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THEMATIC ISSUE ARTICLE: SYMBOLS, SIGNALS, AND THE ARCHAEOLOGICAL RECORD

Learning in Lithic Landscapes: A Reconsideration of the Hominid "Toolmaking" Niche

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Abstract This article reconsiders the early hominid "lithic niche" by examining the social implications of stone artifact making. I reject the idea that making tools for use is an adequate explanation of the elaborate artifact forms of the Lower Palaeolithic, or a sufficient cause for long-term trends in hominid technology. I then advance an alternative mechanism founded on the claim that competency in making stone artifacts requires extended learning, and that excellence in artifact making is attained only by highly skilled individuals who have been taught and practiced for extensive periods. Consequently both competency and expertise in knapping comes at a high learning cost for both the individual learner and the social group to which they belong. Those high intrinsic costs of learning created contexts in which groups selected cost-reducing forms of social learning and teaching, and in which specialization could develop. Artifacts and their manufacturing processes probably acquired functions as social signals—as honest signals of valuable capacities. The magnification of these signals, through competition between knappers and through inspiring later craftspeople, may account for a substantial amount of the accumulated elaboration visible in the archaeological record. Consequently lithic artifacts operated as material symbols from an early time in hominid evolution.

Keywords Lithic technology · Lower Paleolithic · Niche construction · Social learning

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Manufacturing artifacts by percussive fracturing of rocks is a behavior that has been continuously employed by humans and their hominin ancestors and kin for the past 2.5–3.5 million years or more (e.g., Semaw 2000; McPherron et al. 2010). Even the earliest stone artifacts evidence systematic transportation of rock in advance of use, coherent selection of appropriate materials, and elaborate and diverse manufacturing procedures that indicate a degree of learning and planning amongst early hominids not typical of modern non-human primates. Production of stone artifacts, called "lithics" by archaeologists, is consequently one of the earliest behavioral traits claimed to be distinctive of humans. But why did hominids persistently construct their niche by investing effort in procuring and flaking rock, teaching and learning how to do so?

Niche construction theory is increasingly being applied to the task of understanding hominid evolution, with a number of recent publications explicitly exploring the way cultural niches were constructed and the subsequent role of those niches in selective processes (e.g., Bleed 2006; Laland et al. 2007; Sterelny 2007, 2012; Collard et al. 2011). However most discussions of the role of lithic artifacts in the human niche treat these objects principally or exclusively as tools, and hence the role of lithic production is typically limited to the context of tool use, with little regard for the context of production. Consideration of the extension of hominid foraging strategies that results from this focus has been profitable (e.g., Whiten and Erdal 2012), but has often limited discussions of early social learning and information transference to contexts of hunting.

This article explores other options for understanding the construction of early hominid niches. In particular it abandons the idea that tool use was the sole driver of lithic production throughout prehistory, and instead focuses directly on what might explain archaeological evidence of hominid teaching and learning, procurement, and production. After a sketch of the archaeological evidence that must be explained I will argue that the early hominid lithics niche was founded on the creation of highly scaffolded learning environment(s) that facilitated transmission of diverse and complex manufacturing processes. In such social contexts master-apprentice relationships were significant for not only learning skills and procedures but also as a context of competition over social roles and identities. I hypothesize that in different contexts this competition might induce stable, normative technological systems, but in others directional, “intensified” technological innovation could occur. These speculations will focus on the archaeological evidence from the earliest industries in Africa: the Lower Paleolithic industries called the Oldowan and Acheulian.

African Lower Paleolithic Industries

Although readers should be aware that those early industries are actually technologically and geographically varied they have often been typified by reference to one common element: the core “tools” of the Oldowan and the handaxes in the Acheulian. In this article these forms will be referenced to reveal some of the problems of the tool-use hypothesis and to illustrate the value of alternatives. To begin with the Oldowan, generally dated to be more than 1.5 million years old and in some regions possibly a comparatively short-lived industrial pattern, there are single platform and bifacial cores, the latter sometimes called discoid or chopper tools, which have been discussed as either blocks from which flakes of stone were struck or as tools themselves. Both outcomes have been seen as being driven by the need to produce tools: either creating sharp-edged flakes for uses such as cutting meat and tendons or creating more robust and heavier core tools for use as choppers and planes. The fundamental issue for archaeologists is not what function they had, but whether the production of such items was completely constrained by material and engineering considerations or whether they represented a series of choices, a narrative arc of decisions that produced objects that could act as signals to others. It has been suggested that Oldowan production became elaborated over time, with the addition of bifaces to create the “Developed Oldowan” (Leakey 1971; Gowlett 1988). However, evidence is mounting that the Oldowan continued to exist as a technical strategy beside the newer Acheulian, and that they are not a simple succession (e.g., Semaw et al. 2009; Lepre et al. 2011). Consequently, the key questions for the Oldowan are whether there was elaboration of the production system beyond what was required to produce a flake or tool edge with minimal trouble and, if it occurred, how the gradual elaboration of production over time can be explained?

Similar questions emerge for interpretations of the Acheulian, a technological system that began at least 1.6–1.7 million years ago and which is characterized by Acheulian handaxes, examples of which are shown in Fig. 1. It was been claimed that handaxes were merely the fortuitous, inevitable, and unintended consequence of striking flakes from a radial core, and that they do not represent design beyond a desire for a sharp edge (Davidson 2002, 2010). More often researchers have presumed that handaxes were designed for use, although only for a single function. Suggestions for hand ax function have mostly revolved around the proposition that they were butchering tools, although novel suggestions of discus-like projectiles or half-buried booby traps on game paths have also been offered (e.g., O’Brien 1981). The evidence advanced for functional hypotheses is principally the recovery of handaxes from places where game was dismembered, and while this might well indicate use of handaxes, tool use fails to explain the diverse and yet elaborate forms of many specimens, or shifts over time and space in the forms produced. Handaxes show high levels of symmetry that were technically hard to achieve, repeatedly approximating the aesthetically pleasing golden ratio as well as resembling an open hand (e.g., Pope et al. 2006; Gowlett 2011). How might we explain such features?

The standard, and most obvious, explanation offered for the persistent manufacture of lithic artifacts has been that hominids benefitted from the construction of hard, sharp, durable tools. That tool-use explanation for lithic production is deeply embedded in archaeological thinking. In the early decades of the last century archaeologists often considered the appearance of artifacts of fractured stone to be a marker of the emergence of new cognitive/cultural capacities, indicating the arrival of “man-the-toolmaker,” and they advanced the proposition that such artifacts were tools that provided a selective advantage by making hominids superior hunters and formidable opponents. More recent studies of lithic artifacts have often also presumed that these artifacts were tools, and have speculated about the economical/ecological roles these objects might have had. However, the evidential basis for those interpretations is thin.

