Current Anthropology Volume 43, Number 5, December 2002

Skill and Cognition in Stone Tool Production

An Ethnographic Case Study from Irian Jaya[1]

by Dietrich Stout

Stone tools represent some of the best remaining evidence of prehistoric behavior and cognition. Interpreting this evidence properly requires models based on observable phenomena in the modern world. For this reason, ethnographic research was undertaken among the adze makers of the village of Langda in Indonesian Irian Jaya. This research, involving observation, interviews, and analysis of lithic products, revealed a technology of great sophistication and complexity. Adze-making skill is acquired through a period of apprenticeship that may last five years or more, during which time the community of adze makers provides a social scaffold for the learning process. Adze production is itself a social phenomenon, defined as much by personal and group relations, social norms, and mythic significance as by specific reduction strategies and technical terminology. Adze-making ability is associated not only with well-developed perceptual-motor and cognitive skills but also with a wealth of technological knowledge. Although much of the complexity of the Langda adze industry would be invisible to an archaeologist, evidence of knapping skill is preserved in attributes of the durable stone artifacts produced. This evidence may be used to develop productive hypotheses about the psychological implications of prehistoric stone tools.

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1. The research presented here was funded through generous grants from the Ligabue Study and Research Center in Venice, Italy, and the Center for Research into the Anthropological Foundations of Technology (CRAFT) at Indiana University. None of this work would have been possible without the remarkable craftsmanship and cooperation of the Langda adze makers, the assistance and companionship of Daniel Balyo, and the invaluable aid of Dick and Margareet Kroneman. I would like to thank Giancarlo Ligabue for his groundbreaking work in Langda and Nicholas Toth and Kathy Schick for advice and assistance in the preparation of this manuscript, including contribution of some of the illustrations. My thanks also go to Polly Wiessner for drawing my attention to the work of John Burton, Anna Stroulia for aid in translation, Paul Jamison for statistical advice, Deborah Wilkerson for lithic illustration, and Cindy T. Cordero for proofreading. Inspiration for many of the questions addressed and perspectives adopted in this study comes from the proceedings of the 1990 Wenner-Gren symposium "Tools, Language, and Intelligence: Evolutionary Implications," held in Cascais, Portugal, and published as Gibson and Ingold (1993). Any faults with the research presented here are, however, mine alone. [Supplemental material appears in the electronic edition of this issue on the journal's web page (http://www.journals.uchicago.edu/CA/home.html).]

Assessing mental activity from the material residues of behavior is a central problem for archaeologists working in any time period. In the case of Paleolithic archaeology, the endeavor is further weighted with evolutionary implications (e.g., Holloway 1969, Parker and Gibson 1979, Isaac 1986, Wynn 1993, Gowlett 1996, Ambrose 2001). Because of their persistence in the archaeological record and because they provide evidence of individual technical acts, knapped stone artifacts are commonly used as a source of information about prehistoric and premodern mental abilities. Although stone tools do not necessarily provide evidence of the full range of their makers' mental abilities, they do indicate certain minimum required competences (Gowlett 1996). In order to assess these competences, we must ultimately rely upon models developed from actualistic research in the modern world. Since it is impossible to observe the evolving technological behaviors of extinct hominid species directly, our reconstructions should at least be able to draw upon an understanding of the modern human condition.

In order to contribute to the development of such an understanding, I undertook ethnographic research among the adze makers (fig. 1) of the village of Langda in Indonesian Irian Jaya. Langda is located on a small plateau in the ruggedly mountainous central highlands (fig. 2), approximately 100 kilometers southeast of the town of Wamena in the central Baliem Valley. Although metal is rapidly replacing stone for most everyday tasks in Langda, the traditional manufacture of stone adzes (fig. 3) is still practiced. These adzes, which were traditionally used to clear land and to work wood, among other functions, are produced by a semihereditary all-male community of skilled craftsmen. This community currently includes both established experts and less proficient or apprentice individuals. The adze makers of Langda were first described by Giancarlo Ligabue, who visited the plateau in 1984 with Gunter Konrad (Ligabue 1985, Salvatori 1986). In 1990, Ligabue returned with Desmond Clark and Nicholas Toth to provide a more detailed description (Toth, Clark, and Ligabue 1992). The adze industry of Langda is also described in Pierre and Anne-Marie Petrequin's monograph on the stone axes of Irian Jaya (1993:217–62) and in O. W. Hampton's (1999) *Culture of Stone*. All of this previous work laid the foundation for my own research in Langda, undertaken during the fall of 1999.

