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Stability and Change in Paleolithic Toolmaking

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Introduction

Culture is remarkable in its capacity to sustain both rapid change and enduring traditions. The rise of social media has occasioned a tectonic shift in cultural norms, language, economics, and politics in less than 20 years, and yet schoolchildren still sing nursery rhymes that are hundreds of years old and learn about farm animals few of them will ever encounter. Different cultural evolutionary research traditions have tended to focus on explaining either the adaptive flexibility or the stable rigidity of cultural traits (Sterelny 2017) and thus emphasized either processes of information transmission and incremental modification (Richerson and Boyd 2005; Henrich 2016; Laland 2018) or stabilizing factors of convergent reconstruction (Sperber 1996; Scott-Phillips, Blancke, and Heintz 2018; Strachan et al. 2021). Each of these is clearly relevant to understanding human culture, and many of the disagreements between the two traditions may be more apparent than real (Sterelny 2017). Nevertheless, theoretical emphases do play an important role in generating research questions and framing expectations. This chapter considers how the expectation that humanlike culture is characterized by change and diversification rather than stability and convergence has influenced interpretations of the Paleolithic archaeological record and shaped big-picture hypotheses about human evolution.

Stability and Change in the Paleolithic

The early archaeological record is widely thought to present a dilemma for human evolutionary studies. On the one hand, even the simplest known Paleolithic tools appear to be outside the behavioral range of modern nonhuman primates (Harmand et al. 2015, 142; Toth, Schick, and Semaw 2006; Braun et al. 2019; Stout et al. 2019) and are thus evocative of humanlike cultural capacities (Holloway 1969; Gärdenfors and Högberg 2017). This includes the reliable reproduction of particular tool forms across vast spans of time and space (Mithen 1999). On the other hand, many scholars consider rates of change in Paleolithic tools to be inhumanly slow and lacking the patterns of diversification and incremental improvement expected from full-fledged cultural evolution (Tennie et al. 2017; Richerson and Boyd 2005; Corbey et al. 2016; Foley 1987). This conundrum has led to various special explanations for the "monotonous" (Isaac 1976) and "bewildering" (Richerson and Boyd 2005) lack of Lower Paleolithic spatiotemporal variation, including proposals that stone toolmaking behaviors were genetically encoded rather than learned (Richerson and Boyd 2005; Corbey et al. 2016) or that Lower Paleolithic hominids lacked the cognitive capacities for innovation (Mithen 1999), imitation (Tennie et al. 2017), or effective teaching (Morgan et al. 2015) necessary for cumulative culture evolution.

These conjectures offer solutions to the problem of Paleolithic invariance, but is this really a problem we need to solve? How strong are expectations defining "humanlike" rates of culture change, and where do they come from? This is an important question insofar as it concerns underlying assumptions that guide hypothesis generation and evaluation. For example, Claudio Tennie and colleagues (2016, 2017) offer slow rates of change as one of several reasons to assume (until proven otherwise) that high-fidelity social transmission was absent in the Paleolithic. Accepting such a "null hypothesis" would make the presence of cultural learning in the Paleolithic an exceptional claim requiring exceptional evidence, and it would have important implications for our ability to recognize and study the borderline or intermediate cases critical to gradualist evolutionary accounts (Stout 2017; Stout et al. 2019).

Similarly, the suggestion that the detailed form of Acheulean bifaces was genetically constrained (Richerson and Boyd 2005), for example, by a "predisposition toward the basic behavioral routines involved, such as invasive bifacial reduction while realizing cutting edges in the secant plane, working from the tip down, and keeping symmetry" (Corbey et al. 2016, 14), potentially offers a cure that is worse than the disease insofar as it posits a level of detail in the genetic instruction of behavior that is theoretically questionable (Laland et al. 2015) and unlike anything known in modern primate tool behavior (Wynn and Gowlett 2018). These concerns echo earlier debates about the plausibility of a genetically specified "universal grammar" underlying human language (e.g., Deacon 1997), an idea that has arguably acted as a major impediment to progress in the study of language evolution (Christiansen and Chater 2017). Considering the theoretical and disciplinary stakes of attempts to resolve the dilemma of Paleolithic stability, it seems wise to make sure that there really is a problem in the first place.

In this chapter, I will argue that the dilemma of Paleolithic stability is more apparent than real and that this misapprehension highlights problems with a number of underlying assumptions about the nature of human culture and technology. These include the prevailing "information transmission" paradigm in cultural evolutionary studies, the dichotomization of individual versus social learning, a taxonomic approach that ranks social learning mechanisms in terms of intrinsic fidelity, and the view that human cultural evolution is broadly directional. Implicitly or explicitly, these assumptions have been built into the highly successful "cumulative cultural evolution" concept that has framed the debate around the origin of human technology in terms of the emergence of particular social learning mechanisms such as imitation or teaching. As an alternative, I advocate a complex, contingent, and variable vision of Paleolithic technological change and stability as resulting from the evolutionary and developmental interaction of a wide range of ecological, cognitive, material, and social factors (Stout 2021a). These factors include, but are not limited to, the rigidity or flexibility of individual cognitive processes supporting technological innovation and social reproduction (Gergely and Király, this volume; Strachan, Curioni, and McEllin, this volume; Roux et al., this volume).

What Is Technology?