The morphology of Lower Paleolithic artifacts cannot indicate that (1) the specimen had been used, or (2) if it had, what uses it was employed for (Hiscock 2014). Most artifact morphologies can function for most purposes, albeit suboptimally, within broad size/weight limits. By altering handgrip, angle of contact with worked material, and the edge used, hominid tool users could have used diverse artifact forms for the same function. Furthermore, the process of resharpening the edge of any tool alters its

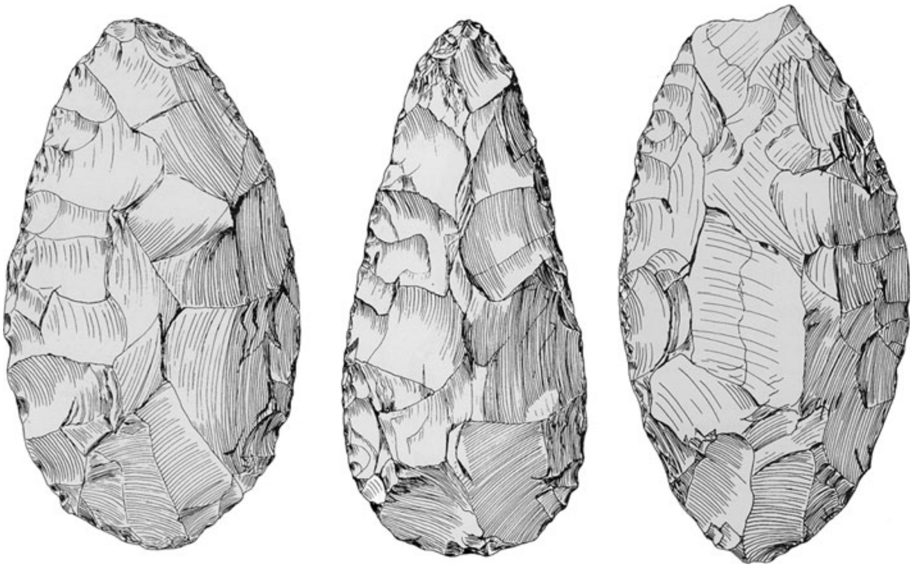

Fig. 1 Examples of symmetrical, well-crafted African handaxes. These are from Kalambo Falls in Zambia, after Clark (2001, pp. 354, 382, and 410)

morphology, making it improbable that any tool could be continually optimal for a single function (Hiscock and Attenbrow 2005). A number of studies have suggested that whether a lithic artifact was made one way rather than another somewhat different way often produced very little mechanical difference in the use activity (see Gowlett 1998; Hiscock and Attenbrow 2005; Waguespack et al. 2009; Newman and Moore 2013 for examples). Consequently, hypothesized associations between particular lithic "types" and particular functions probably underestimate the complexity and dynamism of form/function relationships that existed in the Paleolithic. And so we are confronted with the prima facie problem: given the multi-functionality of any of the morphologies, why were distinct morphologies manufactured, and why is there change over time of these morphologies?

Certainly the sharp, hard edges of stone would have offered hominids a functional effect they enjoyed, but as morphology and technology are not simply connected to function, tool use explains only the selection of stone as a raw material. The Paleolithic sequence of lithic artifacts represents a different interpretative challenge, namely why lithic production shows clear but complex patterns of chronological change? The nature of change is varied, and many key technological shifts are not restricted to conventional stadial categories in the archaeological record such as Lower Paleolithic, Middle Paleolithic, and Upper Paleolithic. For instance, ovate, symmetrical bifaces that could be classed as varieties of "handaxes" coexisted with, or as part of, the Oldowan, changed in form geographically and over time during the Lower Paleolithic (e.g., Schick and Toth 1993; Gowlett 1998; Kyara 1999; Clark 2001; Reti 2013). Regular production of elongate flakes ("blades"), once thought to characterize the Upper Paleolithic, is now known to occur intermittently, on multiple occasions, over more than half a million years, beginning within the Lower Paleolithic (e.g., Monigal 2001; Johnson and McBrearty 2010; Faivre 2012). And in Africa small, distinctive, back-blunted flakes, called microliths, cycled in and out of production since the late Lower Paleolithic, over more than 300,000 years (e.g., Barham 2002; Hiscock and O'Connor 2006). Such patterns are not simply tied to directional or cyclical environmental changes in resources or tool use on those resources (e.g., Hiscock et al. 2011). The persistence, gradual elaboration, and in some cases repeated reoccurrence of suites of technological behavior and versions of the same artifact form over very long periods of time are impossible to explicate in terms of tool use.

In recent years attempts to explain investment in such technological elaborations have pursued the possibility that they were complexly constructed, costly signals that helped configure social interactions (see Gamble 1998, 2012). Since we know that costly signals can involve morphological elaborations, such a mechanism offers potential in explaining the temporal trends in lithic artifacts within the Lower Paleolithic. And yet the proposals have not been compelling. For example, a sexual selection model has been extensively discussed over the past decade, following the proposal by Kohn and Mithen (1999) that hand ax symmetry demonstrated skills that help attract mates, and that the production of elaborate lithic artifacts represented a signal that enhanced fitness. This proposition has been extensively criticized, with many commentators remaining unconvinced that this would have been a mechanism for mate selection (e.g., Machin 2008; Hodgson 2009; Nowell and Chang 2009). The gender of artisans is not known, and a proxy for other skills would hardly be needed in small social groups when success in other activities such as foraging or political negotiations could be observed. Nor is it obvious that handaxes would be a good proxy for these other skills. Additionally there are a number of evidential problems such as the possibility that individual handaxes may have been extensively reworked (Iovita and McPherron 2011) and so the morphology of each specimen was not fixed for display but changed, making comparisons between artisans more complex than Kohen and Mithen envisioned.

Spikins (2012) has offered an alternative model that costly signaling in hand ax production offers a cue that the maker was "trustworthy" because the effort of making the specimens displays willingness to exceed self-interest in making a visually pleasing object, and that the self-control displayed in the difficult manufacturing process would transfer to emotional control in human relationships, creating reduced violence and increased fidelity. However, self-interest is embedded in the signal itself, and there is no reason to think self-control in the manufacture of potential weapons need translate into reaffirming and empathetic social relationships. More importantly, the trustworthy model as it has been framed offers no coherent mechanism for the evolution of this signal of trustworthiness.

Nevertheless, models of signaling remain worth examining for the Lower Paleolithic. While signaling mechanisms may provide fundamental insights into why lithic artifacts were made the way they were, the way forward is to understand the dynamics and costs involved in lithic technology and costly signaling using lithic technology. I will argue that the production systems employed by early hominids to make artifacts were expensive principally in terms of the learning/information transmission they required, and that a focus of learning underpins the social dynamics that resulted in incremental change in technology over long periods. One of the key costs would have been acquisitions and transmission of information about the manufacturing process: the cost of learning necessary technical skills, of developing sensitivity in diagnosing the physical properties of rocks, of creating and maintaining shared knowledge about the distribution of knappable rock within the landscape. A simple example of the learning investments required to make a lithic niche operational is the first step in the production chain: the acquisition of suitable rock materials.