As was recognized long ago by the Soviet psychologist L. S. Vygotsky (1976:20–23), human tool behavior involves a close integration of cognitive and symbolic processes with "practical intelligence" or "technical thinking." The capacity for skilled technical performance is

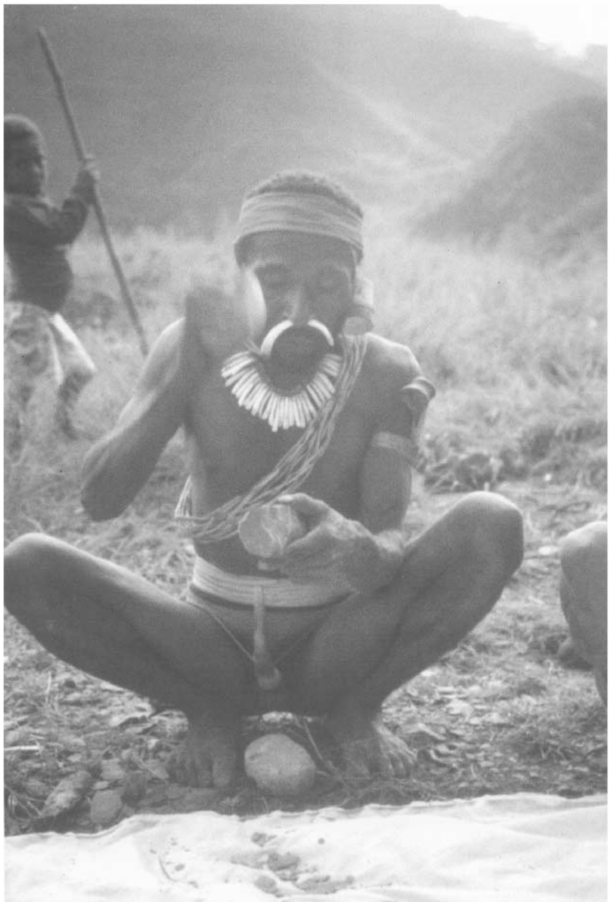

FIG. 1. *A skilled Langda adze maker in traditional dress.*

a central aspect of human mentality that may be considered alongside symbol use as a hallmark of humanity (Oakley 1954, Preston 1998). It is ultimately not the presence or absence of any specific type of behavior that embodies human uniqueness but the "generative interplay" between tools, language, and society (K. Gibson 1993).

In the words of Leroi-Gourhan (1965:35), "the tool exists only with the gesture which renders it technically efficient." Human technology is not a static collection of material objects and technical facts but a dynamic system of skilled and goal-directed action in a social context (cf. Ingold 1993:433–36). One way in which to appreciate the nature of human skill is from an "ecological" or "perception-action" perspective. This view, arising out of the work of J. J. Gibson (1979) and N. Bernstein (1967), sees skill as a dynamic property of the organism-in-environment system rather than as an internal program expressed by the mind. Skill acquisition is a process of learning how to act in order to solve a problem rather than one of acquiring some rigid motor formula. The acquisition of tool-using skill in particular involves learning to perceive the action possibilities afforded by relations between objects (Lockman 2000) through the dynamic coupling of perception and action.

