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Two Developments in the Mind of Early *Homo*

THOMAS WYNN

*Department of Anthropology, University of Colorado at Colorado Springs,
Colorado Springs, Colorado 80933-7150*

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Analysis of early stone tools from a perspective of developmental cognitive psychology reveals that the transition from *Homo habilis* to *Homo erectus* was accompanied by important developments in cognitive ability. From the spatial concepts used in stone knapping, and the nature of the shared intentionality required for the manufacture of bifaces, two specific cognitive abilities stand out. The first, termed relative decentration, was the ability to divorce action more completely from the direct perception of ego, thereby allowing *Homo erectus* to construct a more complex external world. The second was the ability to coordinate a greater number and variety of concepts at the same time. Both of these abilities indicate that *Homo erectus* could have used much more complex organizational schemes in its day to day behavior than those used by *Homo habilis*. © 1993 Academic Press, Inc.

INTRODUCTION

Understanding *Homo erectus* is undoubtedly one of the keys to understanding human evolution. Variability in *Homo erectus* fossils has become the raw material for debates concerning evolutionary stasis and gradualism (Rightmire 1981; Wolpoff 1986), the nature of diversity and speciation (Delson and Dean 1992), and the nature of the evolution of early *Homo sapiens*. Paleoanthropologists do not doubt that *Homo erectus* generally, or a population of *Homo erectus,* was an evolutionary antecedent of modern humans; the issues of contention concern the mode and pattern of this evolution. Of equal significance is the question of behavioral evolution. *Homo erectus* was the first hominid to live well outside of the tropics and the first hominid likely to have used fire, to cite just two milestones of hominid behavioral evolution. These behaviors are unknown for living apes and earlier hominids. On the other hand, *Homo erectus* presents us with no convincing evidence for such modern behaviors as intentional burial or personal ornamentation. *Homo erectus* appears to have been neither ape nor human in a behavioral sense and it is this intermediate status that makes its understanding so important.

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The evolution of cognitive abilities may have been one of the developments that set *Homo erectus* behavior apart from that of its predecessors; *Homo erectus* may simply have been more intelligent. The fossil evidence supports such a hypothesis, if we assume that there is some correlation between brains and cognition. *Homo erectus* had a brain that was larger than those of *Australopithecus* and *Homo habilis*. In addition, the overall shape of *Homo erectus* brains also appears to have been more modern that those of its predecessors (Holloway 1983). Unfortunately, brain size and gross shape tell us relatively little that is specific about cognitive abilities; they merely indicate a difference. For a more detailed assessment of cognition we must turn to the archaeological record. Despite problems of postdepositional disturbance and sample size, archaeological evidence is the only real behavioral evidence we possess; hominid activity was at least partially responsible for the patterns that we see. With appropriate methods and theories we can, in fact, identify some of the cognitive abilities that lay behind these patterns (Gowlett 1984; Wynn 1989).

Developmental cognitive psychology provides the theoretical basis for the following analysis. Studies of the growth of cognition in children have provided psychologists with examples of coherent systems of thinking that are less powerful than those employed by adults. In this sense, children at various points in ontogenetic development can supply hypothetical models of earlier phylogenetic stages. Moreover, these models have proved useful in comparative studies of primate behavior (Parker and Gibson 1990). However, although developmental psychology has the potential to provide complete models for comparison (chimpanzees compare well to 3-year-old children, for example), such an approach almost certainly undervalues differences. A more valid approach is one that focuses not on whole-cloth comparisons but on much more narrowly defined cognitive abilities. Developmental psychology provides a wealth of evidence and interpretations for the development of fairly specific cognitive abilities (spatial thinking, for example), and, more important, some of these more narrowly defined abilities can be recognized in the archaeological record. It is this second, more modest approach, that is taken here.

My focus is on the transition between *Homo habilis* and *Homo erectus*. By *Homo habilis* I mean the makers of Oldowan tools. This is perhaps a dangerous assumption. The taxonomic status of the large-brained, small-bodied, hominids that lived in East Africa between 2 and 1.6 myr ago is far from clear; indeed, current thinking favors two species, *Homo habilis* and *Homo rudolfensis*, with only the former found at Olduvai (Tattersall 1992). Moreover, based on hand anatomy and association with tools, there are good reasons for thinking that the robust australopithecines were tool users (Susman 1992). There is a clear association at Olduvai between stone tools and *Australopithecus boisei,* for example. However, there appears to be a general consensus that *Homo habilis* made the tools; it had the larger relative brain size (a dangerously circular argument) and the robust australopithecines possessed a more specialized vegetarian dentition and therefore were unlikely to have been the scavenger responsible for the bone refuse at archaeological sites (a better argument, though there is now evidence that *Australopithecus robustus,* at least, was not a pure vegetarian (Sillen 1992)). For purposes of this comparison, I assume that *Homo habilis* was responsible for the Oldowan tools. By *Homo erectus* I mean early *Homo erectus,* as represented by early Pleistocene fossils from East Africa and the contemporaneous archaeological remains. This restriction effectively eliminates from consideration many well-known and rich archaeological localities from Europe, Asia, and Middle Pleistocene Africa. Such a narrowing of focus is unavoidable; the status of late *Homo erectus* and its relationship to early *Homo sapiens* is unclear, especially in Europe. Such famous sites as Torralba and Hoxne may be the products of early *Homo sapiens,* rather than *Homo erectus,* and the behavior inferable from them irrelevant to understanding the initial behavior of the latter.

The transition from *Homo habilis* to *Homo erectus* was accompanied by a change in the archaeological record. The Oldowan was a flaked stone industry in which emphasis appears to have been on size and the shape of edges; there is little evidence that the makers were interested in the overall shapes of the artifacts (Toth 1985). Oldowan tools, especially at certain localities at Olduvai itself, have been found associated with the fragmented remains of small, medium, and even large mammals. Recent analyses of these remains have provided a picture of scavenging as part of the adaptation of *Homo habilis* (Potts 1988). The appearance of *Homo erectus* on the East African scene does appear to have coincided with the appearance of bifaces in the archaeological record. This coincidence should not be construed as an equation; many assemblages from the appropriate time frame, the Karari assemblages from East Turkana, for example (Harris and Isaac 1976), lack bifaces and yet are almost certainly the product of *Homo erectus.*[1,*] Unfortunately, early biface sites, regardless of which cultural/industrial group we assign them to, rarely provide the kinds of faunal and distributional evidence that have been so important in the recent interpretations of Oldowan behavior (recently discovered sites in Ethiopia may help remedy this (WoldeGabriel et al. 1992)). Indeed, early Acheulean sites are almost invariably found in deposits where the artifacts have been moved significant distances (Leakey 1971). Archaeologists are therefore left with the artifacts, but little in the way of

[*] See Notes section at end of paper for all footnotes.

context. Of these artifacts, it is the bifaces that represent the clearest contrast with what went before.