Mapping Geological Resources in a "Lithics Niche"

Procuring material for artifact manufacture demands an understanding of the inorganic materials being worked, and an ability to track geological resources across the landscape. Since these practices are not known to have been needed by hominids before the development of lithic technology, early knappers must have been obliged to develop new ways of exploiting and conceptualizing their landscapes.

Once established, the habitual use of rock demanded both individual learning and information transmission about the geological character of the landscape. The ease and success rate of knapping and the edge-holding capacity of tools produced can vary markedly between, and within, each petrologically distinct class of rocks. Significant petrological differences in the knapping characteristic of rocks can be identified by understanding subtle and variable combinations of texture, color, shape, luster, and even sound cues. These cues allowed hominids to select, transport, and knap specimens that offered high potential for reduction, and to avoid carrying or working nodules that offered little potential. Reading geological resources in this way requires expertise in a new domain of knowledge about the natural world.

Given the weight of rock and the unforgiving nature of the knapping process, hominid knappers would have been advantaged by knowledge of how to differentiate suitable rocks: favoring fine-grained/microcrystalline siliceous sedimentary like some quartzites and cherts, or uniform textured igneous rocks such as basalts and tuffs. But even more detailed differentiation of the knapping potential of any block of stone would have been advantageous. For example, knappers might estimate likely homogeneity or cortical thickness (by lightly striking the block and listening to the sound, or by inspecting lines, cracks, and surface textures), and select pieces with preferred sizes and shapes, so as to invest in optimal pieces. All of these behaviors are visible within the early African industries.

Although traditional archaeological approaches interpreted the lack of multiple implement categories in the earliest African industry—the Oldowan—as showing its simple and unsophisticated character, recent studies have revealed an economy of stone transport and working that is coherent and systematic. An explicit test of the archaeological evidence from two key sets of African Oldowan locations—Olduvai Gorge and Koobi Fora— demonstrated that early hominids were not merely targeting the closest, cheapest rock source (Reti 2013). For instance, in locations such as Olduvai Gorge Bed II, in "Developed Oldowan" and Acheulian assemblages, there is evidence that material was not transported from the nearest source, but that volcanic rock (green phonolite) used specifically for the manufacture of bifaces, was transported into the lake basin from some distance (Kyara 1999, p. 393). Reti (2013) has additionally shown that at the DK site, also in Olduvai Gorge, manufacturing on rocks with high import costs was done efficiently whereas low-cost materials were treated without concern for material conservation. Those studies indicate that hominids not only recognized the economics of material procurement and translated those costs into planned treatments of each material, but also that these practices were learned and transmitted over multiple generations.

Such a strategy to provision places (Kuhn 1995) could be a response to a number of factors, including a need to decrease transport time to butchering locations. There is also evidence for relocation of both flakes and cores, and presumably tools, between sites/caches (McNabb 1998), raising the question of whether simple containers were employed in the transport. In any case there was a composite set of strategies supplying bases and individual foragers rather than a single economic strategy. Increasingly it is evident that in the Oldowan raw material from diverse sources was strategically selected and relocated to provision diverse and articulated manufacturing systems (Braun et al. 2008; Reti 2013). Even within the Oldowan the evidence suggests detailed and extensive mapping of lithic resources, and selection of and investment in comparatively expensive materials for more elaborate bifacially worked pieces.

Early hominids were sensitive to the energetic costs of transporting rock. Over distances of only 3–5 km or less there is measurable adjustment of technological activities in response to reduced material availability and increased replacement costs (e.g., Blumenschine et al. 2008). In some contexts hominids employed different technological systems to reduce importation costs (Braun and Harris 2009), and the strategies/designs were transmitted between groups occupying the same region (Reti 2013). Solving transport and processing costs for lithic materials was a typical component of provisioning behavior from an early point in the lithic niche. It is now clear that provisioning patterns and cost-reduction strategies for Oldowan industries were structured in respect to detailed mapping of the distributions of lithic sources across the landscape. The same conclusion undoubtedly applies to coeval and later Acheulian industries.

Constructing mental maps of territory, food, and water resources, potential dangers, and access ways is a fundamental capacity of animals and in some taxa involves significant information transference. These mapping dispositions and capacities would have been recruited for additional purposes in the lithic niche. Hominids who were already mapping the distribution of food patches or predators and who became habitual knappers would have, of necessity, added observations of outcrops/exposures of rock, the abundance, morphology, size, and fracture characteristics of knappable rock, to their resource mapping activities. It is the implication of this new mapping that is noteworthy here.

Some rock suitable for knapping was probably encountered in the process of foraging/hunting. But lithic and organic resources do not map onto each other perfectly in many landscapes, and so simply observing geology while foraging would have produced very partial knowledge of rock resources. Hence it may have been valuable for groups to invest in dedicated lithic mapping so that effective procurement choices could be made. Lithic resources are structured as a result of different mechanisms, and must be understood by different principles, to organic ones: they are not themselves always susceptible to tracking and are not generally renewable on the same temporal scale. While early hominids would not have grasped the geological processes underpinning the geographical distribution of lithic resources, they would have developed and maintained shared representations of the distributions of lithic materials in their environment. These representations probably operated in a somewhat different manner to those developed for organic resources, since lithic materials have unique profiles of encounter, processing, and transport costs and offered the potential for long-term storage without processing.

Certainly the selection of lithic materials, and therefore the representations of their location and abundance, integrated complex arrays of information across multiple perceptual modalities, to accommodate variability in relevant characteristics such as weight, texture, and shape of rock nodules. Additionally, in the process of lithic mapping, and of exploitation of some lithic resources, hominids might have encountered predators that would otherwise be avoided or minimized, and so lithic mapping would have required expansion of the mapping of biological phenomena within the landscape.

One archaeological pattern that probably evidences a concern for mapping—even manipulating—lithic resources by Lower Paleolithic hominids is the transportation of blocks of stone to nodes in the landscape. Good quality materials are not found uniformly in any landscape, and in the sedimentary basins of the East African Rift quality knappable rock displayed a patchy distribution. Oldowan hominins stockpiled stone at locations spread across the landscape. This pattern has been explained in a variety of ways, such as the proposal from Potts (1984, 1991) that lithic material was cached to reduce transport costs of carcasses to safe locations where they could be processed with lithic tools. Such a cost reduction strategy required forward planning, since investment occurred substantially before returns, as well as territorial security, since the group investing would need to be confident no one else will use it. This delayed return strategy probably operated over extended periods and tied early hominid landscape use to a network of artificially constructed nodes of material.

The "cobweb of persistent places" (McNabb 1998, p. 21) documented for early hominids in east Africa was elaborately constructed, and supplying rock to these places for artifact manufacture involved many facets: constructing mental maps of lithic resources, ranking the different sources for different knapping purposes, planning the location of caches, evaluating the cost/benefit of supplying a place from alternate sources, selecting nodules, and transporting nodules or worked items. It seems that comprehension of material properties for selecting suitable rocks for knapping and mapping of geological resources within the landscape was something that emerged relatively soon after knapping began and hominids constructed a lithic niche. Development and transmission of these geological understandings would underpin activities of social learning and public practice. Those activities would also have been shaped by the requirements of a technology based on fracturing rock.

