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Niche Construction, Cumulative Culture, and the Social Transmission of Expertise

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ABSTRACT

This paper argues for the following key claims: (i) There is an important difference between learning specific procedures and the acquisition of skill. (ii) By the last 100 k years of the Pleistocene, and probably earlier, hominin lives depended not just on the mastery of specific procedures, but of broad-based skills. Pleistocene lives depended on expertise. (iii) This know-how included technologies dependent on specific physical procedures (toolmaking, hide preparation, and the preparation and use of other soft materials) but also more cognitive skills; these included tracking, local natural history, and navigation. (iv) These more cognitive skills cannot be learned by imitation or any similar method, as they are not expressed in distinctive, signature motor acts. Even for those skills that do encompass specific physical skills, imitation of a model's specific motor sequences is at most one aspect of skill acquisition. The most crucial cognitive capacity is the ability to integrate information streams from multiple social and physical channels. (v) In addition to specific cognitive capacities, there are social and demographic preconditions of skill transfer across generations. (vi) The reliable transmission of the cognitive capital of one forager generation to the next is supported by an adaptive, efficient learning niche.

INTRODUCTION: CUMULATIVE CULTURE

One of the few relatively uncontroversial claims about the evolution of human social life is that it involved a massive expansion of cultural learning (see, for example, Tomasello, 2000; Boyd, 2018). The result was a qualitative difference between human cultural learning, and the cultural learning of all (or almost all) non-human animals. Human cultural learning, it is said, is cumulative. The cultural learning of other animals is not. Cumulative cultural learning enables communities to increase their informational capital—their stock of know-how and knowledge—over generations. Cumulative cultural learning also enables individuals to acquire "culture dependent" traits (Tennie et al., 2017); that is, skills or capacities that they could not acquire by unassisted individual learning. This aspect of human cultural learning has had momentous consequences, making possible the geographic, ecological, and demographic expansion of our lineage. That expansion depended on adaptation to the specifics of the local environment. For the most part, this adaptation is cognitive and behavioral, depending on cumulative cultural learning. Adaptation begins with an initial phase of innovation and retooling, as hominins moved into new environments (or experienced abrupt change), followed by the faithful transmission of successful innovations to succeeding generations, together with a certain amount of ongoing fine tuning. In addition, long-established and important cultural adaptations can trigger genetic accommodation via gene-culture coevolution. One well-known case is the association between lactose tolerance and herding economies (O'Brien and Laland, 2012). But as Wrangham (2009) has shown, this is just a recent and relatively minor example—the whole hominin machinery of ingestion-digestion has been transformed by cooking. Crucially, even in these cases, cultural adaptation comes first and comes quickly. For example, archaeological evidence suggests that most or all of Sahul was occupied within a few thousand years of arrival, despite the impressive physical, biological, and climatic differences between Sahul and Island South East Asia (Allen and O'Connell, 2020).

This standard picture comes with the claim that cumulative culture depends on high fidelity cultural learning (an idea developed in most detail by Michael Tomasello (1999), and following him, Claudio Tennie et al. (2016). Accumulation (the idea goes) depends on innovation, and successful innovations are typically small improvements in technology or technique, for example, an improved binding or more reliable glue to bind an adze to a shaft. Small improvements can only spread within and across generations if novices notice and adopt the improved design. If novices just pick up the general pattern of the adze from models as guides to their own crafting, the innovation will be lost. The same is true if cultural learning is "conformist," with novices copying the most usual design of the adze in their community. At the beginning, the new design is necessarily atypical. So accumulation depends on noticing and adopting the difference[1]; high fidelity social learning, probably coupled with the intelligent assessment of models.

I will argue that the standard view is misleading in four ways. First, there is much more to cumulative culture and the generation of culture-dependent traits than incremental improvement, of refining, and improving existing procedures or tools. Iterative improvement is indeed important. Dietrich Stout is responsible for a fine study of axe-making in West Papua (Stout, 2002), and there are many steps between a hand-held cutting tool and a hafted Papuan adze. But the efficiency of cultural learning also increases bandwidth. Foragers know far more about their environment than any single individual could discover without aid (Richerson and Boyd, 2005; Henrich, 2015; Boyd, 2018), though it is probable that any single fact is independently discoverable. Their natural history database is a culture-dependent trait. Second, the standard model overstates the importance of specific procedures, specific causal recipes. These do indeed play some role in human adaptation to local environments. For example, eating cornflour as a staple risks pellagra, a chronic disease caused by lack of niacin. Many Central American communities add ash to cornmeal, reducing its calorific value but releasing niacin. As Joseph Henrich (2015) has emphasized, this is a specific causal recipe transmitted culturally. But informational capital often consists of skills, and a skill is not a specific causal recipe, or even a set of causal recipes. The ability to make an Acheulian handaxe is a skill, not mastery of a fixed procedure or set of fixed procedures. A knapper cannot learn and apply a fixed formula, for stone varies too much in shape and fracture properties. The same is true of ecological skills like managing a habitat with fire. Australian Arnhem Land Aboriginals use fire for many purposes. This includes direct and indirect hunting, making travel through thick scrub easier, and, clearing camp sites of insects and snakes. But fire must be used carefully, with attention to the current and predicted wind, the local terrain, and especially its relief, the local vegetation, and the season (Garde, 2009). Third, it is indeed true that the reliable transmission of a community's informational capital to the incoming generation is an essential feature of cumulative culture. But in general, that does not require imitation or other forms of high-fidelity cultural learning, where a novice accurately copies the knowledge or know-how of a specific model. Fourth, as a consequence, cumulative culture does not depend on cognitive adaptations specific to cultural learning. Rather, it depends on an adaptive learning niche, though fully exploiting that niche depends on minds adapted to life in complex social environments.