Before proceeding, it is necessary to specify what we mean by "technology." Perhaps surprisingly, this is not a simple question. According to Leo Marx (1997), the term *technology* has its origins in the seventeenth century but did not come into widespread popular usage until the 1930s. In this process, its original meaning as a field of study focusing on the "useful" or "mechanic" arts shifted to a far more sweeping label for the new configurations of materials, institutions, and socioeconomic relations of the industrial revolution that were so radically transforming society. As such, technology emerged as a concept intimately entwined with notions of power, progress, and value and was used to both promote and critique an emerging capitalist system (Marx 1997). Arguably, this contributed to an even further broadening of meaning in which technology can refer to anything from a collection of physical hardware (tools and machines) to an abstract system of rules (Dusek 2006) and is commonly used as a marker of prestige or importance rather than a theoretically meaningful label.

For example, even the simplest Paleolithic stone tools are conventionally referred to as products of a "lithic technology" for little apparent reason other than the fact that they were tools. This terminology implicitly asserts the evolutionary importance, cultural nature, and human uniqueness of the earliest stone artifacts by linking them to a broader narrative of technological progress over human evolution (cf. Kuhn 2021). It is not usually seen to require explicit justification despite ongoing debates about precisely these points (e.g., Tennie et al. 2017; Wynn et al. 2011). Conversely, authors wishing to emphasize continuity with nonhuman primates have applied the label "technology" to ape and monkey tool use (Wynn et al. 2011), again without explicit justification. These usages may or may not be appropriate—the key point is that absence of any justification or discussion essentially reduces technology to a prestigious synonym for "tool" (see also Osiurak and Heinke 2018).

At the other end of the spectrum, the meaning of technology has been expanded to include everything from music (Patel 2019) to behavior modification (Skinner 2002). For example, French philosopher Michel Foucault wrote extensively about modern "technologies of power." While these could implicate material elements (e.g., bodily techniques, spatial arrangements), they are technological primarily in the sense of being a system of social rules or practices (Behrent 2013). This allowed Foucault (1988) to enumerate technologies of production, sign systems, social control, and the self without worrying about whether any actual tools, machines, or equipment were involved. Foucault's approach to technology as a social phenomenon seems to have arisen out of contemporary interest in industrial organization and reflects a deep ambivalence about the progressive versus dehumanizing effects of emerging technological systems (Behrent 2013). However, it also risks robbing the concept of technology of any specific meaning by expanding it to encompass almost any aspect of human culture and cognition. Are kinship systems a form of social technology? Do traditional meditative practices constitute a technology of the self? Are languages and number systems cognitive technologies? These questions are evocative but present a technology concept that is arguably too broad and amorphous for systematic theoretical analysis.

A reasonable middle path between over-reduction and over-expansion is supplied by the *technological systems* approach, which defines a technology as an integrated system of hardware, people, skills, knowledge, social relations, and institutions applied to practical tasks (Dusek 2006; Hughes 1987). This conceptualization is specific in a way that respects the history (Marx 1997) and colloquial usage of the term, thus avoiding confusion while retaining key features that made technology seem like an interesting topic in the first place. However, it leaves the critical question of what exactly constitutes a "practical task" unaddressed—essentially asking readers to make a subjective and value-laden judgment about what qualifies. To address this, I (Stout 2021a) proposed an evolutionary grounding of the concept in which technological tasks are practical in the specific sense that they involve the kind of material production necessary to support distinctive human life history and reproductive strategies.

In this "technological niche" (Stout and Khreisheh 2015; Stout and Hecht 2017), surplus production funds a biocultural reproductive strategy (Bogin, Bragg, and Kuzawa 2014) in which community members who may not be close biological kin donate resources (e.g., time, effort, food) to support offspring. This strategy allows costly investments in extended development and reduced offspring mortality without reducing fertility rates, thus supporting the protracted learning periods, extended life span, and large brain size that enable further surplus production (Kaplan et al. 2000) through the innovation and intergenerational reproduction of technological skills, knowledge, and equipment (Henrich 2016; Richerson and Boyd 2005; Laland 2018). Critically, this framework emphasizes that technological skills and knowledge are not simply "transmitted" or copied across social networks but must be actively reproduced (cf. "reconstructed" in Strachan et al. 2021) by individuals through extended learning processes (Lew-Levy et al. 2017) involving a complex mix of social interaction and individual trial-and-error practice (Sterelny, this volume; Ericsson, Krampe, and Tesch-Romer 1993; Lave and Wenger 1991). Building on the technological systems approach, this evolutionary framing supports a theoretical definition of technology as a behavioral domain of socially reproduced, collaborative activities involving the manipulation and modification of objects to enact changes in the physical environment.

According to this definition, technologies extend beyond simple tool use to encompass longer causal chains (e.g., use of a tool to construct a mechanism to harvest a resource to make a product) involving (1) the coordinated activity of many individuals, (2) the use of objects and materials in a wide range of roles other than as handheld instruments, and (3) the processes of social reproduction that sustain and elaborate technological systems. At the same time, this definition constrains technology to *materially instrumental* activities primarily intended to produce physical effects and excludes *communicative* activities primarily intended to affect the thoughts, behaviors, or experiences of the self or others. Whereas culture is a broader term that clearly encompasses both kinds of activity, technology is here defined by its focus on the former.