Lithic Technology and Lithic Debris

Fracturing rock by applying an external force exceeding the elastic limits of the material is a process archaeologists call knapping. Production of stone artifacts through fracturing is a difficult and, more importantly, an unforgiving activity. It is unforgiving in two senses. Physically it is dangerous if poorly or inexpertly practiced because the slivers of rock fractured off are always sharp, sometimes sharper than scalpels, and can inflict deep and debilitating wounds to the hands, legs, and (from flying shatter) eyes. The benefits of sharp, robust tool edges so often emphasized by archaeologists must be assessed against the risk of infection or reduced limb or eye function that can result from the process of producing those sharp edges in unsanitary contexts and without medical treatments. Those physical risks will be heightened for some technical actions, for some raw materials, and for learners, but they remain ever present (though not equally probable) for all knappers, even experts working in ideal conditions. In conditions in which (1) skill diminished the risk of injury, and (2) unaided trial/error learning has higher risk costs than assisted learning, which is effective in teaching relevant skill, then the reduction of injury probability alone might be an adequate incentive for investment in teaching. It is likely that lithic technology would frequently meet those conditions. However, if such conditions were often met then these considerations may have shaped divisions of labor within hominid groups from the earliest times. For instance, in contexts where a group undertook a manufacturing process that carries a substantially higher risk for inexpert individuals there would have been selective advantage to develop systems of craft specialization in which a fraction of the group focused their energies on knapping, at least on those processes in which enhanced skill reduced physical risk, and where that specialization was rewarded through reciprocity in resource redistribution as well as kudos. The substantial learning costs attached to gaining knapping expertise would have enhanced that social trajectory (see below). We know that in late prehistoric and historic contexts where more standardized outputs were important socially/economically, such as in commercial exchange systems, lithic manufacture was typically the domain of craft specialists (e.g., Torrence 1986). Masterful knapping performances can be found in archaeological lithic assemblages from all time periods, and there is no doubt that knapping experts, perhaps specialists, existed from the Lower Paleolithic, that is, from before 1.5 million years.

It is worth noting that even the early archaeological industries, Oldowan and Acheulean, display considerable knapping complexity and diversity. Oldowan assemblages document raw-material selectivity, transportation, and varied technical approaches to knapping (Hovers 2012). For instance, from at least what is classified as "Developed Oldowan" there were a variety of knapping procedures and outcomes, reflected in the different categories that archaeologists identify (e.g., burins, bipolar cores, or *outils escailles*, unifacially retouched flakes or "scrapers," unidirectional cores, bidirectionally and discoidally flaked cores, and symmetrical bifaces called handaxes). The Acheulean proper is distinguished by its extensive bifacial reduction, forming "handaxes" or "cleavers" (bifaces with a truncated end). These industries are not always easy to distinguish: Oldowan assemblages sometimes have large numbers of bifaces and in some regional sequences there is chronological overlap of these industrial patterns rather than simple evolutionary replacement (e.g., Isaac 1977; Gowlett 1988). Recent experiments establish that there were broadly equal motor control and manipulative complexity in both Oldowan and Acheulean knapping, and that in some expressions both technological systems were elaborate and planned—the differences between them were a combination of emphasis on manufacturing strategies, elaboration of technique and strategy, and heightened skill sets in the Acheulian (e.g., Stout et al. 2009; Baena et al. 2010; de la Torre 2010; Faisal et al. 2010). Processes underlying these shifts are clarified by considering the technical details of lithic production.

The process of manufacturing artifacts by fracturing rock is unforgiving in a technical sense. To create fractures the knapper must apply force to the outer surface of a nodule of stone. This can be done, especially in small specimens and at the end of the production process, by pushing on the rock with a pointed object (such as a piece of bone or antler), but by far the most common approach is to strike sharply with a rounded stone hammer or antler/wood baton. If sufficient force is imparted in the right direction, by a blow located in the right place, a flake of stone will be struck off. However, an unsuccessful blow does not leave the rock structure intact: if the force is inadequate to complete a fracture, conical fissures are still created, and these may inhibit subsequent blows creating a successful fracture. When a fracture has been initiated, its passage through the rock is still affected by the force input (itself a summation of blow location, blow hardness/velocity, blow angle, hammer size, shape, hardness, and elasticity), but it is also affected by the interaction of the blow with the surface morphology and size of the item being struck. We know that in most circumstances a fracture will be significantly determined by the configuration of topography on the outer face of the rock struck, with the fracture typically traveling sub-parallel to that surface, and preferentially following zones of higher mass such as ridges between the scars of flakes already removed. Each flake removal changes the morphology of the nodule, replacing convex with concave topography down the center line of the fracture, leaving raised areas to the left and right, thereby shifting ridges laterally, and in effect reproducing some modified version of the previous core morphology. This of course poses knappers with the problem of how to alter the shape of the object being flaked when the material removed tends to replicate characteristics of earlier morphological states. Rapid state transitions can sometimes be created by knappers (such as burinations, truncations, and large simple notches), but in most contexts only gradual, directional sequences of flake removal are viable or effective means of engineering morphological transformations.

No lithic production sequence has an inevitable outcome. Details of the location and nature of each blow affect the outcome of individual fracture events, and a designated outcome is contingent on each of the individual flaking events forming the (often long) production chain. At any point in the *chaîne opératoire* a poor strategic choice in the location of force application, a mis-struck blow, a flaw or inclusion in the rock, a failure of the hammer stone, or some other difficulty, might construct surface morphologies that make it substantially more difficult or even impossible to transform the object into a specific form. For instance, a blow placed slightly too far from or too close to the edge, or placed in line with a low rather than high area, or with insufficient force, will often cause the fracture to terminate abruptly (what is called a step or hinge termination), leaving a “cliff” of thicker material in the center of the piece that would limit further flaking if it was not removed. Some technical difficulties of this kind arise quickly, perhaps unexpectedly, but others have a gradual, almost predictable, onset, such as the increased difficulty of immobilizing the struck piece as it is held in the hand and becomes progressively lighter from having flakes struck off, often requiring the knapper to use progressively smaller hammers in the work. Such problems emerge in most sequences of reduction, and make the creation of any designated shape difficult. For this reason knappers typically have a repertoire of responses to problematic morphologies with which they attempt to recover appropriate shapes, to thereby “stabilize” and maintain control over the transformation process. More expert knappers have a larger repertoire of responses and heightened sensitivity to emerging problems, enabling their responses to be initiated early in the sequence.