Applying these conclusions to the deep past, I shall conclude that (i) Late Pleistocene human lifeways depended on the acquisition of skills, not just causal recipes. (ii) Skills cannot be learned by copying from a model. A skill is productive, in that a skilled agent is capable of adaptive responses to situations and challenges not previously experienced, and, in particular, to experiences that were not part of his/her training set. (iii) Those skills were (often) culture-dependent traits. The skill repertoire of Late Pleistocene humans could not have been acquired without major social support. (iv) That social support consisted of an adaptive learning niche. The social environment scaffolded learning through a mix of material resources, social inputs, and opportunities to explore and experiment in relative safety.

CUMULATIVE CULTURE, INCREMENTAL IMPROVEMENT, AND THE EXPANDING BANDWIDTH OF CULTURAL LEARNING

It is certainly true that one important route to culture-dependent traits is through incremental improvement of an existing tool or procedure. Consider, for example, the pathway from a simple wooden spear with a shaped and fire-hardened tip to an Inuit fishing spear or leister (a kakivak), a three-pointed, barbed, spear whose outer prongs curve slightly inward towards a shorter middle point. There are multiple innovations required to develop a kakivak from a simple spear, including mounting and binding the spear-heads and the barbs. Since each is a significant challenge in its own right, it is vanishingly unlikely that a single individual could generate the whole sequence of innovations. So this is a paradigm form of cumulative culture, where each stage in spear evolution was a platform for further improvement. But cultural mechanisms that make cumulative culture possible support various forms of positive feedback (Table 1). The model of cumulative culture as incremental improvement zeros in on just one of these—an existing tool, or an existing procedure, provides a platform for the further improvement of that very procedure. In addition, though, the greater efficiency of cultural learning ramps up the total volume of information or skill a novice can acquire. This expansion of the total information and skill set of individuals in a community in turn increases the probability of specific improvements in a particular technology. For example, composite tools usually require bindings and/or adhesives, and these in turn are often made from plant materials. The more plants a community recognizes and uses, the more likely they know of one suitable as a source

TABLE 1. FEEDBACK LOOPS.

Cultural Learning Positive Feedback Loops
Incremental improvement: an existing tool or procedure serves as a platform for further improvement
Bandwidth expansion: the greater speed/efficiency of cultural learning drives up the total informational resources of an agent
An expanded set of growth points: a larger repertoire of skills and information provides a wider range of potential take-off points for further improvement
An expanded option set: a larger repertoire of skills and information improves the prospects of innovation by recombination and novel uses
Enhanced bootstrapping: agents with more baseline skills and knowledge have greater chances of acquiring further skills and knowledge

for bindings or glues. Foragers are rightly famous for their extensive knowledge of their local habitat. Forager herbals typically consist of hundreds, sometimes thousands, of plant species that individuals can recognize (often despite quite marked seasonal changes in form). Often, these are put to a variety of uses (for Australian examples, see Latz, 1995; Clarke, 2007; Cahir et al., 2018; Clark et al., 2018). Any specific element in these herbals is individually discoverable, but the total volume of information represented by an ethnobotanical herbal is formidable.

Furthermore, once the skill and technology levels pass a certain threshold, other forms of positive feedback kick in—the expansion of individual informational capital has positive feedback effects. Relevant background knowledge makes learning new information faster and more effective (Osiurak and Reynaud, 2020). It also makes successful innovation more likely by making opportunities for innovation by recombination more salient. For example, once cordage has been invented, say, for snares, new regions of design space open up—for sprung traps, for bows and fire drills, for nets of various kinds and designs, for bindings, for fitted clothes, for bags, and for constructing simple shelters (for the importance of recombination, see Arthur, 2009). Cordage powers a general capacity to fasten one object to another, changing a community's niche. So too does the control of fire. The greater and more diverse the skill base of an agent or a community, the more techniques and technologies come within range. In this respect, the hill climbing metaphor (Dawkins, 1996) of complex adaptation by incremental improvement is quite misleading. It does not capture the fact that some innovations expand the space of possibilities and change the shape of the fitness landscape.

Dietrich Stout's (2002) ethnographic study of Papuan stone adzes is a classic example of a technology that is the result of incremental improvement. The adze head is both edged and shaped to fit a slot in the shaft. This is itself shaped and polished. The attachment site is reinforced with both adhesives and bindings, and with a shock absorber to reduce the chance of the stone cracking on impact. While stone is hard it can be brittle, and a softer wood segment between the head and main shaft reduces the likelihood of cracking. The pathway from hand-held one-piece tools to a mounted Papuan adze required improved techniques for stone working; the ability to recognize and shape wood that is strong and flexible; the ability to make glues and bindings; and, recognizing the value of a shock absorber and the ability to make and place one. These innovations are modular and productive. They can be (and doubtless typically are) redeployed elsewhere in expanding a community's material culture. It is not just that cumulative cultural learning expands the bandwidth of cultural learning as well as supporting incremental improvement. There is positive feedback between expanding bandwidth and incremental improvement. We do not know the deep history of the Papuan adze, but its bindings may well have been initially used in quite different technologies (seacraft or nets, for example), and redeployed in adze making. There is a contrast here with genetic evolution. The changes that appear in the genetic evolution of complex adaptations have this feature of ready redeployment to a much lower degree[2].