The perception-action perspective challenges traditional distinctions between cognitive and motor behavior and points the way toward a more integrated view. In this view, thinking and doing are both behaviors of the organism-in-environment system; they are simply different behaviors. To use the example of Thelen and Smith (1994), weaving and thinking about weaving both emerge (in part) from patterns of neuronal activity. These patterns may have partially overlapping histories and components, but the critical difference in the overall ensemble remains. Neuropsychological research on mental imagery (review in Kosslyn, Ganis, and Thompson 2001) has demonstrated just such overlap between internal conceptualization and external perception, as well as characteristic differences. This overlap may help to explain the well-known capacity of mental practice to enhance performance (e.g., Driskell, Copper, and Moran 1994).

In any case, a human technology like weaving clearly involves both weaving and thinking about weaving, as well as talking and acting about weaving. A proper study of technology must address this entire continuum of behaviors. Although the traditional anthropological distinction between knowledge and know-how (e.g., Hodder 1990) may be overly rigid, it is important to recognize that some kinds of goal-directed actions are more conceptual than others. This differentiation is particularly important from an evolutionary perspective in that differences in neural substrates may also be involved.

Much of the conceptualization inherent in human technology relates to the fact that technology is itself an inherently social phenomenon. Stone knapping, like other technical skills, takes place in highly structured social and physical contexts (Ingold 1997) that serve to provide "scaffolding" (Wood, Bruner, and Ross 1976) for skill learning and performance. Humans live in a constructed environment, physically, socially, and cognitively. Information is not simply confined within the heads of individuals but distributed throughout this constructed environment. A concrete example is provided by Gatewood (1985:206–7), who describes the way in which the design of a salmon-fishing boat on which he worked provided a "spatial mnemonic" that made it easier for him to learn his job. In a similar fashion, P. Graves (1994) has pointed out that the information inherent in the design of a bicycle is integral to the acquisition of bike-riding skill. In the case of adze making, vital information is embodied in the spatial organization and storage of resources as well as in the physical characteristics of the tools and materials used.

Skill learning and performance are also structured by social context, particularly with respect to such critical parameters as task definition, motivation, and support. Instruction provided by more experienced individuals is one particularly obvious example of the role of social context. Ideally, such instruction enables learning within what Vygotsky (1976:84–91) refers to as the *zone*