The development of the biface has generally been accorded a significant place in the history of hominid tools. Clark (1971), for example, used it as the hallmark of his Mode II technology. The biface has been subject to extensive interpretation, including reconstruction of manufacturing techniques (Jones 1981), experimental use in butchery (Toth and Schick 1986) and throwing (O'Brien 1981), microwear analysis (Keeley 1980), and cognitive analysis (Gowlett 1984; Wynn 1979; Donald 1991). This attention to one artifact type can be attributed to the poverty of the contextual information, but it also results, I believe, from our perception that the development of the biface marked a significant contrast with what went before. I suggest here that this perception derives from our recognition of something human-like in this product of *Homo erectus* minds. More to the point, these human-like features resulted from some identifiable cognitive abilities possessed by *Homo erectus.*

My interpretation of bifaces will be built on an assumption of intentionality; I believe that *Homo erectus* intended that bifaces look the way they do. This is an arguable point. Davidson and Noble (1993), for example, argue that any overall shape of bifaces, even late examples, was an unintended consequence of a process of removing flakes from a core. Their argument is worth consideration, especially for the comparatively crude examples dating from the early Pleistocene. One can imagine a flake production procedure that results in an ovoid, pointed, bifacial mass. However, there are some examples of early bifaces that *cannot* be accounted for in this way, and which indicate that the knappers were concerned with the final shape of the mass. Figure 1 is of a cleaver from upper Bed II at Olduvai. One edge appears to have been knapped to mirror the other, an unlikely accident. Figure 2 is of a handaxe from upper Bed II. Its ficron-like shape also appears unlikely to have been an accident. Artifacts such as these indicate that the shape of the final product *was* a concern of the knapper and that we can use this intention as a tiny window into the mind of *Homo erectus.*

SPATIAL ABILITIES

Artifact shapes inform us about spatial concepts. Any action in space, including stone knapping, requires some understanding of space. When the knapper flakes stone, he or she must direct this action according to a plan that includes arranging the action in some way. This can be as simple as bashing a stone repeatedly or as complex as planning the successive reductions of a prepared core. Knapping produces patterns of successive flake removals and, in some cases at least, intended final shapes. Both

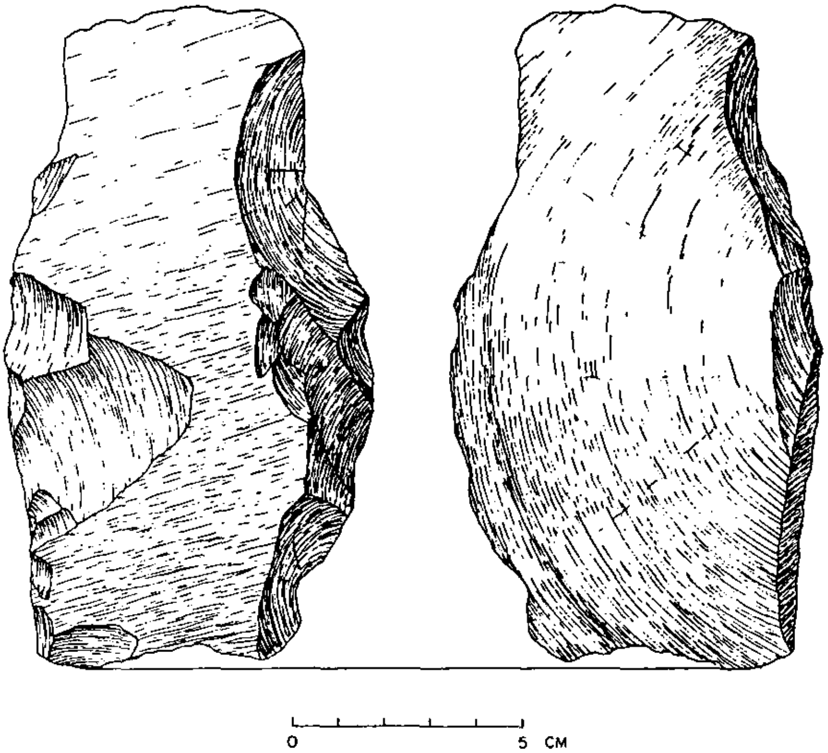

FIG. 1. One side of this cleaver from Upper Bed II at Olduvai mirrors the others.

can be examined to answer questions concerning necessary spatial understandings. Such argument from patterns to antecedent behavior is, of course, basic to all archaeology. In this case the antecedent behavior of interest is a characteristic of the knapper's mind.

This approach entails two methodological caveats. First, one can only reach conclusions concerning the minimum spatial concepts necessary to produce a particular pattern; the hominid may have possessed more sophisticated concepts but simply did not use them to knap stone. Second, one must be careful about attributing intention (see earlier discussion). For example, early Pleistocene assemblages often include very round spheroids, and one might be tempted to use them as evidence for a concept of diameter or radius (as this author once did), but here the pattern—roundness—was almost certainly an unintended result of extensive use as a basher (Toth 1985). Despite these caveats, careful analysis of spatial patterns has been able to reveal some interesting things about hominid minds, including the minds of early *Homo*.

