent what is needed and point us, sometimes forcefully, in the direction of how to accomplish it.

RESEARCH AGENDA EXEMPLARS

In chapter 1, Wimsatt reviews the conceptual geography of cultural evolution and the kinds of elements required for an adequate explanatory account. This involves several additions to those factors typically considered in extant theoretical formulations. In particular, development plays a central role and includes two main interacting components: the developmental dependencies of individuals in acquiring complex skills and the social and institutional structures that scaffold this development. Interactions among these components involve an intercalation of both endogenetic and exogenetic elements. In turn, these elements interact with the development of groups (like business firms or professions) and the institutions they construct to mediate their interactions. All of these interactions are significantly scaffolded by evolving artifact structures. Some of these are general infrastructure, such as written language, exchange markets, or power and communication networks, whereas others are specialized to particular tasks and roles, such as mathematics curricula, machine tools, computer hardware and software, scientific theories, or medical training.

Wimsatt argues that an adequate theory of cultural evolution must be capable of incorporating, describing, and explaining these complex interactions. In order to do so, the roles of transmissible elements, developing biological individuals, organizations, institutions, and artifact structures must be delineated individually and articulated jointly, with special attention to understanding the scaffolding relations between them. The conceptual geography proposed is intended to provide a landscape in which the different forms of structure and scaffolding relations found in the other contributed papers can be situated in appropriate contexts of interpretation. This landscape then offers a template to guide the process of articulating the Babel of different approaches, perspectives, and subjects that are necessary to comprehend the polyphony of culture and its change through time. The inclusion of additional considerations of structure amplifies the range of phenomena that can be accounted for by theories of cultural evolution. It also encourages the synthesizing of theories for the evolution of culture, cognition, and technology. Furthermore, the use of these elements to make the criteria of adequacy within the problem agenda explicit encourages the use of categories and processes drawn from traditional social sciences, which then makes it possible to increase the explanatory power of an interdisciplinary theory of cultural evolution.

The next three articles (chapters 2–4) explore dimensions of scientific and technological change that operate at three different scales. Sabina Leonelli discusses the formation of two organizations for managing biological data and research that have become central to tens of thousands of researchers. The first involves an organization that acts to standardize ontologies in genomic and proteomics research. This standardization is an institutional creation that is crucial to communication across different databases and facilitates the conjoint utilization of the data contained therein. Although incommensurability was never a problem for communication between scientists across revolutions in the way some philosophers imagined in the 1970s, these fixed and institutionalized artifact structures turn out to be a crucial element for communication between modern computerized databases whose syntax is less tolerant of variation than the negotiated meanings of conversing scientists. Leonelli's second case involves the emergence of steering committees for model organism research in the United Kingdom, which play a central role in determining priorities, funding, and coordinating research. In both cases, these organizations emerged "spontaneously" (i.e., without central planning), and Leonelli documents the different factors and features of how they came into existence. These organizations have developed and maintain institutions that mediate communication and organize research, as well as scaffold activities, on national and international scales. Leonelli employs research from sociology on the formation of social movements to further understand the processes relevant to the origination of these organizations. Her analysis provides a paradigm for how work on cultural evolution can articulate with existing theory in sociology.

Nancy Nersessian employs her deep and multifaceted ethnographic research on the development of interdisciplinary investigations in bioengineering to look at knowledge production in the laboratory and the creation of new multidisciplinary communities. Her study illuminates how researchers from biology and bioengineering learn to build bridges between their disciplinary perspectives. This "bridge-building" activity includes the construction of laboratory systems, the integration of modeling and "soft" bioengineered experimental systems, and the training of both graduate and undergraduate students. Nersessian becomes a participant–observer in this activity through her involvement in the design of curricula to systematize such interdisciplinary training. All of this was possible because of her detailed tracking of laboratory life, the dynamics of research, and the intercalation of training and research practices in unparalleled breadth and depth. The resulting account of the coevolution of practices, experimental systems, research, training of individuals, and curricula simultaneously deals with multiple dimensions of experimental practice and culture, the interactive evolution of models and knowledge, and the role of all these factors in the generation of scientific careers. This is a remarkable exemplar for science studies generally, as well as for cultural evolution in particular, and a penetrating reflection of the necessary articulation of multiple analytical perspectives.