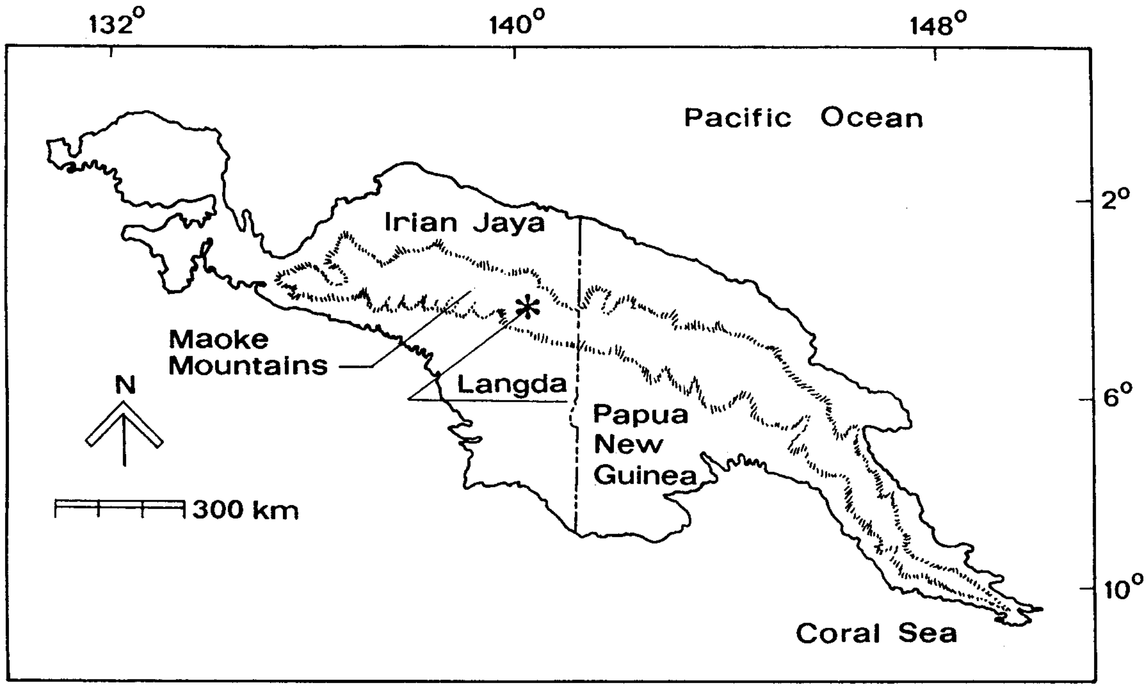

FIG. 2. *The island of New Guinea, showing the location of Langda.*

of proximal development, a learning space defined by the difference between "actual" (unassisted) and "potential" (instructed/collaborative) ability. Learning occurs within this zone as the result of the structure and modeling provided by the instructor, which function as a kind of scaffold for the "guided rediscovery" (Ingold 1997:111) of competence by the student.

Although somewhat more subtle than direct instruction, interactions with the broader social environment also need to be considered. For example, the demands of learning a difficult skill like the wheel-throwing of pottery may influence the technique's distribution in different social contexts (Roux 1990). Students of "everyday cognition" have examined some of the ways in which such differences in social context are reflected in learning and performance. Major factors include motivation and emotional involvement, continuity with prior experience, degree of task definition, and flexibility of acceptable solutions, among others (Sternsberg, Wagner, and Okagaki 1993:206). It is the influence of such factors that explains why, for example, some individuals perform better on a task involving price comparison in a supermarket than on an "equivalent" paper-and-pencil task (Lave, Murtaugh, and de la Rocha 1984). In short, no task exists apart from the physical and social matrix that gives it structure and meaning. In order to appreciate the mental dimensions of stone knapping or any other skill, this fact must be taken into account.

Unfortunately, this kind of detailed contextual information is difficult to derive from the fragmentary archaeological record. To exploit fully what the record can tell us, it is necessary to use interpretive models based on observable phenomena in the modern world. One important source of such actualistic data is study of (and by) modern nontraditional knappers (e.g., archaeologists, hobbyists). The nontraditional context is especially suitable for experimental investigations of particular stone-knapping technologies (e.g., Bordes 1947, Crabtree 1966, Callahan 1979, Toth 1985), including their mechanical (Dibble and Pelcin 1995), biomechanical (Marzke et al. 1998), and neurological (Stout et al. 2000) dimensions.

In an ideal world, actualistic study of nontraditional knappers would be augmented by ethnographic research with diverse groups of traditional stone knappers. Such research could begin to explore some of the broader contextual variables surrounding the realization of stone-knapping skill by individuals and groups. Roux, Bril, and Dietrich (1995), for example, have provided a particularly good example of the exploration of skill in an ethnographic context. Unfortunately, traditional social contexts in which to study lithic technologies are very rare in the modern world. In addition to the precocious work of Skertchly (1879) with English gun-flint makers, contemporary reports come from a handful of groups in Ethiopia (Gallagher 1977, Clark and Kurashina 1981, Brandt 1996, Weedman 2000), India (Roux, Bril, and Dietrich 1995), Australia (Tindale 1965, Gould 1980, Hayden 1977), and New Guinea (Vial 1940, Strathern 1970, Burton 1985, Toth, Clark, and Ligabue 1992, Petrequin and Petrequin 1993, Hampton 1999). Shrinking this sam-

FIG. 3. *A finished adze from Langda.*

ple even further is the fact that the traditional manufacture and use of stone tools in Australia appear to have ceased by at least the early 1990s (Cane 1992).

The adze makers of Langda provide a rare and invaluable opportunity to study a skill-intensive knapping craft in a traditional social context. Obviously, any such case study provides but a single example of the myriad ways in which lithic technologies might be incorporated into modern human societies. Due caution is of course required in attempting to draw inferences about the past based on such limited evidence, and this is especially true when dealing with premodern hominid species. Nevertheless, the example provided by the adze makers of Langda remains of great value. The real contribution made by these craftsmen is not in providing answers about the past but in helping us to frame productive questions.