Prior to *Homo erectus,* hominid stone tools were about what one would

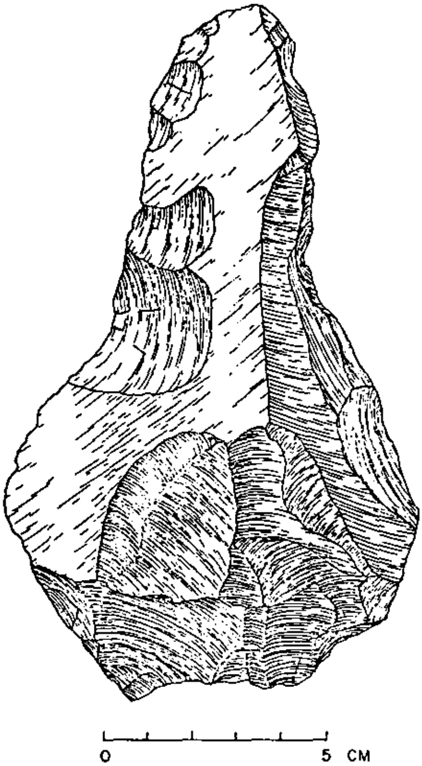

FIG. 2. This handaxe from Upper Bed II at Olduvai has bilateral symmetry.

predict for stone knappers employing the spatial understandings typical of apes (Wynn and McGrew 1989). Knapping patterns on the tools indicate that the hominids were concerned with edge configurations, but not overall shape (Toth 1985). Any overall shape was an unintended consequence of this concern with edges. The evidence also indicates that flakes were more often the target than were the cores from which they were removed. Nevertheless, the patterns on cores still inform us about the spatial concepts used to remove the flakes, and these were invariably simple. The knappers employed only five basic spatial concepts: proximity or "nearbyness," the pair, the boundary, sequential order, and a distinction between angular and curved.[2]

Proximity is simply the idea of directing action toward one general area so that elements are near one another. Anything beyond *random* bashing requires this, but there are some Oldowan artifacts (often termed polyhedrons) that required no more. Such a simple spatial idea will produce flakes. The pair is more complex in that it requires not just vicinity but adjacency, which is a more directed spatial relationship. By using a previous flake scar as a platform for a subsequent blow, the knapper increases the chances for success and, perhaps, increases the average size of the resulting flake. This action, in isolation, requires a concept of pair. The pair naturally leads to consideration of the boundary, which is any feature dividing a spatial field into two distinct realms. A bifacial edge constitutes such a boundary. In order to maintain a bifacial edge the knapper must use it as a reference dividing the "faces" of the artifact and must direct his action of knapping away from the boundary onto the separate faces. The caveats of necessary competence and intention must be applied here. It is possible that repeated applications of a concept of pair could yield a bifacial edge, so a conservative interpretation would cite the pair as minimum competence. However, some Oldowan bifacial edges appear to be too extensively modified for the minimum interpretation to be credible; it just seems likely that some idea of the edge as a boundary was in use (Fig. 3, for example).

A few Oldowan artifacts required a concept of sequential order, the positioning of successive action not just in pairs but in sequences, one after another. These artifacts, usually termed scrapers, have had a series of contiguous trimming flakes removed from the edge of a large flake or, in a few cases, a core. They are not common in the Oldowan (indeed, appear to be absent from the East Turkana Oldowan sites) but are a common feature in later industries (the Karari steep scrapers required this concept, for example). The distinction between angular edges and evenly curved edges also appears to have been one that occasionally concerned Oldowan knappers. There are a few "awls" from Olduvai sites, which suggest that the knappers could produce projections. To produce a projection, one must conceive of it and also direct knapping to either side of the proposed point (Fig. 4). Such an interrupted sequence is more difficult than any of the above notions, and is in fact a rudimentary kind of two-dimensional shape.

The first four of these spatial concepts are topological in nature; they

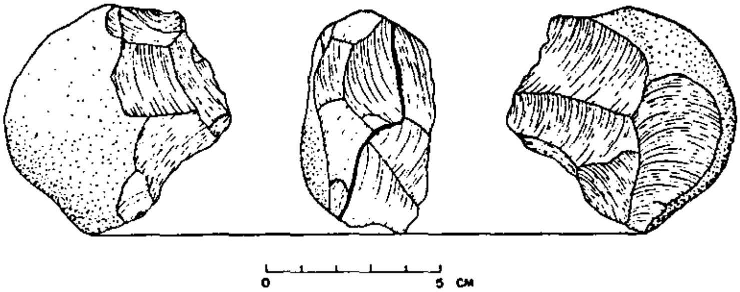

FIG. 3. The edge on this chopper from Bed I at Olduvai acted as boundary in the spatial field of the artifact.

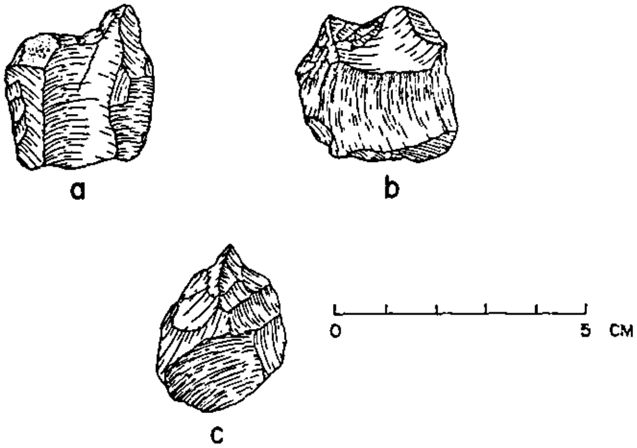

FIG. 4. The trimmed projections on these "awls" required a concept of angular shape.

are qualities of spatial arrangement that remain true regardless of changes in such euclidean qualities as the size of edges and angles and projective qualities such as straightness. Many topological concepts are intuitively simpler than those of other geometries and, indeed, appear earlier in concepts of space used by children (Piaget and Inhelder 1967). They are also the kinds of spatial concepts used by apes. Chimpanzees use concepts such as proximity everyday in the wild. Nut-cracking is a good example; Tai Forest chimpanzees position nuts on anvils (usually tree roots) and then strike the nuts with a hammer using a two handed delivery (Boesch and Boesch 1990). The directed juxtaposition true of pairs is also required for ant fishing, termite dipping (the probe must be positioned in relation to the tunnel), and extracting honey. In Morris's (1962) work with chimpanzee "art," his subjects employed concepts of boundary (inside–outside) and order (sequences of lines in fan shapes).