In an intricate and technically demanding narrative, Michel Janssen offers a groundbreaking analysis of how prior theory and mathematical methods can scaffold and structure the development of new theory. In doing so, he details how different elements facilitate this process in a productive manner. He considers five historical cases involving the transformation of classical mechanics and electromagnetic theory into quantum mechanics and relativity theory. Janssen exploits the nature of scaffolding explicitly to argue against a Kuhnian picture of scientific revolutions as destructive replacement and new reconstruction on different foundations. He paints a picture of subtle transformation and extension of theoretical structures. These often leave crucial elements of the older structure informing or supporting the newer edifice, which yields a continuity that makes the transformation intelligible and the progressive evolution of science plausible. The elements that are preserved in the transformation and the roles they play suggest problem-solving heuristics with broader import in cognitive psychology and elsewhere in science. Janssen's account is applicable to theoretical change in other domains and is an important contribution to the literature on scientific change more generally.

Chapters 5–7 provide different models of cultural processes and point toward more systematic perspectives in the study of cultural change. Jacob Foster and James Evans offer a theoretical structure that has been largely missing from theories of cultural evolution: an account of heredity in cultural and technological systems based on a general treatment of reticulate phylogenies. Although this allows for traditional tree-like phylogenies as a special case, their analysis makes it possible to treat cultural heredity in all of its complexities, including not only multiple parentage with contributions of different degrees but also skipped generations. Examples include the recovery of a buried artifact, inspiring subsequent invention, recombination of elements from different lineages, and the black boxing of sets of features that are subsequently inherited as a unit. The absence of such an account has been especially vexing because of the central role that heredity played in the development of neo-Darwinian evolutionary theory. This important theoretical contribution regarding formal characteristics of the reticulate aspects of cultural inheritance involves new concepts (e.g., transmission isolating and accelerating mechanisms) and new inferential tools that are particularly appropriate to the more plentiful "fossil" records we often find with technology in comparison to paleontology. In a striking parallel, most aspects of this structure also apply to the acquisition of information and skills in individual development, giving a further tool for the analysis of generative entrenchment throughout ontogeny.

Mark Bedau gives us a superb case study in his analysis of descent relations within the patent system. This is an unusually tractable and rich example that relates directly to technology but just as adequately represents the characteristics of descent and the modification of theories in the sciences. The patent record contains tremendous detail about inventions and their varied ancestors. Well-developed software tools are available for mining this detail. This combination of detail and methods to explore it establish a parallel with biological model systems, making the patent system an excellent model for cultural evolution ("the right organism for the job"). (These features also suggest it is an unusually appropriate case to apply Foster and Evans' analysis of cultural inheritance.) One of Bedau's striking findings is just how promiscuous technological inventions are (in the sense of the multiplicity of their parentage). The patent system model makes it possible to ask and answer new questions: Has the multiplicity of parentage increased since

WWII with increasing cross-disciplinary communication? This analysis nicely documents "door-opening" inventions where one technological invention stimulates other inventions in diverse areas.

Marshall Abrams uses agent-based modeling (ABM) to study the evolution of coordinated irrigation practices by different communities to manage limited water resources and pests in Bali (a paradigm case for anthropologists). ABM has the advantage of modeling a population of individual agents that may have different and modifiable characteristics and has become a common tool in modeling cultural evolution. These diverse characteristics could be the product of different programs for behavior, different experience (if their behavior is modifiable through learning), or both. In such populations, both individual characteristics and the spatial distribution (or population structure) of the agents they interact with matter and can be used to model the formation of complex task groups (see, e.g., chapter 12). (This kind of structural diversity was inaccessible to modeling before the advent of ABM and is an important move toward "thick description.") These interactions are studied with a large number of *Monte Carlo* simulations that have randomized values of variables other than those being scrutinized to get averaged effects of the experimental treatments. Although ABM dramatically increases the degrees of freedom one can model (parameters must be specified for each agent), it is also fraught with problems of how to interpret the results. Abrams's model succeeds in explaining the phenomena robustly, though it is relatively complex. However, he considers a simpler model that bundles interactions into a single parameter and shows that it does not work except under very limited circumstances. This demonstrates that under some circumstances model complexity is necessary to get empirically adequate results. It also corroborates earlier social science claims that the spread of religious practices favoring cultural *coherence,* which are also correlated with local success in crop yields, could have mediated the coordination of irrigation practices.