So while most of the explicit discussion of cumulative culture is focused on the incremental improvement of a capacity, that is only one element of the story. Boyd and Richerson (2005) illustrate the importance of cumulative culture with examples of explorers in the nineteenth century getting into trouble and dying, or relying on locals to save them from starvation. For they just do not know how to find food, water, or shelter. One of their favored examples is the failure of the Bourke and Wills expedition to northern Australia, despite Aboriginal aid (Richerson and Boyd, 2005). The lesson is that cumulative cultural evolution gave the locals the information, skills, and tools they need to survive. But what is impressive about foragers' understanding of their local environments is the volume of information they have mastered. Any one item, an observant individual could learn for himself/herself. But that would take time. Learning with the help of others is much more efficient, and so vastly more can be learned.

RECIPES, SKILLS, AND EXPERTISE

The cultural evolutionary models of Richerson, Boyd, Henrich and others focus on the incremental construction and reliable transmission of specific procedures. These are causal recipes. For example, Henrich (2016) discusses three such procedures. One is manioc detoxification. Manioc is a good staple, but to be eaten safely; cyanide derivatives must be removed. This requires a multi-day, multi-step processing sequence, including scraping, grating, and washing the fiber to extract the starch. That starch is then allowed to sit for a couple of days before it can be cooked and eaten. A second example is Fuegan arrow construction. This is also a multi-stage procedure requiring the precise choice of wood (from a particular bush), followed by distinct techniques for straightening, strengthening, polishing and fletching the arrow, and mounting a tip. We have already met a simpler example, cornmeal preparation. These procedures are "causally opaque;" those who deploy them do not know why they work. But they do not need to know why these procedures work. Indeed, it is best if they realize they do not know, for they are then not tempted to modify the procedure, very likely making it less effective.

Specific procedures are important, as the pellagra example shows. Such specific recipes are simple, modular, and independent of the rest of the agent's repertoire of capacities. But while these procedures matter, hominin life in the Late Pleistocene, and very likely the Middle Pleistocene, also depended on skills. In this respect, the Fuegan arrow example is likely to be more typical, as arrow making is a skilled activity that cannot be captured by mechanically following a specific recipe, as natural materials vary so much. Life in our societies requires high levels of demanding skills. Consider contemporary cases of high skill: a skilled driver, a good barrister conducting an examination in court, a high-class chess player, and a test cricketer. Experts in a domain (i) typically act in that domain fluently. In routine circumstances they make good decisions while being able to attend to other activities. A good driver can drive safely while telling a story; (ii) respond on the fly rapidly and often successfully to the unexpected; (iii) anticipate variations in their contexts of action and adjust accordingly. On a low-bouncing pitch, a batsman can tune himself to play forward; and, (iv) finally, expertise is typically acquired through long learning and practice.

Life in forager communities, including Pleistocene communities, also depended on skills as well as specific modular procedures. This dependence on skill is as deep in time as the Acheulian, for handaxes cannot be made by learning and applying a fixed procedure (Stout et al., 2014; 2015). The same is true of ecological skills central to forager lifeways. Trackers and herbalists have mastered a skill, rather than having memorized a recipe or set of recipes. There is an enormous amount of information available from a trackway in a dry riverbed or a lake edge (for beautiful depictions illustrating this, see (Ennion and Tinbergen, 1967). But an expert eye is needed. Specific tracks are often superimposed on others; the tracks vary in their freshness; in the direction and mode of travel they indicate; and likewise, in the condition and emotional state of the animal(s) responsible. They are rarely continuous, and so a tracker will often need to recognize the individual peculiarities of the target animal's traces on different substrates. Expert tracking requires much more than memorizing the specific, ideally complete shape depicted in a field guide (Liebenberg, 1990; Shaw-Williams, 2014; Shaw-Williams, 2017). The same is true of being a good herbalist. Guides to plant identification picture the whole plant (and relevant parts, usually flowers and seeds) in ideal light and growing conditions. Our herbalist must recognize the plant in sub-optimal viewing and growing conditions, in a range of seasons and growth stages, as well as knowing what to do with the plant, once recognized. Skills are *productive*. A tracker's road to expertise requires much practice, with much careful observation of specific tracks. The "training set" is extensive. Even so, a skilled tracker can interpret trackway combinations she has never seen before (Shaw-Williams, 2014).

In his *Modularity of Mind*, Jerry Fodor (1983) introduced the idea of a cognitive module, an idea then taken up in nativist evolutionary psychology. Face recognition is a paradigm example. Modules are (i) fast: we recognize faces incredibly rapidly, often from quite degraded input, like a passing glance; (ii) automatic: you do not have to decide to try to recognize a face; (iii) involuntary: you cannot help but recognize faces; (iv) wholly or partially opaque to introspection; you cannot tell how you do it; (v) face recognition does not depend on directed learning or teaching: one acquires the capacity without making any specific effort; and, (vi) the capacity is somewhat neurally localized, and can be lost without losing much else.