In sum, the spatial repertoire required for Oldowan tools was no different from that recognized for modern apes. The same cannot be said for the tools of early *Homo erectus*. Early biface assemblages include tools that required all of the concepts of the Oldowan spatial repertoire plus two more: a concept of symmetry and a concept of spatial amount. Both are rudimentary, by which I mean simpler that they appear in true euclidean guise, but they are sufficient to place the *Homo erectus* spatial repertoire beyond that currently known for apes or attributable to *Homo habilis*.

Western common-sense notions of symmetry can be broken down into two simpler concepts—congruency and transposition (mirroring or rotation). When a congruent shape is rotated or mirrored we say that the resulting shape is symmetrical. This is symmetry in its narrow sense, and we cannot argue for it in the repertoire of *Homo erectus* because we cannot argue for true congruency of shape. However, we can argue for mirroring, which requires reversal of a spatial pattern. Qualities of the shape can be preserved and reversed without also preserving precise angles and lengths; in this sense an S and a Z are symmetrical figures, but not congruent. When a spatial pattern also conserves measured distances between points, we say there is a congruency. However, reversal itself does not require congruency and can operate on simpler shapes (reversal is in fact a topological notion). This is precisely what we see in the bilateral symmetry of early bifaces (Figs. 1 and 2, for example). One edge often does mirror another in reversing some qualities of edge shape (a recurve for example) but the mirroring is not quantitatively precise. The kinds of two-dimensional shapes appear to be on a par with the angular–curved distinction seen earlier in the Oldowan; simple changes in two-dimensional outline such as reversal of direction or a projection. These are simple two-dimensional patterns, which in themselves do not require new spatial understandings. What is new is the concept of reversal of a spatial array.

Some of *Homo erectus'* tools indicate use of a rudimentary spatial amount, the diameter. The evidence for this spatial concept consists of bifacially trimmed artifacts known a discoids (Figs. 5 and 6). Here much hinges on the matter of intention; did the knapper intend for the artifact to have this final shape or was this the serendipitous consequence of bifacial trimming of a mass that was naturally round or perhaps a consequence of continuous trimming for the production of flakes? Many, perhaps most, of the artifacts typed as discoids can be explained in terms of the latter two processes, and parsimony (minimum competence) requires that we grant these explanations precedence. The discoids in Figs. 5a and 5b, both from Oldowan sites in Bed I at Olduvai, can be understood in this way. However, a few artifacts required something more. The extensive modification of the discoid in Fig. 6 and the position of the trimming on the discoid in Fig. 5c, both artifacts from upper Bed II sites, suggest that the knapper was also interested in producing a round shape. The simplest way to conceive and execute such a shape is to use one visible diameter as a template to which all diameters are compared. Such a diameter is a *quantity* of space, albeit a very local one.

The use of symmetry and spatial quantity contribute to a long-appreciated characteristic of bifaces—their overall two-dimensional shape. As Toth (1985) and Isaac (1984) have persuasively argued, earlier Oldowan tools have no overall shape; the emphasis was entirely on edge configuration and size. *Homo erectus* appears to have been interested in more than edges, and this interest supplies us with some clues to *Homo erectus'* spatial cognition.

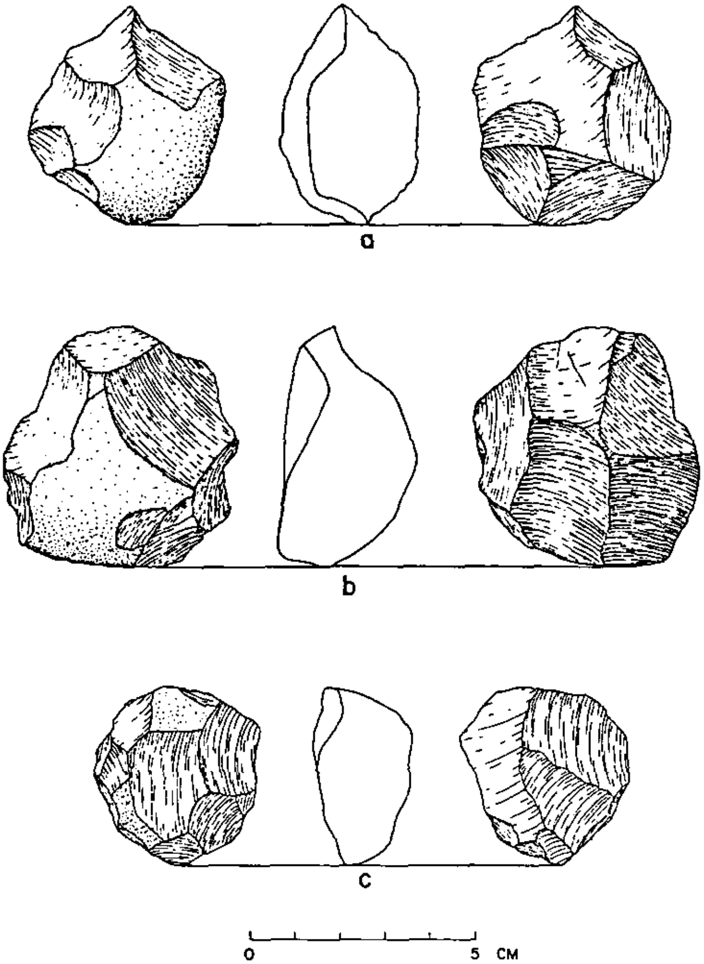

FIG. 5. Discoids. Artifacts a and b are from Bed I at Olduvai; artifact c is from Upper Bed II.