Stoneworking systems were sufficiently complex in all time periods (see Schick and Toth 1993, pp. 118–122) that the articulation of problems and responses is not deterministic. For early prehistoric technological systems that have been richly explored by archaeologists it is clear that ancient knappers employed a repertoire of problem-solving practices conditioned by a variety of factors, including the context and manifestation of the problematic morphological feature, the skill and goal of the knapper, as well as the nature and cost of the material being worked. The implication is that knapping is a dynamic as well as a complexly unforgiving activity, and if knappers are to achieve a defined outcome they cannot maintain the same mechanical action or strategy (except perhaps in the shortest and most simple sequence), but instead they need to draw upon a nuanced knowledge of possible knapping practices and likely outcomes.

The length and success rates of production sequences were contingent on many factors, including material properties, starting morphological conditions, and knappers’ skills. Because of the complex and powerful interactions that occur during knapping, summarized above, goal-directed transformations indicate the application by the knapper of elaborate production plans that included a repertoire of recovery/maintenance procedures. Production of regular, symmetrical, and intensively flaked artifact forms such as handaxes or bifacial points cannot be the result of haphazard blows, and nor are they an inevitable outcome of knapping (contra Davidson 2002). For this reason the engineering constraints of these complex, dynamic lithic production systems indicate that earlier hominids, like modern knappers, would have had detailed mental projections of how to proceed with the production process. Those projections represent extended sequences of actions. For instance, strategies for constructing and maintaining viable platforms relative to shape of the worked piece often involve projecting at least five to ten actions ahead—a requirement of the knapping dynamic because the decisions made by the knapper many actions previously have a consequence for morphology, and therefore the outcome of a specific blow. Of course knappers today, and presumably in the past, reduce some of the labor of mentally processing long sequences through tactics of both compartmentalization and routinization of activities and choices, though even then there is a need to constantly monitor the stability of the process. However, decision-making processes and knapping actions remain ramified, even with semi-standardized modules of behavior being employed, and the capacity of any knapper must largely depend on the level of knowledge and learned physical skill that individual has acquired. At the same time, the imperatives of the knapping process produce distinctive demands on learners and construct contexts for that learning.

The argument to this point is that knapping long and/or regular sequences is intrinsically a complex process that requires competency at a number of levels simultaneously: bio-mechanical capacity to strike accurately and forcefully; the capacity to anticipate and identify emerging problems in the specimen morphology and to apply an effective action from a repertoire of potential responses; the capacity to plan ahead, which involves mental projections of both future actions and predicted outcomes. As discussed above, current evidence suggests that these statements apply to both the Oldowan and Acheulian industries, although length and difficulty of production chains increased with the introduction of extensively flaked bifaces of the kind found in Acheulian assemblages. Production of extensively flaked, symmetrical handaxes is one indication of hominids developing not merely basic competencies but high skill levels in the physical and mental tasks of knapping.

I now move to the implications of that conclusion, first for conceptualization and memory in early hominid artisans, and subsequently for the nature of social learning carried out in early hominid groups to develop such high-level competencies in at least some individuals.

Lithic Narratives

A critical requirement for the acquisition of even moderate knapping ability is the development of a capacity to perceive and conceptualize the trajectory of change within the production sequence, or *chaîne opératoire*. Comprehending the sequence involves the construction of a narrative that describes, or at least "summarizes," both the technical actions of the knapper and the changing morphology and size of the piece being worked. For knappers this narrative serves to articulate the specific decisions about each blow with the short-term and overall goals in working the piece, but more importantly it allows the knapper to do two things. First, by imaginatively projecting the narrative forward the knapper can use the past morphological trajectory of the specimen to anticipate desired future forms and to compare those projected forms against the emerging actual morphology to identify the emergence of problematic states that might trigger an altered set of knapping actions. As explained above, the incremental development of undesirable features can result in dire engineering difficulties unless the trend is recognized early enough for simple actions to rectify the situation, thereby obviating the need to implement changes in technique or strategy that might (1) require more of the specimen to be reduced, (2) heighten the risk of damaging/breaking the specimen, or even (3) preventing the piece being completed as initially intended. Tracing the production narrative is a key way by which knappers can plan and monitor the success of their actions. Given the complexity of knapping dynamics it is likely that any extended reduction sequence indicates the existence of narrative mapping by the knapper.

This is so because learning how to complete individual knapping actions is not by itself all that is needed to master any particular technological strategy and to operationalize any specific sequence of lithic reduction. Skill acquisition for a knapper involves not only learning to manipulate objects to create desired fractures, it also involves developing a capacity for creating narrative maps that allows sequences of actions to be constructed in response to the complex of factors constructing any knapping context. Each knapping sequence is a unique variant of a more generalized strategy of reduction, a variant that reflects knappers' reactions to the specific configuration of material, morphology, and size of each piece. Narrative depictions require multi-valency to represent normal patterns of reduction, recognize variability in process, and contain a basis for defining interventions. Growth of both knapping skill and knowledge in individuals and groups would have been facilitated by developing more sophisticated narratives of the operation of manufacturing sequence.

The development of a capacity for developing extended narratives, recalling past examples and projecting detailed imagined ones into potential future situations is likely to have been a key transformation in hominid cognition. The argument put here is that the incremental development of a capacity for planning and implementing long lithic production sequences involves recollection of and conjecture/imagination about long event sequences, and as such may have been one of the basic mechanisms driving improvement in hominid narrative construction, and related human preoccupations with time. As Shaw-Williams (2013, this issue) argues, imaginative projections and narrative construction probably also developed in the context of early hominid tracking. The cumulative effect of the development of projection and memory in two independent components of hominid life, i.e., trackway reading and lithic narrative, may have powerfully magnified the cognitive transformations in early hominids.

Narrative depictions of lithic production sequences offered opportunities for exploring the relationship between knapping actions and material outcomes, and therefore further enriched the learning contexts discussed below. Hominids would have possessed capacities of pattern recognition and memory built on cognitive processing of stimuli/cues available in the natural world, but in knapping individual hominids were constructing a complex artificial environment where mechanical causes could be examined by replicating significant events, where the effectiveness of instituting innovative variants could be evaluated, and where experiments could be constructed. Given those features, knapping created a learning context in which hominids individually learned to plan and identify causation (or at least action–response relationships) through the examination of regularities in the success or failure of manipulating the complex production system with goal-oriented actions. Furthermore, the narrative construction facility can be applied to specimens made by others in a process of "reverse engineering" that would enable guided experiments to replicate/imitate the observed specimen. This kind of individual learning would have taken place within the context of interactive social learning.

However, it is unlikely that such lithic narratives could be built and operationalized by individuals on only a process of associative learning. Trial and error by someone beginning to learn knapping would be expensive to supply stone for, would heighten physical risks, and might rarely be successful, a combination that would discourage further practice. Even when trial and error enhanced knowledge and skills, the lengthy process of mastering knapping skills would mean long delays between the initiation of learning and substantial rewards. While "local enhancement," when learners have access to materials and can closely observe knappers, might reduce the costs and disincentives of independent trial and error (Henrich and Gil-White 2001, p. 174), that process would still offer limited opportunity. Much of the knowledge that underlies knapping is subtle and not easily observed, so that even associative learning reinforced and guided by observation offer limited learning capacity. This implies that scaffolded social learning, perhaps with a gestural language, played a significant role in the Hominid lithics niche from even the earliest times. Such an inference is consistent with Stout's revelation that neural circuits implicated in language were increasingly employed during knapping in the Lower Paleolithic, especially as knappers began to produce thinner bifaces (Stout et al. 2009; see also Stout and Chaminade 2007).