The Adze Makers of Langda

The Langda plateau is located at an elevation of 1,860 meters (Hampton 1999:251) in the Ey (French: *Heime*) River valley, about 800 meters above the river itself. The plateau is surrounded on all sides by soaring mountain peaks and the precipitous slopes of deeply incised river valleys. Thick vegetation covers much of these slopes, and travel to nearby villages, even those within sight of the plateau, can take the better part of a day. Even a visit to the stone quarry sites on the banks of the Ey River below Langda involves a round-trip of two and a half to three hours. [More detailed discussion of the research area is presented in appendix A in the electronic edition of this issue on the journal's web page.]

At the time that this research took place, in the fall of 1999, there were seven men living on the plateau who were actively involved in adze making. These included three acknowledged experts, three apprentices, and one older man who was recognized as an established craftsman but whose skill was of a lower level. The research presented here also includes two experts from neighboring villages who visited the plateau during the study period and one complete novice from Langda who had had no prior experience in adze making, bringing the total to five experts and five relatively unskilled knappers.

AN OVERVIEW OF ADZE PRODUCTION

Stone adze heads are produced from dark gray-green boulders found along the banks and in the bed of the Ey River. The river flows several hundred meters east of and 800 meters below the plateau at the base of a very steep slope (fig. 4). The boulders exploited by the adze makers range in size from about 30–40 centimeters to several meters in maximum dimension.

The raw materials used by the adze makers have been identified petrologically as variably metamorphosed basalt, basalt/andesite, and metabasalt/andesite with a range of textures including fine-grained, fibrous, and ophitic (lath-shaped plagioclase crystals enclosed in later-formed augite) (Hampton 1999:84; Petrequin and Petrequin 1993:226). The quarrying of these materials is usually done in groups, with the more experienced men leading the search for materials of suitable quality. Individuals interviewed indicated that finding high-quality material is one of the most difficult and important aspects of adze production.

Because of the time required for the search, quarrying activities often continue for several days or more at a stretch. During this time, the adze makers will spend nights together in huts located near the banks of the river or along the slopes of the valley below the plateau. Boys and girls often accompany the adze makers on such quarrying trips. During the study period, two two-day quarrying trips were made to the Ey River, with nights spent in huts at Tukuplu and Yintong.

Quarrying begins upon arrival at the river on the first day and when sunlight reaches the bottom of the river valley on subsequent days. The adze makers select a particular stretch of the river on which to focus for the day and disperse to look for promising boulders. The Ey River is swift-flowing, and its banks are too steep to approach it in many places; access is gained at various cobble bars or "beaches." These locations are given names such as Kaltehme Dala, Amal Dala, Ambrume Dala, and Kwating Dala (*dala* = beach). At least some of these locations