Once acquired, a skill is operationally like a Fodorian module. Consider literacy. An agent literate in English recognizes "skill" as a word of English rapidly, automatically, involuntarily, without apparent effort, even if the word is blurred. But their developmental trajectories are very different. A skill like literacy often takes years to develop and requires considerable levels of effort and investment. Consequently, learning environments are often structured to ensure the reliable acquisition of socially important skills. The cognitive psychology of skill and expertise is complex and contested, though with an increasing recognition that it is much more than finely honed pattern recognition (Christensen et al., 2015; 2016). Rather, expertise in a domain depends on some complex combination of perceptual capacities, pattern recognition capacities, motor skills, procedures, and more general declarative information. For example, experts have some capacity to represent their own skills, allowing them to diagnose and repair errors, to improve through targeted practice, and, often, to offer useful advice and demonstration to others. As a demonstration is typically slower, stylized, with crucial elements repeated or exaggerated, an individual demonstrating a skill requires some explicit, top-down understanding of the skill demonstrated. But this is rarely complete and not always accurate[3].

RELIABLE TRANSMISSION WITHOUT HIGH FIDELITY LEARNING

Richard Dawkins (1982) has shown in particularly compelling ways the fact that biological adaptation, especially complex, incrementally evolving biological adaptation, really does depend on high fidelity inheritance mechanisms. He points out that genes-as-replicators satisfy two essential conditions of an inheritance mechanism that can contribute to the evolution of complex adaptation. In the formation of the gametes that fuse to produce a viable diploid nucleus, each gene is replicated with high (though variable) accuracy. But if a copying error of G in generation N produces a variant, G* in N+1, that variation is itself copied at the N+2 generation. That is essential for adaptive change. If G* happened to confer a fitness benefit on its bearer, that phenotypic adaptation would disappear if G* reverted to the ancestral type, G, at the N+2 generation. So genetic replicators are: (i) copied with high fidelity, but (ii) if a copying error is made, that error is then copied on. While the preservation of new adaptive variation is as critical for cumulative cultural evolution as it is for cumulative genetic evolution, crucial differences have been understated. The genetic model of cumulative culture is somewhat misleading.

TRANSMISSION: RECONSTRUCTION VS. PERSISTENCE

One of the architects of the niche construction literature, John Odling-Smee (see, for example, Odling-Smee and Laland, 2011; Baker and Odling-Smee, 2013) has written extensively on the importance of ecological inheritance. Odling-Smee primarily had in mind physical and biological modifications of a population's habitat that persist, so that this changed habitat comes to be occupied by the succeeding generation. Ecological inheritance so understood is important in human biological and cultural evolution. For example, there is little doubt that Australian Aboriginal fire practices transformed the biota and soils of much of Australia. But ecological inheritance also plays a central role in the preservation of a community's informational capital. In part, that is because a community's material products persist, and play dual roles as instrumental and informational resources. They act as partial or complete templates for the production of their replacements. Peter Hiscock (2014) points out that lithic tools are particularly valuable informational resources, both because they persist so well over time, and because their scar pattern preserves aspects of their production history. But material products are also resources allowing novices to practice their skills. Adam Boyette (forthcoming) documents the remarkable competence of young Congo foragers in their use of blades, a consequence of the fact that as young children they have ready access to the blades of the whole community. Any not in use can be commandeered for play and experiment; semi-functional ones are often given as toys.

Less obviously, some collective social phenomena persist. A child born into the Walbiri community must learn the vocabulary, syntax, and phonology of Walbiri. But she does not have to invent the language. She joins an ongoing language community, with its developed vocabulary distinguishing and labelling the important physical and social kinds of her world (Walbiri, for example, has a very rich kinship vocabulary). Walbiri persists over generational change; it does not have to be reconstructed. Its persistence scaffolds further cultural learning. For example, exposure to distinct names for similar plant species is itself a crucial hint to the novice. Those distinct names tell the novice that there is an enduring difference to recognize. Just as the incoming generation does not need to create their community language anew, they do not have to recreate the community herbal—it is an element of ecological inheritance. The same is true of institutions. For example, Barry Hewlitt, Adam Boyette, Sheina Lew-Levy and others have documented the role of mixed gender, mixed age play groups for forager lifeways (for reviews, see Lew-Levy et al., 2017; Boyette and Hewlett, 2018; Lew-Levy and Boyette, 2018; Lew-Levy et al., 2018). From about 3 to about 12, children spend most of their day in these autonomous groups, exploring their world and learning key forager skills. The play group composition changes as older children become more adult focused, drifting out as younger ones are drawn in. But the group itself persists as a locus of peer-to-peer teaching, collaborative learning, play, and play-work hybrids, as children collaborate, explore, and learn from one another in an environment with some adult protection (though forager adults are not helicopter parents). In these groups, children have access to advice, access to equipment, and access to public information. For much adult activity in camp takes place outside in full view (for a striking example of collaborative learning in a supported environment, see Naveh, 2016). The play group is a learning niche that persists, even as children move through it. Children do not have to create for themselves this social and educational environment; they just move into it, then leave it behind as they graduate. The play group is like a whirlpool at the bottom of a waterfall—persistent, stationary, even as water moves through it. Olivier Morin (2015) notes that these autonomous, child-organized groups continue in vestigial form even in far more regimented western cultures. This is shown by the long lifespans of various children's games and rituals, maintained in these groups by peer-to-peer transmission. To a considerable degree, then, the collective information of a community is preserved as an ecological inheritance rather than being rebuilt at each generation.