This definition recognizes that communication is an inherent part of the collaboration and social reproduction characteristic of technological systems but also specifies that it is not their ultimate goal or product. Thus, there could be technologies for the production of physical communications tools such as books, musical instruments, or computer networks, but there would be no "technologies" for training people in these skills, nor for effective storytelling, musical composition, rhetoric, or social messaging. Systematic approaches in these communicative domains might then be termed "arts" or "sciences" rather than technologies. This semantic distinction is important because materially instrumental versus communicative goals tend to present different functional demands, design constraints, and cultural evolutionary dynamics. This reflects the fact that the former are shaped by physical situations and materials, which may be relatively invariant across time and space, whereas the latter address human psychology in the context of specific cultural systems of meaning. Of course, some instrumental goals (e.g., production of particular artifact shapes, textures, or colors) are themselves occasioned by superordinate communicative goals. The stance advanced here is that it is nevertheless both possible and useful to distinguish the material constraints relevant to the former from the culturally situated psychological constraints on the latter. More to the point, this definition is not intended to lead to hair-splitting arguments about whether liminal cases are or are not proper “technologies” but rather to a focus on what is theoretically interesting about technologies (Stout 2013) and a more careful analysis of interwoven technological and nontechnological aspects of cultural phenomena (Stout 2021a).

Paleolithic Technologies?

By this definition, it is not immediately clear that various Paleolithic stone toolmaking behaviors actually qualify as technologies. Rather than arguing over the label, however, this should serve to focus our attention on assessing the expression of the three core features of technology: production, collaboration, and reproduction. Critically, these are not traits that can simply be ticked off as present or absent; rather, they are dimensions of variation. Focusing on these aspects encourages us to take a closer look at the archaeological evidence from multiple perspectives. Although quite a bit of recent attention has focused on assessing the nature of social reproduction mechanisms indicated by early stone tools and the implications for rates of change (Tennie et al. 2017; Morgan et al. 2015; Gärdenfors and Högberg 2017; Stout et al. 2019), this has been largely independent of attention to the complexity of production systems or demands for collaborative action. And yet these dimensions are clearly related to one another. The theoretical definition of technology adopted here directs our attention to this broader set of interacting factors when attempting to understand stability and change in the Paleolithic.

For example, what indications are there for longer technological production chains extending beyond immediate handheld tool use? In the earliest record, we might consider resource procurement, transport, and management (Reeves et al. 2021; Linares-Matás and Clark 2021) as well as the possibility that lithic artifacts were themselves part of a larger system for the production and use of wooden hunting and digging tools (Hayden 2015). More direct evidence for expanding technological systems comes later—for example, in the production of shaped antler and bone percussors that were themselves used as equipment for stone toolmaking (Stout et al. 2014; Moigne et al. 2016) and with the subsequent appearance of hafted, multicomponent tools (Barham 2013). In addition to placing increased demands on mechanisms of social reproduction (Pargeter, Khreisheh, and Stout 2019), such increases in complexity may themselves be inherently destabilizing and tend to favor increased rates of change. This is because (1) highly connected, interdependent systems are more susceptible to rapid transitions, including collapse (Scheffer et al. 2012), and (2) increasing technological complexity may have autocatalytic effects on innovation and diversification as more elements become available for recombination (Stout 2011; Lewis and Laland 2012). These potential effects of size and complexity on rates of change and stability further direct our attention to the collaboration needed to support elaborated technological systems.

Technology is perhaps most clearly distinguished from simple tool use by its mobilization of collaborative action by many individuals over extended periods of time. This is allowed in part by the concrete materiality of technology, which provides a durable medium for interaction across time and space, but it also requires underlying cognitive and social mechanisms for interactive coordination (Stout 2021a). Despite the fact that this capacity for collaboration is regarded as a distinctive and critically important human social cognitive trait (Tomasello and Gonzalez-Cabrera 2017), it has received relatively little attention in the study of Paleolithic stone tools. Evolutionary accounts have instead focused on zooarchaeological evidence of cooperative hunting (e.g., Stiner, Barkai, and Gopher 2009) or an inferred context of cooperative breeding (Hrdy 2009; Hawkes 2014). This perhaps reflects an implicit perception of stone toolmaking as a solitary activity or the pragmatic difficulty of identifying signatures of collaboration that would be visible in the lithic record. However, modern human lithic technologies are often highly collaborative (Reynolds 1993; Stout 2002; Apel 2001), and the possibility of Paleolithic collaboration warrants further attention. Theory (Stout 2021a) and ethnographic evidence suggest that collaboration is increasingly likely as lithic technological systems become more complex—for example, in the production of hafted tools (Stout 2002; Reynolds 1993). Activities such as the quarrying of large flake blanks (Shipton 2013) for Acheulean handaxe making, the production of complex adhesives for hafting (Wadley, Hodgskiss, and Grant 2009), and the heat treatment of lithic raw materials (Brown et al. 2009) seem to be promising subjects of study in this regard.

In sum, social reproduction is clearly a core feature of technology, but it is unlikely to tell the whole story of why and how fast Paleolithic technologies emerge, change, and disappear. Critically, increasing technological complexity and the more extensive collaboration required to support it come with costs as well as benefits. Longer production chains obviously require more immediate effort but also increased investments in the skill acquisition (Pargeter, Khreisheh, and Stout 2019) and social coordination (Currie et al. 2021) required to maintain them. For technological innovation to occur, benefits must outweigh these costs in the currently prevailing socioecological setting. This creates the possibility for fitness valleys separating highly stable local optima from theoretically possible increases. A classic example is the spread of agriculture, which was not a simple process of invention and adoption but rather involved complex coevolutionary interactions of changing crops, environment, and social institutions (Bowles and Choi 2013). Conditions of Paleolithic technological change are less well known but are likely to have involved multiple factors in addition to hominin social learning capacities (Tennie et al. 2017) and the population dynamics of information transmission (Powell, Shennan, and Thomas 2009; Derex and Mesoudi 2020). In order to create theoretical space for these more diverse causal pathways, it may be helpful to reconsider the core "culture as information" paradigm that dominates cultural evolutionary theory (Stout 2020).