Neither symmetry nor spatial quantity appear in the spatial repertoires of modern apes. Although some claims have been made for chimpanzee use of symmetry or balance in art (Morris 1962), more recent controlled studies indicate only concepts of boundary and filling-in of vacant space (Boysen et al. 1987), neither of which is symmetry or even true compositional balance. Chimpanzees do attend to certain spatial qualities when drawing or painting, but these are all the relatively simple topological qualities one would predict from their natural organization of space in the wild. As we have seen this spatial repertoire also appears to have been the one used by *Homo habilis*. By using concepts of symmetry (reversal of

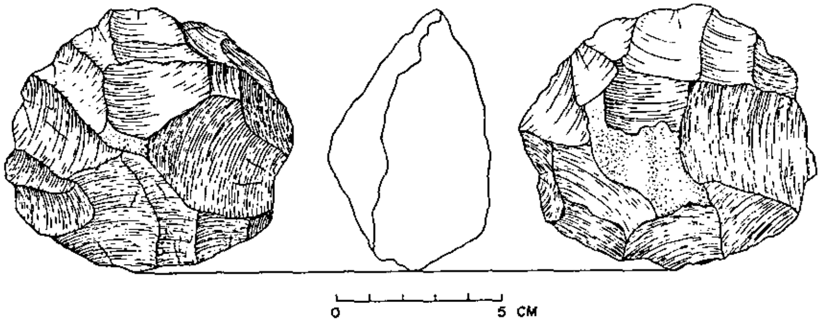

FIG. 6. This discoid from Upper Bed II at Olduvai required a concept of constant diameter.

spatial array) and spatial quantity (diameter), *Homo erectus* demonstrated abilities beyond the range of ape spatial competence. This conclusion is in itself an important one. It is also possible to examine more precisely what these concepts suggest about the minds that used them.

One possibility is that *Homo erectus* possessed a perceptual repertoire that attended preferentially to certain regular shapes. This is a narrowly Gestaltist approach in which symmetry and round are "good" Gestalts whose regular features are somehow mapped into the perceptual hardware of the brain. Hominids would tend to produce such shapes, other things being equal, because the shapes themselves were seen as pleasing. Although such an interpretation might be relatively simple in a Darwinian sense (selection for certain shapes) it also poses the more troubling question of the possible selective advantage of such a perceptual system. What possible advantage would perception of symmetry give? More troubling from a methodological point of view is the question of whose Gestalts—ours or *Homo erectus'*? Perhaps modern archaeologists see bifaces as symmetrical because *we* preferentially see symmetry; once again the caveat of intentionality rears its head. The position of trimming on some bifaces suggests that the symmetry is not just ours, but *Homo erectus'* too.

Use of symmetry and spatial quantity also indicate that the mind of *Homo erectus* was capable of at least slightly greater complexity of thought. Although the Gestalt approach emphasizes the global characteristics of these spatial concepts, it is also possible to consider them more analytically. Two features stand out: the number of elements that must be coordinated, and the nature of the necessary transpositions. To conceive a diameter, the knapper needed to have attended to a particular spatial quality (the interval between two opposite points on the circumference) *in addition* to the spatial qualities of proximity, order, and boundary discussed above. More telling, the chosen interval needed to be compared to the other edge-to-edge intervals. Although it is possible that the knapper used some sort of physical device, it is more likely that the comparison was made in the knapper's mind by transposing the model interval to different points on the spatial field of the artifact.

Similar thinking is required for bilateral symmetry. In addition to proximity, boundary, and order, the knapper needed to consider the two-dimensional configuration of one of the edges (similar perhaps to the angular–smooth distinction). This required consideration of more elements, though the number is still not much higher than those used by earlier hominids. It is the nature of the transposition that is informative. Not only must the knapper have attended to the plan shape of an edge, he must also have *reversed* all of the internal qualities of that shape (direction of a turn, for example) in order to produce the symmetry. This transpositional ability suggests that the mind of *Homo erectus* was capable of "stepping back" from the immediate perceptual and motor constraints of knapping and as a consequence was able to coordinate the motor elements into more complex patterns. Such thinking is comparatively more abstract than that arguable for *Homo habilis*.

SHARED STANDARDS

At the core of the above interpretation of spatial concepts is the question of intentionality. Although this remains an arguable question, I believe that the evidence for intentionally imposed patterns is strong enough to warrant the conclusions I have drawn from them. Further analysis of cognitive ability rests on a second arguable assumption, that of *shared* intentionality. It is common, for example, for textbooks to cite bifaces as evidence of standardization, which carries the implication that the makers attended to some shared standard of shape. On the surface, this may appear to be a large analytical jump on the part of archaeologists; after all, should not shared intention be difficult to document? Are there not more parsimonious interpretations of the redundancy we see in the shapes of bifaces? As it turns out, shared intention *is* the most parsimonious interpretation. If we accept that the shape of a biface is not entirely a serendipitous consequence of producing flakes (see above), then we must explain why the same basic shape was repeated again and again. It seems wildly unlikely that every *Homo erectus* stone knapper conceived of this shape on his own; he must have learned it from someone. Such learning of a shape is shared intention. This conclusion holds even if the shape was somehow "determined" by a particular function. If O'Brien's (1981) and Calvin's (1993) arguments for bifacial projectiles were convincing (which I find them not to be), the shape must still have existed as a shared intention.

The nature of shared intentionality can be used to investigate cognition.

In the following discussion I use two different perspectives. The first focuses on how such ideas might be conceived and operationalized in the manufacture of an artifact. The second looks at how such a shared idea could have been learned and what this implies about cognition, especially representation.

Recent work in cognitive anthropology helps us understand how shared intentions come to be incorporated into the manufacture and use of a tool. The following analysis is based heavily on the Kellers' studies of the cognition of tool behavior (Dougherty and Keller 1982; Keller and Keller 1991). During an episode of tool use, an actor brings together many considerations in order to complete the task at hand. These include individual motor abilities, knowledge of materials, considerations of economy of effort, the use to which a tool will be put (in cases of tool making), and many others. These "constellations of knowledge" can vary considerably in terms of complexity; some tasks require more sequences of action, more complex motor control, or a greater variety of material, and so on. Constellations are largely idiosyncratic. An artisan assembles his or her own constellations based largely on personal experience. Tool behavior is largely nonlinguistic behavior, which is why apprenticeship is so essential (Keller and Keller 1991; Wynn 1993). Nevertheless, an artisan often does consider what others do, and the social context of tool behavior is an important consideration in the construction of constellations; at least we know it is an important consideration for modern artisans. However, what about *Homo erectus*? When we reconstruct the constellation of knowledge necessary to produce and use a biface, we must incorporate some consideration of what other *Homo erectus* were doing. The idea of appropriate shape was shared with others and acquired from others. Even though we do not know the specific significance of this shape, we must include it as a component of the artisan's cognitive plan. Such a constellation is more complex than any known for apes or required for Oldowan tools because it required an increase in the number of considerations brought together for any task and, more significantly, an increase in the variety of relevant knowledge. Basic stone knapping and use requires a constellation of knowledge tailored to the task at hand—knowledge of edges, flaking procedures, raw material, motor patterns of use, and so on. If the actor must add considerations of what is socially appropriate, he or she must include a domain of knowledge not directly relevant to a particular task. The domain of social knowledge intrudes into that of tool use. Cognitively, such coordination of disparate behavioral domains is more difficult than coordination within a single domain (see discussion of hierarchical reasoning below).