FIDELITY VIA REDUNDANCY

The genes of a new organism are assembled together as the result of a single copying event. To the extent that adaptive change depends on new genes and gene combinations, these genetic resources derive from this single copying event. Somatic mutation aside (and in bacteria, lateral gene transfer), these resources cannot be modified, revised, or supplemented. When an agent learns culturally, it need not be, and often is not, the result of a single learning event. To the contrary, the ethnography of forager learning documents massive redundancy. Forager children almost always have multiple opportunities to learn crucial skills, and often at times and in circumstances of their own choice. Once learned, the culturally acquired trait is not fixed. Change and supplementation is possible, though for adults, transition costs encourage a good deal of conservatism in considering a switch to a new practice. So while it is true that cumulative culture requires generation N+1 to acquire the informational capital of N more or less intact, that does not require high fidelity learning at *any particular episode*, nor high fidelity learning from a specific model by a specific novice.

LEARNING WITHOUT COPYING

Consider a novice exposed to some critical cultural practice, for instance, Joseph Henrich's poster example of manioc detoxification, a causally opaque procedure that must supposedly be learned by exact copying. If and as novices attend to this procedure, typically over a series of exposures and an array of models, they do indeed have the opportunity to form a cognitive representation of this practice. That representation is then used to guide action. This action may resemble the action sequence of the models, or it may not—the novice may be a slave who wants to poison her hosts. Despite the language of imitation, this cognitive representation is not a copy of the cultural practice (this point has been pressed by Dan Sperber and his colleagues; see originally Sperber, 1996). In forming this representation, the novice has to extract the relevant information from what she sees hears, smells, and touches. Her experience is multi-modal and sensory—the representation she constructs guides action through a causal procedure. This action-guiding representation is certainly not a copy of her sensory experiences (vividly recalling the smell of grated manioc does not tell you how to grate manioc), and it is likely to be more abstract than a specification of a motor procedure. It will be if (for example) she can also describe the procedure. Much of the informational input is irrelevant and discarded; it does not matter whether you grate with the left hand or the right, or how you wash the fiber, so long as you collect the starch that you wash out. No specific kind of scraper is essential. The shape of the container in which the manioc is soaked does not matter, but its relative volume does. The essential causal recipe must be extracted from a good deal of irrelevant noise. Once extracted, it can be then used or modified for the agent's own purposes. This is typical, even of the cultural learning of a specific causal recipe.

Paradigm copying processes are content-neutral but fidelity-sensitive. Genetic replication is high fidelity, with fidelity independent of the specific protein for which the copied gene codes, or indeed whether the gene codes for a protein at all. The same is true of, for example, tracing paper used to transfer a design from one medium to another. The accuracy of the tracing is independent of the content of the design. Cultural learning is typically content-sensitive. The capacity of a novice to assemble an effective representation from a variety of informational channels depends on the novice's pre-established skills and knowledge. The novice observing the detoxification of manioc needs to understand a good deal of what she is seeing in order to extract the crucial causal recipe from the irrelevant aspects of particular performances (for experimental data on the role of this pre-existing knowledge, see Osiurak and Reynaud, 2020). This is true even of so-called "over-imitation" cases, for the physical actions of the novice are often quite different from those of the model (Gergely and Király, forthcoming). There is experimental evidence that artisans who are the most adept at reproducing traditional designs are also the best at producing new designs or adapting to novel materials (Bril et al., 2010; Roux et al., 2018). These artisans have learned a productive skill, they have not just internalized a template. There is similar ethnographic evidence about the musical performance of Central African foragers—the adept can both reproduce and innovate (Lewis, 2009, 2015, 2016).

Even cases which appear to involve simply copying from a model actually involve interpretation and potential redeployment. Theorists of change sometimes distinguish between invention and innovation; an invention is the initial change in practice or technique; innovation occurs only if that initial change is picked up and established. Unless cultural learning is strictly vertical, innovation in this sense requires interpretation. Incremental improvement requires an audience to notice and value the novel variation in design and to adopt it. Audiences interpret and evaluate what they see. If causal opacity produced extreme conservatism—blind faith copying—it is hard to see how innovation could establish through oblique or horizontal spread. Moreover, there are central forager skills that almost certainly have been built cumulatively, across multiple generations, and where cultural input is crucial, but where that cultural input does not take the form of demonstrating or modelling action patterns. Consider ethnobotany or tracking. For both, social input is critical. But in, say, becoming an expert tracker, the social input is not a model of specific motor procedures. Copying physical routines plays very little role in learning to track; it is mostly a matter of the young spending time with good trackers, watching what they do, attending to what they notice, listening in, and practicing. Joseph Henrich (2015) has suggested that endurance hunting was probably important to many forager communities, and this is a mode that requires high level tracking skills, because tracks are rarely continuous, and because it is important to assess the condition of the animal. In his account of San endurance hunting, Henrich describes the collaborative nature of adult interpretation, and the opportunities this provides for the less expert to eavesdrop. Moreover, in some cultures there is explicit teaching; there are photos in an Australian field guide of Aboriginal-made tracks, made as teaching devices (Morrison, 1981). Likewise, B.J. Love (2009), in his book on Australian Aboriginal life in the Kimberleys, describes a child's game where one makes a track and the others have to guess what it is. So learning to track has major social input, with some explicit teaching, but imitation plays very little role.