Given the effort and information required to master lithic production techniques, and the richness of social information that can be conveyed in both performance and product irrespective of subsequent object use, it is worthwhile exploring the social context of early hominid lithic production and the involvement of this production in sending social signals.

Lithic Apprenticeships and Social Learning

Learning to fracture rocks is not very difficult. Learning to knap rocks in a controlled manner, and dealing in a masterful way with the dynamics referred to above, requires a substantial investment in learning by the individual and their group. Some of this learning, and certainly the acquisition of basic competencies, was perhaps embedded in other activities such as tool use or childhood play, but the evidence from recent archaeological experiments and from the biographies of master replicators, such as Crabtree, Callahan, Flenniken, or Bradley, indicates that high levels of expertise are acquired over long periods of training and through processes of interactive learning under the supervision of a skilled practitioner. For instance, in one recent experiment experienced knapper Metin Eren practiced a single knapping strategy under the detailed verbal and non-verbal instruction of expert knapper Bruce Bradley (Eren et al. 2011). Over 3 months Eren knapped levallois cores, a specific form of elaborate biface reduction, and at the end of the period Eren was competent in the manufacturing process but still had measurably greater error rates and lower flake symmetry than Bradley, and in the vast majority of specimens it would have been possible to distinguish between master and student using either the cores alone or the flakes from them. Learning rates will vary between tasks and individuals, but experiments such as this give some indication of the effort involved in obtaining knapping expertise that would enable a knapper to efficiently and regularly produce standardized and elaborate forms. The cost of gaining even moderate expertise should be understood within the economic context of how to supply enough stone for a knapper to practice. Since suitable lithic materials are not uniformly distributed across most landscapes, the cost of extended learning includes the cost of provisioning learners with rock which may be converted into suboptimal products, potentially a high transport cost if rock is taken to knappers and a high scheduling cost if knappers regularly relocate to lithic sources.

In addition to those economic costs, hominid groups required social structures with which to facilitate the learning process. Theories of apprenticeship offer an obvious insight into the learning experiences that would have been constructed. Apprentices learn through observation of, imitation of, and instruction by, more experienced practitioners. In this context apprentices acquire not only the physical skills and mental comprehensions required to work in the lithic medium but also the local cultural production habits and standards for judging what forms are functionally or socially valuable. The apprenticeship process is intimate. It involves substantial investment as the novice learns conventional engineering and economic procedures and norms for self-evaluation as well as substantial problem-solving capacities that are critical in lithic production. The result can yield powerful scaffolding (pace Bruner 1960) in the instructional environment that supports enhanced skill acquisition through the interactions/mentoring embedded in the social learning process. These propositions were employed to great effect by Sterelny (2012) in his hypothesis about the evolution of learning environments and rich information transmission within the hominid lineage. Sterelny argues that once lithic artifacts were regularly made they became part of the hominid lifestyle and created a context which selected for physical and cognitive capacities that facilitated the technology, producing a feedback loop capable of not only augmenting the technology being created and reinforcing the richness of information conveyed in the apprenticeship process but also constructing a framework for social learning that could be transferred to other tasks and contexts.

Such apprenticeship processes offer powerful ways for understanding the emergence of social learning in the hominid lineage, and can help explicate the amplification of skilled production and the accompanying learning systems inferred from the archaeological record. For example, because I argue the prolonged learning process to master one or more systems of lithic technology encouraged the development of apprentice-master relationships, which were transferable to other learning contexts, it would also have generated (or at least contributed to) a series of secondary conditions transforming social life. I would expect that one consequence would be the enhancement of differentiated labor roles and the growth of specialization within small groups (and the consequent strengthening of apprenticeship learning to maintain intergenerational transference of skill). Over time that feedback could generate the incremental buildup of, and concern for, knapping skill that would make sense of the emergence of complex and extended production chains as seen in the Acheulian hand ax. Furthermore, quality assessments and interpersonal rivalries that might develop within apprenticeship learning contexts have the capacity to either stabilize and maintain production norms to some degree or alternatively to drive gradual augmentation of production and produced goods. As archaeologists have depicted hominid technologies, both early and occasionally late ones, as being "stable" and little changing over long periods or alternatively as slowly evolving elaborations, it may be worth exploring the possible contribution of apprenticeship contexts to those patterns of technological change. Some of the plausible connections can be illustrated by thinking of lithic production as performance-driven.

Lithic Performance

Whilst the manufacture of ritual artifacts may have occasionally have been carried out in secretive contexts, where only a small fraction of a group could observe the events, it is likely that the noise of the knapping process, the quantities of rock (and hence transportation costs and visibilities) that would be required, and the persistence of the debris created (see below) would make attempts to always hide production near to impossible. It is more likely that knapping was typically a relatively public performance from the inception of the behavior in the early Pleistocene, with knappers working in public spaces where all, or at least substantial portions, of the group could in theory watch. Archaeological residues of knapping in sites with food residues and hearths suggests that public performances of knapping were common, and there are some instances reported of Lower Paleolithic workshops that might represent the activities of a guild of knappers working material from a source together, though whether in cooperation or competition is not known (Gopher and Barkai 2011).

Public performance of production carries no substantial risk of "knowledge theft" by casual observers, as rapid knapping actions are difficult to comprehend to the unskilled. However, comparably skilled rivals might gain from observing their competitors, leading to the development of procedures such as distractions to mislead observers (superfluous steps, noise/song, and so on), body positions to obscure process, and batch processing to limit the number of production stages visible at once. Notwithstanding such efforts to control information transmission during knapping, public performances would have performed two potentially important roles.

First, within apprenticeship learning there is a need for group approval, which implies public performance and perhaps even represented "graduation" that signified acquisition of identity/status as someone who is a knapper. Pratt (1988, 1998) argues that the establishment of "authenticity" is a key requirement of a successful apprenticeship, creating in the student not only a competency in the task but also an understanding of the social context of the task that affects its value, use, and reception by other group members. Establishing such authenticity might be as simple as being seen to knap with knappers, to have acknowledged access to lithic sources, to participate in lithic acquisition forays, to be used as a source of advice or as a model for learners, and to have the products judged as worthy (useable) and conforming to group convention within an acceptable tolerance.