Culture as Information

By the mid-twentieth century, the Modern Synthesis (MS) of evolutionary theory had firmly established evolutionary biology as a mathematical and statistical enterprise dealing in abstract genetic units (Pigliucci 2009). The central "genes as information" paradigm embodied by the MS was succinctly expressed by Eörs Szathmary and John Maynard Smith (1995, 231), who wrote: "Developmental biology can be seen as the study of how information in the genome is translated into adult structure, and evolutionary biology of how the information came to be there in the first place." This informational metaphor was rapidly appropriated to describe human culture as "an information-holding system with functions similar to that of cellular DNA" such that "the instructions needed for coping with the environment and performing specialized roles are provided by learned information, which is symbolically encoded and culturally transmitted" (d'Andrade 1984, 198). In anthropology, such symbolic informational approaches soon fell out of favor and were replaced by more enactive (Geertz 1973), dialectical (Giddens 1976), and embodied (Bourdieu 1977) conceptions of culture as something people *do* (e.g., practice theory). However, the informational conception has remained dominant in the study of cultural evolution. As Peter Richerson and Robert Boyd (2005, 5) specify: "Culture is information capable of affecting individuals' behaviors that they acquire from other members of their species through teaching, imitation, and other forms of social transmission."

This is somewhat ironic, as the population-based gene-culture coevolutionary thinking pioneered by scholars like Richerson and Boyd has now become an important part of an "Extended Evolutionary Synthesis" (EES) specifically questioning the MS conception of biological evolution as the transmission and expression of genetic information (Laland et al. 2015). The EES proposes a more inclusive and materially grounded conception of evolution in terms of dynamic, multidirectional processes such as reciprocal organism-environment causation, constructive development of adaptive phenotypes, and inclusive inheritance through nongenetic social, cultural, ecological, physiological, and epigenetic mechanisms. As a result, a wider range of evolutionary causes beyond mutation, selection, drift, and gene flow are emphasized. There is some controversy as to whether the processes highlighted by the EES are actually novel or important for evolutionary theory (e.g., Futuyma 2017), but there does seem to be broad agreement that they are worthy of further investigation. The suggestion here is that the cultural evolutionary component of inclusive inheritance could use a similar rethink. As with the EES more broadly, this should not be construed as a repudiation of past work or even as presenting previously unrecognized mechanisms and empirical findings. In fact, one of the reasons the EES has been so controversial is that its primary contribution is theoretical or even philosophical rather than empirical (Pigliucci and Finkelman 2014). The EES takes a stance on the nature and goals of evolutionary explanation whose relevance and appeal will depend on the questions and objectives of different research programs (Welch 2017). This is equally true with respect to the study of cultural evolution.

Richerson and Boyd (2005, 259) explicitly state that their definition of culture as information is a pragmatic one, intended to promote productive research, rather than the only possible one. In this respect, it has clearly been successful and has generated an ever-growing body of literature elucidating everything from the influence of population size and structure on cultural evolution (Henrich 2004; Derex and Mesoudi 2020) to the relevance of variation in learning strategies (Kendal et al. 2018; Miu et al. 2020). As with gene-centered approaches to biological evolution (cf. Welch 2017), the power of this informational approach stems from its relative simplicity, broad generalizability, and amenability to formal modeling. However, these broad strengths may be less well suited to explaining the precise causal-historical details of particular cases (Stout 2018), especially when variables employed in formal models are difficult to relate to empirical measures of real-world data. This parallels the case with the EES, which may be most relevant and helpful to researchers interested in explaining particular evolutionary histories (cf., Welch 2017).

Transmission or Causation?

According to the EES, "phenotypes are not inherited, they are reconstructed in development" (Laland et al. 2015, 1–14). The same might easily be said of cultural concepts and practices. In fact, the need for such individual "reconstruction" is a core premise of Cultural Attraction Theory (CAT) (see Sperber 1996; Sterelny 2017; Strachan et al. 2021; Scott-Phillips, Blancke, and Heintz 2018; Claidière, Scott-Phillips, and Sperber 2014). Illustrative examples of CAT tend to focus on communicative (e.g., songs, jokes, stories) rather than technological culture. They thus emphasize psychological rather than ecological and material explanations (Scott-Phillips, Blancke, and Heintz 2018) and often continue to describe culture as transmitted information (e.g., Strachan et al. 2021). Critically, however, CAT explicitly extends to practical skills and material mechanisms of attraction and more precisely theorizes cultural reconstruction and attraction as products of complex causal chains rather than information transmission. This conceptual shift from information transmission to causal relations is subtle but important and mirrors the EES move to a more inclusive vision of inheritance involving more than just genes. While a case can be made that DNA codes information (Maynard Smith 2000), and intentional communication certainly does, material conditions influencing evolution (e.g., constructed niches) or skill learning (e.g., equipment) can be considered "information" in only a loose metaphorical sense. Causal relations provide a more robust and inclusive framework for thinking about the diverse mechanisms potentially involved in reproducing and altering the patterns of behavior that constitute culture (cf. Roepstorff, Niewöhner, and Beck 2010).