On one view, cumulative culture depends on cognitive adaptations specific for cultural learning, adaptations that support high fidelity imitation (for a recent defence, see Tomasello, 2020). On the view suggested here, the cognitive mechanisms are those that make it possible for us to live in complex, inter-dependent communities, using rich but difficult to exploit resources. In such communities, adaptive decision-making will often require the integration of multiple streams of information from social and natural sources. Any decision to engage in collaborative foraging will require such integration. Agents manage complex trade-offs with considerable time depth, requiring judgements about the natural world (the severity of environmental risk; whether a resource target is predictably located in time and space), and the intentions and competences of other agents. James Woodburn (1982) describes mobile foragers as pursuing immediate return subsistence strategies. But this refers only to the fact that their subsistence does not depend on food storage. Decisions about mobility, investment in material technology, and social and sexual alliances all involve considerable time depth. This assessment and integration of information flow from multiple sources is central to skill learning as well. This is particularly evident in the hybrid learning discussed next.

HYBRID LEARNING

In the case of instrumental skills and knowledge of the natural world, the relevant representational structures are typically assembled from a variety of social and natural informational channels. Forager cultural learning is robust not just because it is buffered by redundancy of models, but because it is redundant in different, independent ways. One aspect of that redundancy is the availability of an array of social and natural information channels. This was implicit in the discussion of BaYaka bladework above. Forager children had free access to any blades not in use. They could use those for just about any purpose, not just cutting or slicing but (for example) as digging tools. They could explore blade dynamics together, collaboratively, and could watch, and get advice from, slightly older peers. BaYaka settlements, like most forager settlements, are small, intimate, and with shelters often with open sides. Moreover, much adult activity takes place in the open (Hewlett et al., 2019). So there was plenty of public information about blade use, and forager children are not excluded from adult activities and workspaces. Indeed, they are often asked to assist with minor chores, giving them further opportunities to practice skills, extending their competence. These are all more or less daily experiences, so by the time a child is six or seven, they have had hundreds of exposures to all these sources of information. This staged, scaffolded expansion of competence is an important aspect of apprentice learning structures, of both formal and informal kinds. Dietrich Stout (2002) documents this staged growth of skill in his study of stone adze making in West Papua.

The ethnographic record suggests that the core cognitive capacity required for cumulative culture of instrumental skills is not imitation, or imitation supplemented by sophisticated theory of mind, but the ability to integrate information from a variety of natural and social sources. As we have just seen, this is a core requirement of adult life too. Children are not passive, solitary, unassisted learners, but nor do they primarily learn by detailed attention to, and memory of, adult activity. They explore actively and collaboratively in environments seeded with informational resources, made safer because that exploration is somewhat supervised and organized by somewhat older peers and adults. This exploratory interaction with material culture and the natural environment makes possible the reliable acquisition of complex, learning-dependent competences. But it does so only with the aid of these rich structures of social support.

Hybrid learning explains the acquisition of most culture-dependent traits. No one learns a skill just from the observation of models deploying that skill. Almost always, targeted practice is part of the acquisition process. Most formal simulations of cultural learning, and quite a lot of the experimental literature, tacitly assumes that if something is learned culturally, all the information is sourced from the model. So in Chinese Whispers style experiments, there are transmission chains from model A to model B to Model C (etc.) where information flows down the chain, and the experimenter manipulates conditions to determine the conditions under which it degrades or survives (for example, if there are several models at each stage, it survives better: for discussion, see Morin, 2015). But lots of cultural learning is not like that; if someone is teaching you how to knap stone, you get information from the stone, and your attempts to shape it, as well as from the model.

THE LEARNING NICHE

As we have seen above, Michael Tomasello has argued that cumulative culture depends on specific cognitive adaptations. Somewhat similar views are defended by Gergely and Csibra (Csibra and Gergely, 2006; Gergely and Csibra, 2006; Gergely et al., 2007). Celia Heyes has developed a variant of this general line of thought, in which the adaptations for cultural learning are themselves learned culturally (Heyes, 2018). An alternative relies on niche construction (Odling-Smee et al., 2003; Sterelny, 2012). The mechanisms of skill transmission noted just above are remarkably efficient. Almost all of us are experts in living in the communities of which we are a part, and different communities require different portfolios of expertise. Despite the complexity of these challenges, most of us acquire the locally essential skill set, and we do so because we are born into social worlds that support and encourage their acquisition (Sterelny, 2012; Flynn et al., 2013). Our learning niche is adapted.