The next six chapters (8–13) explore diverse methodological problems and structural factors relating to the reproduction of skills and the transmission of knowledge. Flintknapping was a skill critical to the emergence of culturally abundant societies because of the role that cutting tools played in the production of many other artifacts that made diverse new practices possible. It required extended manual practice and tutelage from an accomplished master and is therefore a plausible prototype for the acquisition of specialized skills and knowledge. Gilbert Tostevin is a Paleolithic archaeologist who has both practiced and taught flintknapping. His chapter addresses the question of what the appropriate unit of analysis for the cultural replication process should be given that nothing is materially transmitted. Earlier generations of archaeologists focused on the finished product of the toolmaking process, but these can be produced in many different ways. Moreover, what is taught and learned is *how* to make it; the final product is the wrong target of analysis. (This is often true for the questions we want to answer for artifacts.) Tostevin applies the distinction between the intimate knowledge a member of the culture possesses (-emic or *savoir faire*) and anthropological nonnative knowledge (-etic or *connaisance*) to the teacher and the learner within the culture, respectively. This sensible observation broadens the application of the *emic-etic* distinction from one of methodological precaution in the interpretation of anthropological results to a widespread and important process in the transmission of culture. Here, the study of cultural evolution suggests an ampliative reinterpretation of anthropological theory. It also illuminates how the learning process is conceptualized. Different theories presume different processes for scaffolding the learning: simple reverse engineering, observation of the teacher making the product, gesturally and tactually assisted manipulation of the learner's hands, and language-assisted teaching. These can also be understood as one or more stages in a longer procedure. By carefully dissecting which details of the making process are visible to the learner who views it from a different perspective than the teacher, deeper insights into the complicated learning process and conditions for cultural reproduction emerge.

Linguist Salikoko Mufwene argues that spoken languages should be seen as communicative technologies that are hybrid biological–cultural products. These exist in and are conditioned by a variegated social ecology and constraints engendered by their mode of expression. According to Mufwene, the Chomskyian picture of an "innate language module" is inadequate on both biological and cultural grounds, whether in terms of the supposition of a single macromutation generating the language capacity or the independence of that capacity from a host of other cultural capacities that travel with it. In contrast, Mufwene uses evidence from phonology, morphology, and syntax to show that language displays the combination of constraints and variation one would expect for the evolution of any adaptation that is directed toward the solution of a common set of problems. For example, one cannot make multiple diverse sounds in parallel, and the resulting linear stream of language is unavoidable for spoken discourse. However, modality matters; sign language escapes this constraint because gestures can take place in three dimensions. Other technologies manifest similar patterns—how something is produced constrains the product. For language, Mufwene claims that naming comes first, followed by predication and an increase of vocabulary. Recursion increases economy and facilitates greater complexity of expression. In this sequence, there is a significant role for generative entrenchment and scaffolding. Spoken language made possible more effective cooperation and diffusion of skills and may have been required for the sophistication of many complex skills. Written language emerged slowly from numerical tallies. Advances in representing sounds increased the power and economy of language, which made cumulative culture possible. These together comprise the most general of infrastructural scaffolds in a society and essentially midwife all other skills.

Massimo Maiocchi reviews the origins of writing, which appears to have occurred independently four times (Mesopotamia, Egypt, China, and Mesoamerica), and then elaborates the case of Mesopotamia, which is better documented and researched than the other three. Written signs or counters first appeared in the eighth millennium B.C.E., but these became more elaborate between 4500 and 3500 B.C.E. with the appearance of inscribed counters and then bullae (hollow, sealed clay pockets containing counters) in Uruk. Large numbers of diverse clay tablets with cuneiform records from a slightly later time were also found there, some with an emerging syntax for the representation of numbers. Flat tablets made storage and indexing simpler and may have become more common for those reasons. Inscriptions originally served accounting purposes, and bullae probably validated legal contracts. This need and the use of clay left an entrenched legacy for subsequent written forms. Cuneiform writing grew out of signs that depicted the kinds of items represented. Lexical lists of diverse kinds proliferated, categorizing both objects and professions, accompanied by a system of weights and measures. However, it was hundreds of years before writing expanded to serve other functions, such as state administration, religious practice, and narrative history. Throughout this period writing was known and used only by a restricted class of scribes. Subsequently, phonetic languages permitted the representation of phonemes, making up words from other languages with a reduction of signs; alphabetic languages went further in reducing the number of signs required. Written language came to structure both social practices and individual cognition generally after moving beyond its more circumscribed role in governance, interpersonal interaction, and information storage.