This is especially true of technology. Causal mechanisms potentially contributing to technological stability and change extend beyond learning processes per se to include relative costs and benefits in particular behavioral systems and ecologies (Režek et al. 2018; Pargeter, Khreisheh, and Stout 2019), social structure (Derex and Mesoudi 2020) and institutions (Bowles and Choi 2013; Brahm and Poblete 2021; Roux 2010), intrinsic features of (Stout 2021a) and interactions between (Kolodny, Creanza, and Feldman 2015) technologies, and potential coevolutionary relationships between these diverse factors (Strassberg and Creanza 2021; Kolodny, Creanza, and Feldman 2016). Indeed, the cultural evolution literature is already replete with examples of material and other causes of technological stability and change, including functional design demands, inflexible production processes, technological entrenchment, innovation cascades, market integration, and environmental change (reviewed by Mesoudi et al. 2013, table 11.2). In the information transmission paradigm, however, such particular features are viewed as proximate mechanisms inflecting local rates and patterns of change rather than ultimate explanations for the origin of cultural diversity and adaptation. As in gene-centered approaches to biological evolution, the latter are expected to be expressed in purely terms of the population dynamics of information variation, transmission, and selection.

An alternative approach would be to emphasize the causal power of such "proximate" mechanisms to actually drive evolutionary change (cf. Laland et al. 2015). For example, there is some debate in the cultural evolution literature over whether technological innovation is usually blind and random (i.e., like genetic mutation), with optimization purely due to selective retention, or whether individual learning commonly acts to "guide" variation toward desired outcomes and allow for optimization even in the absence of selection (Mesoudi 2021). A largely neglected third possibility in this debate is that material and social conditions can also guide variation and affect retention. A simple nonhuman example is the way in which the durability of artifacts associated with primate tool use can facilitate the reproduction of tool behavior (Fragaszy et al. 2013). In humans, ecology, ideology, and economics can affect the nature, frequency, and retention of innovations (Lew-Levy et al. 2020; Greenfield 2003; Macfarlane and Harrison 2000), and particular technologies may be more or less evolvable due to the modularity versus interdependence of component parts or procedures (Martin 2000; Mesoudi and O'Brien 2008; Charbonneau 2016). The famously accidental discovery of penicillin by Alexander Fleming was made a lot more likely by the physical and institutional infrastructure of his bacteriology lab at St. Mary's Hospital, and even then, purification, clinical application, and mass production of penicillin took more than a decade of effort from a large community of people receiving government support in a wartime setting (Gaynes 2017). The further one zooms in on particular histories of technological change and stability, the more helpful it becomes to consider diverse causes beyond information variation, transmission, and selection. As argued in the previous section, the utility of such particularism may often depend on the nature and scale of the questions being asked. Growing appreciation of the complex, multilineal, intermittent, asynchronous course of human evolution (Antón and Kuzawa 2017; Falk et al. 2005; Holloway et al. 2018; d'Errico and Stringer 2011; Vaesen and Houkes 2021) suggests that greater resolution may be needed to adequately explain the origins, tempo, and mode of cultural evolution in the Paleolithic.

Cumulative Cultural Evolution?

Another foundational premise of the informational paradigm is that there exists a strict dichotomy between social and individual learning, with the former providing the information transmission mechanisms necessary for adaptive cultural evolution to occur (e.g., Boyd, Richerson, and Henrich 2011). Early on, this was perceived to produce a paradox insofar as a mixed population of individual and social learners has an equilibrium mean fitness no higher than a population of pure individual learners (Rogers 1988). This is because the benefits of social learning are frequency dependent under the assumption that copying is cheap but fails to track environmental change or produce fitness-enhancing innovations. However, Robert Boyd and Peter Richerson (1996) showed that allowing individuals to pursue mixed strategies of individual and social learning can indeed produce incremental improvement in a fitness-enhancing skill and thus increase population mean fitness. Eventually, this can lead to the emergence of skills that would have been beyond the inventive capacity (the "reaction norm") of individuals in the first generation, a process that Boyd and Richerson dubbed "cumulative cultural evolution" (CCE).

This model assumed that social learning requires specialized psychological mechanisms that come at some cost. This stance was inspired by the cultural learning concept (Tomasello, Kruger, and Ratner 1993) that sought to explain human cognitive uniqueness as a product of enhanced social learning mechanisms including imitation, instruction, and collaboration. High-fidelity reproduction by these mechanisms was proposed to support a cultural evolutionary "ratchet effect" that allowed the accumulation of modifications over generations, later described as "improvement" (Tomasello 1999, 5) and attributed to one key biological innovation that put humans on a qualitatively different cultural path of evolution. The assumed costs of high-fidelity social learning were found to create a barrier to the initiation of CCE (Boyd and Richerson 1996), potentially explaining its rarity in nature. According to this argument, accumulation must begin with simple skills that are within the inventive potential of individuals. Insofar as the benefits of learning these skills socially (i.e., decreased cost) remain small relative to the costs of enhanced social learning mechanisms, this creates an "adaptive valley" that must be crossed before CCE can start to produce the body of complex, difficult-to-learn, and useful cultural content that would allow these expensive mechanisms to pay for themselves and initiate sustained biocultural feedback. These ideas lead to a picture of CCE as a unique and characteristic human trait—a unitary capacity that emerged as a key event (Boyd, Richerson, and Henrich 2011; Tomasello 1999) or a crossing of a coevolutionary Rubicon (Henrich 2016) that put humans on a novel evolutionary trajectory.