Pleistocene humans were foragers, and ethnographically documented forager communities organize the transmission of essential skills especially efficiently and reliably, and despite the extremely demanding nature of forager expertise. The forager education system is remarkably efficient. Forager children become competent adult foragers, with useful skills and considerable ability to act autonomously in their early teens, and with the help of social practices that reduce adult opportunity costs. Forager ethnography converges on the following picture. (i) A forager's education develops over three main phases. Young toddlers learn primarily from their parents (mostly the mother). From childhood to early adolescence, the young forager spends most of the day in a mixed age/mixed gender play group. Within this group, learning is a mix of collaboration, individual exploration, practice, and horizontal transmission, but also from some participation in adult activities. From early adolescence, social learning becomes predominantly intergenerational, with a variable mix of oblique and vertical transmission. (ii) Forager children are free-range. To contemporary western eyes, the play group operates with remarkably little adult supervision, with the children having considerable control over their own time budgets. (iii) Forager children acquire a basic forager competence remarkably early. By their early teens they are still to acquire only their community's most demanding skills. (iv) Explicit teaching is mostly restricted to norm acquisition, esoteric knowledge, and the most challenging subsistence skills. (v) Children are included in the adult world. Forager campsites are compact and intimate, with much of domestic life in the open (Hewlett et al., 2019).

This pattern seems to be remarkably widespread, low cost, and effective in building the competences needed for adult life (for reviews of this ethnography, in addition to those already cited, see Hewlett and Lamb, 2005; Konner, 2005; Hewlett et al., 2011; Konner, 2011). This learning niche increases the efficiency of cultural transmission, bringing otherwise inaccessible skills within reach. But it does so in concert with minds well-tuned to life in a complex social world. The learning niche works in synergy with culturally adapted minds. This picture of forager learning rests on ethnography, and there is always a legitimate question about the extent to which ethnographic evidence can be projected back in time to warrant similar claims about Pleistocene foragers. Pleistocene environments were different in their biology, geography, climate, and economics from those of the near-contemporary foragers of ethnographic record. The hominins of the deeper Pleistocene (earlier than about 200 kya) were biologically different from living humans too, perhaps in important ways[4]. Certainty is not possible. But strong considerations favor the relevance of forager ethnography to at least the Late Pleistocene, to those living at and after the acceleration of technological change and differentiation, an African change beginning somewhere between 200 and 100 kya.

First, the general picture of the three-phase forager education system, with a middle phase of extensive exploration learning and horizontal cultural transmission, is drawn from a wide range of ethnolinguistic groups, geographical areas, and ecologies. So it is not the product of a very specific set of circumstances, and it is very unlikely to be the result of a historical accident in a founding community, inherited by foragers as widely spaced as Australia, the Indian subcontinent, and Central and Southern Africa, and separated by at least 50 k years (and probably more, if recent dates of Australian colonization are supported (Clarkson et al., 2017).

Second, it is an efficient, low-cost system of forager education—reliable while reducing the impact of children on their parents' time budgets, and to some degree, their resource budgets. For the competence of their young makes those young partially self-supporting. This is made possible by the adults' own skill levels; the efficiency of their foraging makes it unnecessary to recruit children into the labor force as soon as they are physically capable of work. Near-teen and early teen children remain in the play group as sources of information and supervision of the younger children. That is not true of many subsistence farming and herding communities, where children of this age work, not play, or play-work[5]. Could late Pleistocene foragers have afforded this education system, or would they instead have been forced to recruit early teen and near-teen children as aids to their parents' foraging? We do not know the efficiency of Late Pleistocene foragers. But the "behavioral modernity" literature suggests that beginning about 100 kya (or perhaps a bit earlier), late Pleistocene foragers exploited a similar range of resources to those known from ethnography (McBrearty and Brooks, 2000). They did so with increasingly similar toolkits (for a striking example, see d'Errico et al., 2012; for a fine review, see Kuhn, 2020), and with an ability to occupy and exploit challenging habitats (desert, rainforest, high latitudes: Gamble, 2013). Moreover, there is no archaeological evidence of routine, intense resource stress (and hence a need to recruit every possible helper).

Third, the factors that make the forager education system adaptive for near-contemporary foragers (and the few that continue to forage) operated in the late Pleistocene too. Pleistocene forager lifeways demanded an even higher skill base, as virtually their entire material culture had to be made within the community (some trade may have been possible); near-contemporary foragers make considerable use of metal and other industrial products. For them too, a three-phase trajectory through their pre-adult life would have supported the reliable reproduction of those skills, and for the same reasons. Central would be the self-managed play group, supported by light-touch adult supervision and teaching, extensive and varied material support, a semi-protected environment as a learning arena, ready access to adult activities, and the public information these activities provide.

Finally, given the extremely demanding skills essential to Late Pleistocene foraging, with its megafauna and its impressive predator guild, and in environments as varied as Australian deserts and glacial Europe, it is hard to think of a sustainable yet radically different organization of the flow of knowledge. The extant forager system is remarkable for its early transition from primarily vertical information flow to extensive horizontal flow. If each adult is expected to find or produce what they need themselves, as is typical among mobile foragers[6], a primarily adult to child flow, with a more prolonged period of vertical information flow, would be very expensive. Children younger than their early teens cannot walk as far or as fast as adults, and so a more adult-centered, adult-supervised, regimented organization of childhood would impose serious inefficiencies on adult foraging. While this is most obviously true of hunting parties, it would also impact gathering, restricting the radius from the overnight camp.

EVOLVING A LEARNING NICHE?

If this is right, the forager learning niche must itself have evolved, presumably through some form of gene-culture coevolution. Reconstructing the evolution of this niche is beyond the scope of this paper, and perhaps beyond the resolution of the archaeological record. But a few factors are worth noting, as these show that there is nothing mysterious about the idea of a niche evolving.