Implicit in the above discussion of constellations of knowledge was the question of learning. The way in which an individual learns can tell us a good deal about cognitive processes. Unfortunately, there has been little serious discussion in the archaeological literature about how early hominids learned stone knapping. Guilmet (1977) made a start, but little has been done since. One occasionally sees reference to imitation or even language, but the only serious recent discussion argues, somewhat in reverse, that *Homo erectus* could not have learned shared ideal shapes because it did not possess a true symbolic ability (Davidson and Noble 1993). Recent primatological literature has tackled the question of observational learning directly, and the results have interesting implications for the kinds of learning that may have been used by early *Homo.*

Observational learning is fairly common in the animal world, but it comes in several varieties with varying degrees of cognitive complexity. Whiten and Ham (1992) have recently reviewed this variety of "mimetic" processes, from mimicry (common in insects) to various forms of social learning. The latter encompasses all of the ways that an act can be learned by "seeing it done," including stimulus enhancement, observational conditioning, goal emulation, and imitation. Much that has been called imitation is better thought of as goal emulation: actor A sees actor B perform a task with a desirable result and A invents a means for achieving that result himself. A has observed B, but has not modeled the actual *form* of the behavior, just attempted to achieve the same goal. It is very likely that much modern human tool behavior is learned in this manner; an artisan often develops his or her own peculiar solution to a technological goal (Keller and Keller 1991; Wynn 1991). In true imitation, A learns not just the goal but also the *form* of the action, that is, the actual motor patterns and sequences used by the model.

On the surface it may appear that imitation is cognitively more complex than goal emulation. After all, a complex of actions must be modeled, not just a single goal. However, recognition of the other's goal is in fact a more difficult cognitive undertaking, because it requires some understanding of another's perspective. "Emulation may in some cases require sufficient intelligence to recognize a goal achieved by others (e.g., 'getting the food raked in') *as* a goal—and a goal potentially achievable by one's own novel problem-solving attempts" (Whiten and Ham 1992:252). One component of visual emulation (as opposed to aural, for example) is the ability to reconstruct another individual's visual perspective, that is, create a "mental representation." This ability is well documented in primates who use social deception (attending to the gaze of another male, for example). In the domain of stone knapping, it is reasonable to conclude that some kind of emulation was involved, in addition to imitation; the novice observed a final product and learned to duplicate it, probably by reinvention. Such emulation would have required some reconstruction of the other's visual perspective. Oldowan tools can all be explained with reference to this kind of learning. One hominid, presumably a *Homo habilis,* observed another (perhaps its mother, if we use chimpanzees as a model) produce a useful stone flake by knapping. This individual then "reinvented" the process through experimentation, practice, and some general modeling of motor behavior. Learning to make a biface was probably a little more difficult.

Learning a shared standard almost certainly requires "metarepresentation," in which individual A must not only reconstruct B's point of view, he must also reconstruct B's *intention.* In the case of a socially shared form like a biface, A must know that B knows the same form (not just sees it), and, more significantly, A must have a "theory" that some forms are appropriate but others are not, and that B has the same theory. Whiten and Byrne (1991) argue that chimpanzees use a form of metarepresentation (which they also term second-order representation). For example, when learning to fish for termites, a juvenile chimpanzee must employ a form of goal emulation in which he or she represents the intention of an adult (to obtain termites) and reinvent the technique; the procedure required is extremely difficult to model by observation, as Teleki learned to his disappointment (1974). This reinvention also requires that the juvenile represent the adult's visual perspective (what the adult sees) and then translate that perspective into what the juvenile sees. As I have already argued, this is almost certainly the kind of learning used for early stone tools. A biface, however, requires something more. Not only must an intention be represented and a visual perspective be translated, the novice must also construct some understanding of the other's idea of what is an appropriate shape. This is not simply a matter of visual representation, or even representation of the other's motivation, it requires an ability to represent what the other *understands.* This is a more difficult task, and is so far unknown for chimpanzees (Whiten and Byrne 1991). We also cannot argue that *Homo habilis* possessed this ability, because Oldowan tools show no attention to "appropriate shape."

DECENTRATION AND HIERARCHICAL COMPLEXITY

The preceding discussion of spatial concepts, constellations of knowledge, and goal emulation indicate that the tool behavior of *Homo erectus* was more complex than that of chimpanzees or *Homo habilis.* This conclusion should not be surprising. However, describing tool behavior in these terms allows a more explicit interpretation of cognitive evolution than the more common-sense impressions that heretofore have prevailed in archaeology. Two cognitive concepts are especially useful. The first is the Piagetian concept of decentration, which focuses on an individual's ability to divorce understanding from the perspective of ego. The second is hierarchical organization, an ability discussed at length by Kathleen Gibson, which emphasizes the appearance of greater diversity of thought and the emergence of higher levels of cognitive control to organize this diversity.

Decentration is a theme that runs throughout Piaget's developmental scheme. When an infant's motor behavior begins to incorporate objects in addition to its own body, we can describe this as relative decentration; the action is no longer centered exclusively on ego's physical being. Later, when a young child becomes aware of perspectives and opinions other than his own, this, too, can be characterized as a form of decentration. Here it is not just action that is decentered, it is the internal representation of action that over time comes to be more and more divorced from a focus on ego. Older children (and young adults) continue this progressive decentration by coming to construct multiple and even hypothetical perspectives that have no tangible reality (four-dimensional spaces, for example). Unlike Piaget's formal stages of development, which have tended to become fossilized into absolute complexes of abilities (that Piaget almost certainly did not intend), decentration is a recurrent theme in ontogeny. One needs not be a recapitulationist to apply such a concept in evolutionary studies. Decentration is a relative measure of how completely an individual can conceive and organize the external world and as such it is a useful way (thought not the only way) to view cognitive evolution.