Chapters 12 and 13 return us to more general issues. Joseph Martin focuses on the role that scaffolding plays in changes that accompany the adoption of new technologies. Scaffolding is relevant to support existing practices and those associated with new technologies, as well as the transitions between them. Martin distinguishes three ways in which newer technologies may relate to older ones: (1) displacement, such as when the internal combustion engine as a power source replaced the horse in propelling cars and trucks; (2) combination, in which a newer technology interacts with and complements an older one (e.g., the Internet can be scaffolded by cable networks); and (3) catalysis, in which a new technology interacts with an older one to generate new capabilities (e.g., how the Internet, with the computer, catalyzes a host of new activities, from electronic payment to the streaming of movies). Although new technologies can spread due to advantages manifested in any of these three ways, we must also consider trade-offs—what they may prevent or inhibit. Frozen dinners contributed to the downfall of family dinners and the interactions they facilitated; the advent of automobile-based suburbs made popular the construction of houses surrounding cul-de-sacs that protected children from through traffic, but their topology made bus or tram-based public transport impractical. What is lost in adopting new technologies leads us to focus on what changes to scaffolding are required to make the transition and what sources of resistance might be present. As Martin discusses, this can lead to better policy decisions when developing and introducing technology.

Paul Smaldino analyzes the function of social identity in facilitating cooperative group formation. Social identity is a particularly important tool in navigating affiliations in complex societies, which have large numbers of different social roles and many individuals who do not know each other personally but must interact with multiple groups in different contexts for different ends. How do such individuals assort into appropriate groups to serve their interests, develop competencies needed for professions, and find mates (inter alia)? For this we need a multidimensional social identity in which different aspects can be expressed in different contexts. (The phenomenon of register switching in language is one sign of changing behavior for these differing contexts.) As a consequence, we can participate in religions, condominium associations, professions, departments, neighborhoods, sports preferences, and team affiliations, plus have ethnicities, sexual identities, and age groups, each of which may compel us to act within that group in different ways to serve our needs and interests. As Smaldino notes, the needs of affiliation involve not only who to cooperate with for common interests but who *best* to cooperate with to serve those interests. Decisions of this kind may demand further differentiating information. In larger societies with more roles, stereotypes associated with identities may serve cognitive functions in conveying relevant information for coordination decisions, such as by signaling a high probability of common knowledge. Smaldino discusses different interactions that could be involved in group formation and how these play specific roles in societies of different size and structure. This chapter provides a crucial theoretical plank in understanding the emergence of complex societies and articulates naturally with Wimsatt's discussion of the need to deal with career trajectories that involve multiple, coordinated cultural breeding populations.

It is implicit in Wimsatt's "Articulating Babel" that an account of cultural evolution requires an unprecedented marshaling of diverse perspectives with local theories. Practitioners often have overestimated the generality, power, and completeness of their particular perspective. Combining these perspectives requires two things. First, practitioners must recognize how and where their perspectives are relevant to generate an adequate explanatory account while accepting that, as perspectives, each of their vantage points is individually incomplete in addressing the complex phenomenon of cultural evolution. The endeavor of making the problem agenda structure explicit and detailing the associated criteria of adequacy provides a rationale for both the relevance and incompleteness of individual theoretical perspectives.

Second, the structure and criteria of adequacy for the problem agenda of cultural evolution demand that the relevant but incomplete theoretical and methodological perspectives articulate with one another in a coordinated fashion to answer different research questions. This is the topic of chapter 13 by Claes Andersson, Anton Törnberg, and Petter Törnberg. They describe *wicked systems* generally, which have characteristics common to the complexity we have observed for cultural evolution. How do such systems arise? Ecological and societal systems combine bottom-up features of complex systems (e.g., path dependence, nonlinearity, chaotic dynamics, and multiple relevant overlapping boundaries) with the top-down organization of complicated systems (e.g., many components, different relaxation times of their interactions, and irregular connectedness). The fact that these diverse facets comprise wicked systems and are studied in different disciplines, which reveal different aspects of the phenomenon of interest, increases the urgency of heeding the organizational structure and criteria of adequacy inherent in the problem agenda. Only this provides an antidote to claims that one theoretical perspective derived from a particular discipline offers a uniquely systematic viewpoint on cultural evolution. The essay by Andersson et al., along with the other contributions to this volume, substantially augment the number and kind of handles available for managing the complex domain of cultural evolution and determining the biases inherent in our modeling simplifications. This will encourage us not only to go beyond the meme but also to better marshal our collective investigative efforts to interdisciplinarily explain the evolutionary dynamics of different facets of culture.

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