However, there is substantial evidence that the cognitive processes and neural systems supporting social and individuals learning actually overlap extensively (Heyes 2018; Olsson, Knapska, and Lindström 2020). Considering them as independent traits in evolutionary modeling may thus be misleading. More conceptually, CAT collapses the social and individual dichotomy by focusing on complex processes of reconstruction rather than straightforward transmission or copying of information (Claidière, Scott-Phillips, and Sperber 2014; Sterelny 2017). This is again particularly relevant and convincing in the case of technology. The materiality of technology often demands precise control of physical contingencies in pursuit of complex goals, and this in turn demands a protracted, collaborative learning process, including dedicated practice in supportive material and social contexts (Stout 2021a; Stout and Hecht 2017). Such intertwined social, individual, and contextual mechanisms are clearly problematic for any strict dichotomy between social and individual learning. Because different technologies are also expected to vary substantially in their particular cognitive and motor demands (Stout 2021a), this also problematizes any attempt to characterize particular learning mechanisms as inherently "high" or "low" fidelity.

The informational paradigm posits a diverse taxonomy of social learning mechanisms ranked by transmission capacity and fidelity. From low to high, the three most widely used categories are *stimulus enhancement* (direction of attention), *emulation* (copying action goals or outcomes), and *imitation* (reproducing specific behavioral means). Although there is some confusion in the literature over the precise meaning of "imitation" (Heyes 2021; Stout et al. 2019), it is commonly argued to be critical to the ratchet effect of CCE (e.g., Tennie, Call, and Tomasello 2009). However, real-world learning and behavior occur on multiple levels of organization and across extended periods of time. Distinctions between goals and means (Stout et al. 2019) and measures of reproductive fidelity (Charbonneau and Bourrat 2021) thus depend on the scale of analysis, and the relevant scale depends on details and objectives of the behavior in question (Stout 2021a; Legare and Nielsen 2015). Similarly, it is expected that the utility of learning strategies ranging from independent exploration to end-state emulation or body movement reenactment will depend on the specific skills to be reproduced rather than some inherent information transmission capacity (Heyes 2021; Stout and Hecht 2017). For example, under even moderately variable conditions, increased reliance on individual trial-and-error learning can actually lead to higher reproductive fidelity than precise behavior-copying (Truskanov and Prat 2018). Experimental work with transmission chains has similarly shown that the importance of different learning mechanisms depends on the particular task and context being studied (Caldwell 2020). Even greater diversity and variability can be expected in the real world, including the Paleolithic.

The recognition of a distinct form of “cumulative” culture evolution emerged as a useful marker in a debate over the possibility of fitness-enhancing gene-culture coevolution (Boyd and Richerson 1996) and has led to much work on the importance of reproductive fidelity and innovation (Lewis and Laland 2012), social learning strategies (Kendal et al. 2018), and population size and structure (Henrich 2004; Powell, Shennan, and Thomas 2009; Derex and Mesoudi 2020) on cultural adaptation. In hindsight, however, it is not clear that the concept of cumulative culture captures anything that is not already encompassed by concepts of inheritance, adaptation, and persistent evolutionary trends that have already been extensively theorized in evolutionary biology (Stout 2021b). Insofar as the concept of fitness is undertheorized in cultural evolutionary studies and invariably represented by some kind of proxy variable (Mesoudi and Thornton 2018), the core CCE criterion of “iterative improvement” carries substantial risk of progressivist misinterpretation. It might thus be preferable to revert to the more precise and the less value-laden terminology from evolutionary biology.

Directionality in Human Evolution

Taken together, these critiques of the informational paradigm highlight a causal diversity that decenters social learning mechanisms as the key factor determining the stability and evolvability of technologies. In so doing, they undermine the influential idea that cumulative culture capacity is a unitary trait dependent on one (Tomasello 1999) or several (Boyd, Richerson, and Henrich 2011; Henrich 2016) key psychological adaptations for learning from other people. If cumulative culture is not a species typical characteristic of *Homo sapiens* (Vaesen and Houkes 2021) that emerged at some key point in our past, then the long-term persistence of some Paleolithic technologies appears less in need of special explanation (or at least not more so than any other case of technological stability or change).

Of course, all this theorizing is well and good, but isn’t it an *empirical* fact that human evolution has followed a unique and consistent path in need of some unifying explanation? There are many unknowns in human evolution, but one thing that has long seemed clear is that our evolutionary history has been characterized by long-term parallel trends toward increasing brain size (Du et al. 2018) and technological sophistication (Stout 2011). The apparent consistency of these trends over so much time and space, and presumably very different selective contexts, has suggested to many that they reflect some kind of intrinsic biocultural feedback dynamic (Washburn 1960; Isler and van Schaik 2014; Holloway 1981; Miller, Barton, and Nunn 2019). Indeed, such feedback lies at the heart of the technological niche concept used to motivate the theoretical definition of technology adopted here (Stout 2021a). Such logic leads one to expect that once this powerful coevolutionary process gets started by some “initial kick” (Holloway 1981), key cognitive adaptation (Tomasello 1999), or crossed threshold (Henrich 2016), it should become self-sustaining across diverse conditions and thus produce the long-term directional trends thought to characterize human evolution on a macro scale.