Decentration is applicable in comparative studies, for example. It is now well-known that many species of higher primate employ deception in social behavior. For example, chimpanzee females may suppress orgasmic cries when copulating with subdominant males; they clearly have some awareness of the perspective of the nearby dominant male (Byrne and Whiten 1988). Chimpanzees recognize themselves in mirrors, whereas monkeys do not. Such a complete concept of self requires a relatively complete concept of others' and ego's location within the social and physical world. Earlier I discussed Whiten's argument for the "representation" of another's intention in goal emulation. This requires not just decentering of visual perspectives but decentering of intention and motivation. From these few examples, I think it is clear that relative decentration is a useful measure of at least one aspect of cognitive evolution and one that is especially useful for primates. How, then, can we extend it to hominids?

Once again, it is impossible to distinguish the Oldowan (and *Homo habilis*) from what we know for chimpanzees. The *ad hoc,* edge-oriented knapping required for these early flaked tools required no more decentration of thought than that of modern chimpanzee tool behavior. Here the archaeological evidence may well underrepresent the hominids' true ability. We cannot, however, assume abilities we cannot see simply because they fit our preconceptions. Early *Homo erectus,* on the other hand, was almost certainly capable of more decentered thinking than his predecessors. Evidence for this decentration comes from both spatial concepts and the standardized shapes of bifaces. The concepts of spatial quantity and reversal of a spatial array both require a decentering compared to simpler topological notions. The diameter must be "extracted" from its physical manifestation as a single edge-to-edge distance and applied elsewhere. From the perspective of ego, spatial features of the perceived artifact must be disassociated from one another and some applied separately. Such increase in complexity requires that ego not only decenter action from himself but also analyze (take apart) this separately existing thing, this artifact. The same holds true for the reversal of spatial field required for bilateral symmetry; the knapper must not only conceive of an independently existing shape, he must manipulate it. The decentration here is not so much the construction of a visual perspective (though this is involved) but the manipulation of internal relations in an object (the artifact) that exists separately from the knapper.

The existence of a shared standard requires greater decentration of thought than anything known for apes. Whiten and Byrne (1991) have argued that not only can chimpanzees reconstruct another's visual perspective (representation) but can also reconstruct another's *intention* (metarepresentation), and use this intention as a goal to be emulated. Such social learning could easily encompass Oldowan tools, but could it also account for the standardization of shape we see in early bifaces? On the surface, this seems plausible. A *Homo erectus* knapper could have observed another make a biface, by representation and metarepresentation formed his own image of the goal, and then used his own procedures to produce a similar result. However, I do not believe this would be sufficient to account for standardization. How would our knapper come to understand the range of acceptable forms? It is possible that he could simply copy only what he has seen. We would then expect accidental differences from case to case to produce a wide range of products over one individual's lifetime, not to mention generations and millennia. This is not standardization, which requires some idea that there is an appropriate or correct goal. If our knapper comes to understand what is appropriate through observational learning, he must not only reconstruct another's intention, he must construct the other's "theory" of appropriateness. This theory is more than an *ad hoc* intention and incorporates community standards. It is therefore a much more complex alternative perspective than that necessary for Oldowan (or ape) tools.

A related but separate feature of cognition is hierarchical organizing ability, the ability to organize greater numbers and varieties of elements under a higher level of control. I base the following assessment on the work of Kathleen Gibson (1990), though I emphasize rather different attributes.

Use of a concept of overall two-dimensional shape is more complex hierarchically than the edge-oriented modifications necessary for Oldowan tools. Both the concept of diameter and the concept of symmetry incorporate the topological notions of proximity and sequence and boundary. To produce a regular diameter, the knapper must coordinate the simple arrangements of proximity and pair as elements in the overriding idea of roundness. No longer are they the goal that achieves the end; they become merely subgoals in the larger plan. Similarly, a simple pattern produced by sequences and interrupted sequences must be reversed in a symmetry, thereby becoming elements in the larger scheme. It is clear, I think, that the spatial patterns produced by *Homo erectus* were more hierarchically complex than those produced on Oldowan tools.

The hierarchies necessary to produce a shared standard are even more complex. Not only must the knapper organize the motor behavior of knapping and coordinate this (by means of spatial concepts) into a useable product, he or she must also incorporate the more "remote" consideration of a standard of shape. This standard is not entailed by the immediate task but exists independent of and prior to that task. *Ad hoc* technologies, which *are* tied to immediate tasks, result in the wide range of sizes and shapes we see in industries like the Oldowan, not in redundant, standardized forms. When *Homo erectus* approached certain tasks, his or her plan must have included reference to a standard stored in memory (and learned by observation). Such an approach to tool use has certain advantages. In *ad hoc* tool behavior the actor must "invent" a new tool for each task, that is, construct a plan of action incorporating all of the necessary elements. When *Homo erectus* approached a task, his plan included a *type* of tool, which is a *general* solution applicable in many different circumstances. To use a modern example, a leaking drain pipe calls up the idea of "monkey wrench," not "I need some kind of lever with a strong gripping end that I can hold in one hand, or two if necessary." Superficially, such a solution appears simpler than the *ad hoc* solution, but in fact it is more complex because it relies on an implicit hierarchy. The idea of the "appropriate tool" subsumes all of the elements in its manufacture. More significantly, some of these elements appear, in the case of bifaces, to be considerations of community standards. The tool knapper/user must coordinate not only mechanical considerations, but "traditional" consideration as well. This requires incorporation of a cognitive domain—social knowledge—that is usually quite separate from the domain of tool use. Coordination of such disparate cognitive domains requires some higher level of cognitive control, one that is more comprehensive than the domain-specific hierarchies of spatial thinking.