Processes of public display and evaluation, in a context where a premium was placed on authenticity by a “guild” of knappers (or by members of the broader group), might act to stabilize, even standardize, the artifact forms produced, and minimize temporal change in those forms by providing strong filters discriminating acceptable and unacceptable production values. There are ethnographic examples of mechanisms by which negotiated norms in lithic tool form were constructed or maintained in multi-person decision making while an individual knapper worked in public (e.g., Hiscock 2004), as well as of societies in which apprenticeship mechanisms were central to learning lithic technology (e.g., Stout 2002). Such corporate decisions, as well as both private and public processes of establishing authenticity, might have a variety of effects, including enhancing the role of patronage as a political mechanism and the establishment of a specialist role carrying status that did not directly involve food procurement. The importance of recognized production specialists, trained within and authenticated through processes of apprenticeship learning, can be considered by raising a second implication of public performance in knapping.

Public production and an apprenticeship framework provided a context for information transmission and for competition between individuals. This is possible because there would have been abundant cues, on the lithic artifacts and displayed in body actions during knapping, that reveal different skill levels between knappers. It is inevitable that those cues would be co-opted as direct signals of craft excellence and indirect or proxy signals of other related competencies (physical and social). The role that such competency signals might play in sexual selection or in negotiating social relationships has already been mentioned. But I have also made the point that usefulness of a lithic artifact as a proxy for other competencies is uncertain. The one thing that lithic artifacts are perfect proxies for is the relative level of skill in knapping, and I propose that it could have been craft excellence itself that was being signaled. However if craft excellence was the event of interest it is likely that not only the artifacts produced but also the public knapping performance were used to judge relative skill.

Why would knappers be involved in signaling their competency and how would knappers benefit from developing expertise? The most likely process would be where status was a reflection of, and perhaps broadly proportional to skill in knapping, leading to deference towards highly skilled knappers in some social interactions. High quality artifact manufacture cannot be consistently faked in a lithic system—there is obvious difference in product, efficiency, and speed between highly skilled and little skilled craftspeople. Even brief observation of a knapper or their artifacts offers reliable and honest indications of their skill. Where that skill is desired by others, status/prestige would automatically and reliably attach to skilled knappers.

There are many contexts in which knapping skill would be valued and rewarded, but a simple example will make the point. In situations in which individuals seek to maximize gain from high quality blocks of rock they have found, quarried, and/or transported, they might ask a knapper of known expertise to work the block. Such decisions to carry rock in the expectation of another individual converting it, through knapping, into a more valuable item than you could make yourself, would invoke both a reciprocal social arrangement and social recognition of skill differentials. However, following the reasoning of Henrich and Gil-White (2001, p. 179), only knappers with skills far above average would be provided with status and treated in this way, since a deference payment would not be cost-effective to individuals with average skill levels. Consequently status differentiation on the basis of lithic skill would operate in a feedback that provided opportunity and identity to the most skilled knappers in a group, a process that would have exacerbated perceived skill and labor distinctions between people, potentially enhancing competition between skilled individuals.

Since a mastery of knapping requires substantial investment, as well as strength and coordination, the existence of masterfully-made archaeological specimens indicates social/institutional mechanisms to support that investment. Rewards for recognized mastery would presumably need to be expressed in terms of support offered to the knapper, who has invested time in practice and material supply that could otherwise have been invested directly in food acquisition. One simple and direct possibility is that apprentices would offer “payment” to acquire access to training, a mechanism described as “kissing up” by Henrich and Gil-White (2001, p. 177). If material transfers, particularly in food, occurred from lithic apprentice to master this might have acted to place lithic expertise above hunting competency in the sense that only competent or excellent hunters might sometimes have access to training to become masterful knappers. Rewards for specialist expertise might also be broader. For instance, it might also be predicted that higher status specialists in lithic knapping would have their opinions valued beyond the domain of their craft expertise. As technology became more technically demanding the value of showing mastery in knapping would be increasingly informative about other traits such as self-control, narrative problem solving, and persistence, and these traits might operate as a further source for deference.

These mechanisms of public performance are likely to intensify the degree of specialization, the investment required to obtain mastery, the signals sent by knapping skill, and the status differentiation that is recognized. For instance, in a context where knappers strive for excellence, and compete for recognition of their performance, the signal of knapping expertise would have been more overt, and more effective, if stoneworking was done as publicly as possible, and the artifacts subsequently lent or exchanged so that their production values both as tools and as esteemed objects could be appreciated. Additionally an expert knapper could amplify the signal by creating more complex-looking artifacts that are more technically difficult to manufacture and more risky to make without breaking. Forms that were elaborated to this end would most likely be ones that were relatively longer and thinner, more symmetrical, had more of their surface area covered by scars, and that had regular arrangements of scars. It is noteworthy that as a class handaxes possess all of these features compared to the Oldowan cores that had dominated very early assemblages, and that some handaxes are remarkably crafted in these terms. In many contexts where there was competition between knappers we might predict amplification of artifact forms over time as each generation of knappers elaborated the objects it produced, compared to the previous generation, by increasing the difficulty of the production process.

This proposition offers an alternative to views that hand ax manufacture does not evidence high-fidelity social learning. Observing variability in hand axe form, some researchers have concluded that this is evidence for lack of standardization and indicates that apprentice learning was not present in the Acheulian (e.g., McNabb et al. 2004; McNabb 2005; Stout 2011). However, variability would be expected in an industrial tradition spanning more than a million years and more than one continent, and indeed variability would be expected if signals with varied content were being created. My point goes beyond this: production quality, complexity, and competency could be judged on extremely variable assemblages and does not imply some production is not masterful or a product of high-fidelity transmission. This echoes Sterelny's (2012, p. 41) point that social learning may have been important to the transmission of manufacturing techniques, and I would add high skill levels.

Long-term trends in lithic artifact production, most noticeably elaboration of the technically more difficult and information-rich knapping strategies, such as the emergence of Acheulian bifaces and their subsequent gradual refinement, might be explicable partly in terms of positive feedbacks between scaffolded apprenticeship frameworks required to teach complex technologies, the signaling of competencies, and other information that accompanies those technologies, and the value for hominid groups of people with planning/problem-solving skills and knowledge of geological resources. It is likely that within Acheulian technologies, when relatively broad, thin, and symmetrical handaxes were manufactured, at least limited craft specialization would have been in place. Elongate and thin symmetrical bifaces would be those that best signaled knappers' skill, and the emergence of those more technically elaborate and fragile handaxes within Acheulian traditions is what the argument above would anticipate. In later industries, such as those of the African Middle Stone Age, that were manufacturing thin bifaces and microlithic implements, the adoption of diverse technical procedures that needed to be mastered, such as soft-hammer and pressure flaking as well as heat treatment, all represent the incremental increase in technical complexity driven by the feedback loops in the lithic niche. These trends towards increasingly complex production activities, signaling differential skill levels, could have operated irrespective of the nature of tool use or environmental context. Presumably the significant change in this process was the transformations created by the onset of composite tools, when lithic expertise could to some degree have been exchanged for expertise working with organic materials.