First, changes in hominin subsistence and social organization can create as a side effect, a proto-learning niche. A shift to home-base foraging creates opportunities for juvenile cultural learning, as many adult activities are concentrated in time and space. Instead of foods being consumed piecemeal, in more or less their natural state, some are prepared and consumed at a home base, often using technologies of some kind (of which fire certainly became the most important). Home base foraging is especially important if tools are made or repaired at the home base as well. This creates opportunities not just for observation learning, but also for investigating and experimenting with tools, partially made tools, and tool by-products. An Acheulian campsite will be rich in flakes, cores, chips and other debris. Fire, once it became an established part of hominin life, extended the time spent in social proximity at campsites, further increasing the opportunities for exploiting public information.

Second, a home-base campsite generates public information, even if there are no changes in cognition or motivation relevant to cultural learning. But as Cecilia Heyes (2018) has pointed out, small quantitative changes in motivation can have important positive impacts on cultural learning. A young hominin will learn more if he/she is more focused on adult activity, and on the products of that activity. Such hominins will watch more closely and/or more often. They will be more motivated to experiment, to try to reproduce those products and the procedures that make them. Moreover, even without active teaching or other forms of active support, a simple increase in adult tolerance allows public information to flow with less loss or distortion: allowing the young to inspect closely what one is up to, when preparing an underground storage organ, or sharpening a flake, allowing the young to handle gear not in immediate use.

Third, from *Homo erectus* or even earlier, hominin social life saw the evolution of increasingly complex and demanding forms of collaborative foraging, a dynamic that selected for changes in hominin cognition and social organization (see, for example, Pickering, 2013). These changes had positive consequences for cultural learning (and for teaching, once that became important). These developments include, first, awareness of information as a resource. That awareness becomes important once a fission-fusion social system is combined with collaborative foraging. Fission-fusion organization creates an information gradient—different agents have different information. That gradient matters when combined with inter-dependent foraging. For then it can matter *to you* if your social partner is ignorant of some critical fact. Second, collaborative foraging selects for communicative abilities ancestral to language, for such foraging can require some joint planning and coordination. Many forms of ambush hunting, for example, require a modicum of planning, role division, and coordination. Third, as Pickering emphasizes, collaborative foraging selects for enhanced executive control—an ability to plan and execute sequences of actions over time, often without immediate reward, as in crafting a tool for future use, or positioning oneself in advance for ambush hunting. Enhanced executive control is important to social learning, for it is also needed for deliberate practice in skill acquisition, Finally, as already noted, this lifeway requires assessing and integrating information from different information channels. This is essential for both adult decision making and hybrid learning.

Finally, hominin life history changed over time. Adults became larger and longer-lived, and the pre-adult period became longer. This lengthened pre-adult period may have been an adaptation, making possible more extensive learning (as suggested by Kaplan et al., 2000; 2009. But even if it was a side effect of changes to adult life history, it improved the time budget for cultural learning, while at the same time imposing extra costs on parents. The shift to a three-phase organization of sub-adult life minimizes those costs without reducing the probability of children surviving to competent adulthood. Indeed, one referee has pointed out that these life history changes may have made a home base at which kids could be creched imperative.

CONCLUDING SUMMARY

Putting this together, the central claims of this paper are that (i) by the last 100 k years of the Pleistocene, and probably earlier, hominin lives depended not just on the mastery of a set of specific procedures, but on broad channel skills and expertise. (ii) This know-how included technologies dependent on specific physical procedures (toolmaking, hide preparation, and the preparation and use of other soft materials) but also more cognitive skills like tracking, local natural history, and navigation. (iii) These more cognitive skills are not expressed in distinctive, signature motor acts. Hence, in principle, they cannot be learned by observing and reproducing the motor sequences of models. Even for those skills that do encompass specific physical skills, imitation of a model's specific motor sequences is at most one aspect of skill acquisition. (iv) While not discussed in this paper, there are social and demographic preconditions of skill transfer across generations. But the crucial cognitive capacity is the ability to integrate information streams from multiple social and physical channels. (v) The reliable transmission of the cognitive capital of one forager generation to the next is supported by an adaptive, efficient learning niche.

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ENDNOTES

[1]Unless cultural learning is strictly vertical; ethnography suggests that this is true only when children are very young.

[2]Though there is redeployment in gene-based evolution too, as Kirschner and Gerhart (2005) show.

[3]First class cricketers assert the great importance while batting of watching very intently the trajectory of the ball through its journey, but John Sutton, using eye tracking technology, has shown that as they prepare to hit the ball, they shift attention from the ball to where they predict that it will pitch (personal communication, passed on with permission).

[4]Denisovans and Neanderthals were different too, but they were very genetically similar, so it is unlikely that their biological potentials were markedly different (though for the contrary view, see Wynn et al., 2016).

[5]I have seen this myself in Namibia, with pre-teen children working as goatherds.

[6]Unless, perhaps, it became a specialization of adults too old to forage. But it is very doubtful that there would reliably be such adults in small, mobile forager communities—mobile enough to stay part of the community; too immobile to usefully forage.

STATEMENT ON USE OF AI

No AI was used in the writing of this article. I leave to the reader the issue of whether NI was used.

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