But what if human evolution is not actually characterized by such trends? For example, Krist Vaesen and Wibo Houkes (2021) have argued that there is actually very little evidence that human cultural evolution has been predominantly cumulative, showing iterative improvement in performance over time (Mesoudi and Thornton 2018). This is perhaps unsurprising for communicative aspects of human culture (e.g., art, religion, ritual) in which performance is always relative to specific cultural and psychological contexts and long-term "improvement" can be an elusive concept. More surprisingly, it may also be true of technology. Technology is the domain most commonly referenced in studies of cumulative culture because its material goals, means, and payoffs appear more easily comparable across time and contexts (cf. Derex and Mesoudi 2020; Vaesen and Houkes 2021). Even so, it is not clear that technology is characteristically cumulative. For example, I argued (Stout 2011) that Paleolithic technological change was cumulative because maximum expressed complexity increased over time by adding levels of hierarchical structure to previously established technologies. While this establishes that iterative increases *sometimes* occurred, it fails to show that they were a characteristic or predominant pattern in technological evolution because it ignores patterns of stability and change in simpler technologies that also existed throughout the Paleolithic (Vaesen and Houkes 2021; Režek et al. 2018). In fact, even a random walk (increase and decrease equally likely) could produce this pattern if complexity has a lower bound constraining variation in that direction (cf. the "zero force evolutionary law" of McShea and Brandon 2010). The absence of a clear and persistent overall trend toward increasing technological complexity or performance suggests that more particularistic explanations of specific instances of Paleolithic change and stability may be needed (Stout 2018).

Could this also be the case for hominin brain evolution? It is, of course, indisputable that the endocranial volume of *Homo sapiens* is more than three times that of *Australopithecus*. Furthermore, quantitative analyses of fossil hominin endocranial volumes over time generally support a pattern of gradual (Du et al. 2018) and accelerating (Miller, Barton, and Nunn 2019) increase over time. These findings are consistent with a microevolutionary process of long-term directional brain size selection on hominin populations within lineages (anagenesis) driven by accelerating biocultural feedback (Miller, Barton, and Nunn 2019). However, there are problems. Most importantly, these analyses do not include the relatively recent small-brained species *Homo floresiensis* (Falk et al. 2005) and *Homo naledi* (Holloway et al. 2018). These species represent either episodes of secondary brain size reduction or the survival of smaller-brained lineages much later in the fossil record than previously thought. Considering that both of these discoveries have occurred within the past 20 years, we must seriously consider that more such examples may remain to be found. If this turns out to be the case, then patterns of hominin brain size evolution would start to look more like diversification above a minimum "ape grade" level, rather than a gradual and persistent directional trend.

A second problem arising from the incomplete nature of fossil record is that it is difficult to be sure that the apparent trend toward brain size increase actually reflects microevolutionary processes within lineages versus macroevolutionary processes of lineage splitting and extinction. Andrew Du and colleagues (2018) found that microevolutionary anagenesis accounted for 64 to 88 percent of hominin brain size change; however, this result is obviously dependent on the taxonomic classification of fossils as well as known first and last appearance dates of these hypothetical species. Unfortunately, neither the taxonomic diagnosis of hominin species (Athreya and Hopkins 2021) in biologically real terms (i.e., as separately evolving lineages in de Queiroz 2005) nor our knowledge of their actual temporal range appear to be particularly reliable, especially for species represented by a small number of fossil specimens. This uncertainty matters because macroevolutionary processes of lineage formation and extinction may involve very different mechanisms (Gould 2002) from the gradual, microevolutionary selection envisioned by biocultural coevolutionary models (Du et al. 2018). For example, an apparently unitary trend could actually reflect the average of a relatively small number of idiosyncratic lineage-level events or a tendency for brain size (or its body size, life history, or ecological correlates) to be associated with increased speciation or reduced extinction rates rather than individual fitness.

These issues in our understanding of the broad patterning of human brain and technological evolution weaken the empirical motivation for positing a key threshold or capacity that initiated a uniquely human pattern of persistent and cumulative biocultural evolution. This may be a tough pill to swallow, as expectations of a hard animal and human boundary (Cartmill 1990) and human evolutionary progress (Ruse 1996) are deeply ingrained in paleoanthropological thought. Indeed, the implications of such a shift in perspective are many and deep and extend to paleoanthropology's tragic role in establishing and perpetuating racist colonial hierarchies (Athreya and Ackermann 2019). For current purposes, they significantly affect our expectations for patterns of technological stability and change in the Paleolithic. In the absence of a robust overall trend, there would be no reason to view stability as anomalous or to expect a single key factor such as cultural transmission capacities (Tennie et al. 2017; Lewis and Laland 2012) and strategies (Lycett and Gowlett 2008; Kendal et al. 2018) or the population dynamics of transmission (Powell, Shennan, and Thomas 2009; Henrich 2016; Derex and Mesoudi 2020) to fully explain rates of change.