Feedback loops in competition between knappers and scaffolded frameworks for social learning are powerful mechanisms that probably contributed to both long-term stability in technological systems and elaboration of artifact form over time. However the lithics niche was certainly even more complex for early hominids because there were other mechanisms operating at the same time. One of these was the reverse engineering or copying of ancient artifacts and technology from ancient specimens found scattered across the landscape.

Lithic Persistence: A Library of Stone

The archaeological sequence displays a diversity of trends: not only stasis or elaboration, but also cyclical reoccurrence of artifact forms. This cyclicity hints at an additional process operating in the lithics niche. A property of lithic artifacts that is distinctive is their resistance to destruction, and so by comparison to other material products of cultural activities they persist in the environment for substantial amounts of time. The persistent presence of lithic artifacts in hominid physical and social worlds created a rich record of cues about what individual knappers had previously accomplished, and about geographical and temporal patterns in human cultural practices. These cues are in fact so rich they are the mainstay of modern scientific readings of hominid cultural evolution. While readings of these cues by earlier hominids must have been vastly different from the ones constructed by archaeologists, it is likely that the technical appreciation of specimen production involved the ability to understand, emulate, and vary the production process. In that case hominid knappers, well before the emergence of *H. sapiens*, would have been capable of employing their facility for narrative construction and their technical familiarity with knapping to read the production history of specimens they encountered in the landscape. One line of evidence for this is that at all time periods hominids scavenged and recycled specimens previously discarded, sometimes evidenced by multiple layers of patina on some artifacts, and the reflaking of these specimens sometimes reflected an appreciation of their form and past production.

One implication of the hominid capacity to read the production history of persistent artifact forms is that it allows for knappers to learn from masters whom they never met, perhaps masters who were long dead. Landscapes filled with lithic artifacts become effectively a library of designs and production procedures, of past experiments and learning experiences, that can be read by hominids with sufficient understanding of knapping. As externalized manifestations of those designs and production systems, such persistent objects provided inspiration and incentive for both innovation and memesis as a hominid knapper reverse engineered and replicated the observed specimen(s) to comprehend and learn the production activity to which it bore witness.

Reading these records of past knapping in a lithic landscape adds a significant temporal dimension to information transfer and learning in small groups, enhancing the fidelity of information flows. For instance, there has been discussion of the risk within small human groups of loss of cultural repertoire that arises from unlucky accidents to members holding unique skills, and of the potential for redundancy in information storage within larger and better-connected groups to buffer that risk and facilitate the accumulation of knowledge capital (e.g., Henrich 2004; Powell et al. 2009). If artifacts discarded within the landscape preserved information about the knapping practices of a missing group member, or indeed of the member of a group never encountered, they represent an external storage that may also buffer the risk of technological loss. The accuracy with which the technology was reverse engineered and reconstructed would determine the extent to which readings of artifacts found in the landscape resulted in restoring an earlier technology and to what extent the result was a novel technology.

This "buffer" may also have played a role in stabilizing early technological systems or even creating technological cycles as earlier technological systems read in the archaeological residues within the landscape inspired imitation at later time periods. Technologies and implement forms were sometimes remarkably recurrent, challenging linear depictions of irreversible cognitive developments. For instance, blunting one margin of a retouched flake to produce what is called a microlith, or backed artifact, is a procedure used periodically in Africa for the last 300,000–400,000 years (Hiscock and O'Connor 2006). Backed specimens from different periods are distinguishable and yet they are also remarkably consistent in many details, a pattern that would be consistent with transmission of a construction form through periodic reverse engineering of persistent artifacts.

The contribution of reverse engineering to technological stability and innovation would not have been uniform at all times and places. Obviously the size of the accumulated library grew over time and, at least in some lands, there would have been a greater range of technological models available for Middle and Upper Paleolithic knappers compared to Lower Paleolithic ones. Greater rates of industrial change in later prehistoric periods are conformable with the proposition that persistent specimens in the landscape were providing greater sources of inspiration at later times. However the visibility of persistent artifacts would not have been geographically even. Abundance of artifacts observable in a landscape would be broadly inversely proportional to the rate of landscape sediment accumulation and proportional to the rate of erosion: the more rapidly artifacts are buried the fewer will be visible on the ground surface, and the higher the rate of sediment erosion the more ancient artifacts will be visible. Thus in stable or consistently eroding landscapes, artifacts more than one million years old may be visible, while in other landscapes there may be little visible after only a few millennia. Given those differences we should predict distinct regional distinctions in the longevity of industrial traditions and the recycling of technological systems and technical practices.

Conclusion

Knapping was neither inevitable nor universally cost-effective for early hominids. Rock is not the only source of sharp edges for tools; indeed in some regions suitable rock is far more costly to acquire than alternatives such as split reeds/bamboo, bone, wood, or shell, while in some areas naturally shattered rocks might serve efficiently as tools. Rock is heavier and more energy-expensive to carry than these other hard materials, adding to transport costs, and it can be dangerous to break, adding to risk costs. While rock is often durable, its use life is not always proportional to its hardness; flesh or plant matter can sometimes make a stone edge dysfunctional almost as quickly as a bone or bamboo one. Consequently, while its widespread availability and hardiness would sometimes have made rock attractive for artifact production, the choice made by hominids to persistently collect, transport, and fracture rocks was not axiomatic. More significantly, decisions to invest labor in extensively shaping rocks, and acquiring the skills to do so, are not explained by the desire for a sharp edge or a functional tool.

The creation of a "lithics niche" by and for hominids involved a complex of social dynamics and different behaviors, the most direct of which focused on lithic procurement and production. Operating within the lithics niche required early hominids to map and understand the geological context of the lithic sources and the mechanical properties of the rocks at each source, as well as to build skill sets that would enable them to maintain core shape through long sequences of flake creation in ways that lowered the risk costs. Making lithic artifacts involved substantial risk, and mastering skills that reduced those risks and improved the outcomes of manufacturing. Such skills could be acquired only with prolonged training, and the development of skills/expertise in knapping required (and selected for) narrative memory that was not associatively acquired. All of these processes revolve around the social learning of lithic technology and operated irrespective of the use(s) to which any artifacts were put.

Knowledge and skill about stoneworking was costly and risky to acquire, but costs/risks were lowered through apprenticeship frameworks for social learning, and apprenticeship learning enhanced fidelity of transmission of elaborate manufacturing sequences. Transmission of lithic skills depended on apprentices distinguishing more skilled knappers, and since various rewards presumably attached to that excellence a context emerged in which there was benefit to be gained by master knappers who developed more ornate and technically difficult artifact production strategies. Knapping and apprentice learning were both processes involving display and public performance of manufacturing practices, a context in which competition between knappers for elaboration/innovation and/or for repetition of forms would have provided feedback loops that might explain evolutionary trajectories of change or stability in lithic technologies that are tracked in the archaeological record. Such feedbacks would also have been facilitated, and complicated, by the ability of knappers to read ancient technologies preserved as lithic artifacts in their landscape. The early hominid lithics niche can in that way be seen as a fundamentally new, socially constructed context in which social learning and information transmission was magnified.

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