Increasing complexity of hierarchical organization, like relative decentration, is a developmental trend in both phylogeny and ontogeny. "In particular, as children mature, their information-processing capacities expand, and they begin to *hold greater numbers of concepts in mind simultaneously*. As a result, they construct mental schemes containing a greater amounts of information and greater numbers of hierarchical levels" (Gibson 1990:144, emphasis mine). It is clear, I think, that a similar trend applies to phylogeny. Chimpanzees, as far as we know, use only a few relatively simple spatial concepts in a relatively uncoordinated fashion. No more can be argued for Oldowan hominids. *Homo erectus,* on the other hand, employed a spatial repertoire that was not just more decentered, it was more hierarchically complex. More telling, *Homo erectus* incorporated socially learned standards in the domain of tool use. He was clearly "holding greater numbers of concepts in mind simultaneously" than modern chimpanzees can do, or than *Homo habilis* did.

DISCUSSION

It is important to emphasize that the above conclusions concerning *Homo erectus'* cognitive abilities constitute a *relative* assessment. The archaeological evidence indicates that *Homo erectus* had a more complex hierarchical organizing ability and could decenter thought more completely than *Homo habilis*. It is also clear, on the other hand, that *Homo erectus'* abilities were not yet modern, or even as advanced as those we can document for 300,000-year-old hominids (presumably a form of early *Homo sapiens*). Modern cognition includes the ability to construct very complex external perspectives and hypothetical external perspectives (general relativity is a well-known example), whereas early *Homo sapiens* could construct internally coherent and logical external frames of reference equivalent to cartesian space (Wynn 1989). When we add cultural "boosting" devices such as writing to modern cognition, the difference is much greater still (the possibility that "shared standards" were a simple form a cultural "booster" is an interesting one, which I cannot pursue here). We cannot argue that early *Homo erectus* used such advanced forms of organization. This relative assessment of *Homo erectus* carries no implications in the form of a cognitive rating scale; I am not assigning an IQ, for example, or a position on a established development scheme. Indeed, there are no modern analogues to *Homo erectus* cognition. Nevertheless, because relative decentration and hierarchical organizing are fairly well-defined cognitive abilities (as opposed to "more intelligent," for example), it is possible to consider what they imply for behaviors not usually visible in the archaeological record. I would like to discuss just two of the many implications: complexity of planning in foraging, and complexity of social organization.

Planning is the ability to project and organize future action (see Parker and Milbrath 1993 for a useful discussion of planning). Although the planning of one's own future action can have varying degrees of complexity, the planning of group action can be especially difficult. One simple way is through leadership/dominance; one individual leads and the others follow (or perhaps choose not to follow). This is the kind of group planning we see most often with chimpanzees. Group planning, if it can be said to be such, is an extension of individual planning. Occasionally, chimpanzees present a more complex picture. In hunting colobus monkeys, for example (Goodall 1986), there is often use of shared intention; by vocalizing and recognition of shared gaze, males come to a common goal. There may even be a shared technique of surrounding (learned through goal emulation?), but hunting episodes rapidly devolve into the successive short term plans of the individual participants. Two abilities would be of great use to chimpanzees here. First, if the chimpanzees could conceive of *everyone's* potential action at the same time (hierarchical ability), each could coordinate his own action in a more effective way. Second, if they could "represent" not just another's gaze and intention, but his potential gaze in different circumstances and his potential *understanding* (decentration), then coordinated action could be very effective indeed. Interestingly, these abilities do not require linguistic communication; in fact, the ability to anticipate another's perspective *reduces* the need for communication.

Of course, chimpanzees do not have these planning abilities. However, *Homo erectus* did. We do not know if *Homo erectus* used these abilities in foraging, but if he did it would have been possible to employ a foraging system in which groups split up and recongregated, a system once suggested for earlier hominids (Isaac 1978) but which cannot be documented in the earlier archaeological record. Such a system requires the ability to represent perspectives and understandings of others and use them in a long-range plan. In addition, group foraging for meat, in competition with carnivores, could be much more effective if each participant could coordinate the represented perspectives of the other participants, especially if this reduced or eliminated the need for vocalization. Both of these abilities would have made *Homo erectus* a formidable competitor in a scavenging and/or hunting niche.

Decentration and hierarchical organizing could have affected social organization as well. Chimpanzee social organization consists largely of one to one (dyadic) relationships. There are some more complex interactions, as when males form alliances, though it is hard to know whether or not these are the result of the individuals making selfish decisions that to us look coordinated. In human social organization, on the other hand, the individual must understand a very complex structure that relates large numbers of individuals. For example, A must not only understand the relationship between B and C, A must also know how that could change with the arrival of D, and how E's understanding of B, C, and D might affect A, and so on. This is the stuff of human politics and, although chimpanzees demonstrate some impressive political abilities these pale in comparison to the simplest human society. The "external" world of human social behavior relies in part on our ability to represent multiple, changing perspectives and organize complex hierarchies of information. *Homo erectus* almost certainly did not rival modern humans in this regard, but he almost certainly lived in an external social world that was more complex than that of *Homo habilis*. Perhaps there were even "theories" (rules) of appropriate behavior, just as there appear to have been theories of appropriate shape. Such a shorthand would facilitate social relations, but would also require implicit perspectives and hierarchies of some complexity. This would be the beginning of a true culture-based social system. The cognitive abilities were there; at this point the details are pure speculation.

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NOTES

[1] It is dangerous to assign hominid types to particular archaeological industries. Archaeologists recognize at least four industries in the early Pleistocene of East Africa—Oldowan, Developed Oldowan, Karari, and Acheulean. These do not present a simple picture of chronological or technological variability. Nevertheless, we have no reason to think that the biface industries that we do find (Acheulean and Developed Oldowan B) were made by a hominid other than *Homo erectus*. It is the chronological coincidence of bifaces and *Homo erectus* that is provocative, not the problematic equation of whole industries to specific hominid taxa.

[2] Stone knapping requires more than just spatial concepts; perceptual and motor skills are necessary. For example, the knapper needed to recognize edges that could be fractured, and aim blows. There is nothing here that is obviously beyond ape abilities. Recognition of acute angles on edges appears to be similar to the spatial distinction between angular and curved, which is a spatial concept that was in the repertoire of Oldowan hominids, though yet to be demonstrated for apes. Nicholas Toth's (1992) current research with the bonobo Kanzi should take us a long way toward understanding what apes can and cannot do as stone knappers.

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