Importantly, this does not invalidate biocultural feedback hypotheses (e.g., Henrich 2016) or their use (Stout 2021a) as theoretical grounding for a definition of technology. It does emphasize that the *potential* feedback effects envisioned would only be triggered in particular circumstances, are unlikely to be indefinitely self-sustaining once initiated, and could produce complex dynamics other than continuously accelerating increase (Stout and Hecht 2017). Indeed, such feedback hypotheses for human evolution are derived from comparative (primate and other) data (e.g., Isler and van Schaik 2014) that identify potential coevolutionary relationships while simultaneously showing that they often do not result in runaway feedback. In other words, biocultural feedback is not a unitary, monocausal explanation for human evolution but rather constitutes a set of general principles or relationships that will behave differently across different contexts. Attempts to understand particular instances of technological stability or change must combine such general comparative principles with particular historical details from disciplines like archaeology and paleontology in order to generate specific explanations (Stout 2018). Sometimes variation in hominin cognition or social learning may indeed be critical; in other cases, alternative considerations such as context-specific costs and benefits (Pargeter, Khreisheh, and Stout 2019; Režek et al. 2018), inheritance of material infrastructure (Pradhan, Tennie, and van Schaik 2012), social arrangements (Powers, van

Schaik, and Lehmann 2016; Currie et al. 2021; Derex and Mesoudi 2020), or interactions between technologies (Kolodny, Creanza, and Feldman 2015) may be key.

Conclusion

Stephen Jay Gould and Niles Eldredge (1977) famously argued that "stasis is data" and needs explanation. This certainly applies to the stability and persistence of Paleolithic toolmaking behaviors such a simple core-and-flake ("Oldowan") or large cutting tool ("Acheulean") production. Yet what is it about this stability that needs to be explained? The so-called California program arising from the work of Robert Boyd and Peter Richerson focuses on uniquely human capacities for cultural accumulation and diversification (Sterelny 2017) and sees stasis as something of an anomaly or even deficit to be explained in terms of cognitive limitations, low population size, or other problems (Morgan 2016; Henrich 2016; Richerson and Boyd 2005). In contrast, the CAT "Paris program" arising from the work of Dan Sperber seeks to explain cultural stability in a variable world (Sterelny 2017) and so focuses on causal mechanisms that create stable attractors (Scott-Phillips, Blancke, and Heintz 2018).

This focus may provide a more felicitous frame for discussing Paleolithic stability, and all of the major proposals can be construed as suggesting different causal mechanisms leading to observed technological attractors. These include psychological factors of attraction such as genetically evolved biases toward certain tool forms or procedures (Richerson and Boyd 2005; Corbey et al. 2016), reliance on particular learning mechanisms (Tennie et al. 2017), or more general perceptual biases (Wynn and Gowlett 2018), as well as ecological factors such as population structure (Powell, Shennan, and Thomas 2009) or characteristic modes of social organization and transmission (Lycett and Gowlett 2008). Archaeologists often emphasize functional forces of attraction, such as design constraints (Wynn and Gowlett 2018) or the role of tools in larger behavioral ecological strategies (Režek et al. 2018). These perspectives generally expect successful strategies to be stable and thus focus more on explaining episodes of change in terms of extrinsic causes of change such as climatically driven habitat shifts (Antón, Potts, and Aiello 2014). Finally, there are evolving organismal factors of attraction such as more general perceptual-motor and cognitive capacities (Stout et al. 2019; Pargeter et al. 2020) or biomechanics and manipulative capacities (Karakostis et al. 2021) that might affect the relative costs and benefits of particular technologies. Most likely, each of these mechanisms and more have been relevant at different times and places in the Paleolithic and would have interacted in complex and historically contingent ways to produce the observed archaeological record (Stout 2018).

This is perhaps unfortunate, as prime mover explanations of human uniqueness as arising from CCE and biocultural feedback dynamics resulting from enhanced social learning capacities are attractive for their parsimony and synthetic power. Humans are exceptional in so many ways at the same time that more piecemeal adaptive accounts do seem to be missing a bigger picture. How likely is it that everything from dexterous manipulation to theory of mind and metacognitive learning strategies would just happen to occur together in one species? By analogy, if one person flipped a coin and got heads 10 times in a row, we would expect some kind of general explanation for this highly unlikely outcome (e.g., biased coin). However, if one person out of 2,000 flipped 10 heads in a row, we would recognize that this is simply an expected result of probability. The appropriate level of explanation for why *this particular* person got that result would then focus on the dynamics of each individual flip. If it is true that human evolution is better characterized by diversification rather than a single directional trend toward increasing brain size and technological complexity, then our explanatory task is more similar to the latter case. We would thus need to focus on particular causes for particular instances of stability and change rather than positing single, overarching explanations. For this perspective, stasis would simply be data rather than an anomaly or exception to a more general evolutionary process.

Importantly, this is not to say that some degree of theoretical synthesis cannot be achieved. As outlined above, comparative and modeling studies of biocultural evolution have identified potential interactions between diverse life history, neural, cognitive, social, and technological variables (Isler and van Schaik 2014; Kolodny, Creanza, and Feldman 2016; Morgan 2016; Kaplan et al. 2000; Muthukrishna et al. 2018) that may allow synthesis of complex evolutionary phenomena in terms of a smaller number of recurring relationships and processes (Stout 2021a). However, the relevant causal relations in any particular case may still vary depending on specific context. Moving away from the information transmission paradigm of cultural evolution and the presumption of an overarching directionality to human biocultural evolution opens theoretical space for considering this wider range of causal relations and explanations for Paleolithic stability and change.

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