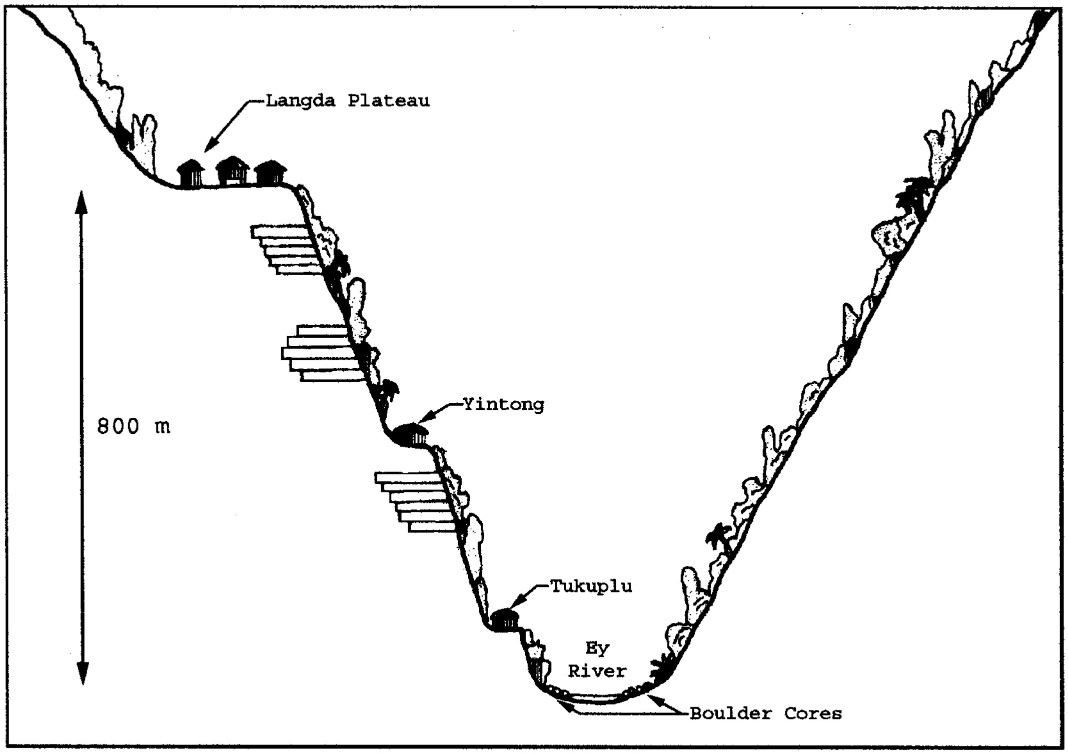

FIG. 4. *The Ey River Valley at Langda.*

seem to have mythic or spiritual significance attached to them.

When one of the craftsmen locates a promising boulder (fig. 5, *top*), a test flake is struck in order to reveal the *bol* or "deep skin" of the rock (fig. 5, *center*). This exposed surface may also be wetted down in order to make its crystalline structure more easily visible (a technique called *magalingna*). Craftsmen who happen to be in the immediate area gather to discuss the merits of the selected boulder, commenting on the size and uniformity of the grain, the danger of internal flaws (*ismar*), and the presence of black (*bataya*) or white (*boladiatenga*, "deep-skin belt") mineral bands (fig. 5, *bottom*). Although they realize that these bands often represent points of weakness in the rock, the adze makers prize them for their aesthetic value.

If a boulder is selected for quarrying, the way in which it is attacked depends on its size (fig. 6). Often, particularly if it is in the flow of the river, the boulder must be moved. For small boulders this presents little problem, but for larger boulders a cooperative effort using opportunistic driftwood levers is often needed. Boys who have accompanied the adze makers may assist with this work.

For smaller boulders, the production of flake blanks (*ya-las* [*ya* = stone]) begins immediately. If the boulder core (*ya-dup*) is small enough to be easily manipulated by hand, blanks will be produced using a medium-sized (~10–15 cm, 0.5–1 kg) hammerstone (*ya-winwin*) and a driftwood anvil (*ya-sigita*). Larger boulders are attacked with a larger (~25–30 cm, 5–10 kg) hammerstone (*dabim*). Both *dabim* and *winwin* percussors are selected in an expedient fashion from the readily available river stones. The *dabim* is commonly raised over the head with both hands and brought forcefully down on the boulder (fig. 7). Legs are spread for balance, and the flaking action sometimes resembles the between-the-legs hike of an American football center (Toth, Clark, and Ligabue 1992). Less commonly, the hammer is thrown.

For the largest boulders, fire is used to aid in fracture. After a large boulder has been sufficiently heated (sometimes for most of the day), it is cracked open and then reduced by direct percussion with a *dabim*. Flakes and large fragments produced may be used directly as blanks or, if they are particularly large, further reduced using the hammer-and-anvil technique described above.

As quarrying activities continue through the day, individual men will alternate between blank production and roughing out. Rough-outs (*ya-temen*) (fig. 8) are produced from blanks through hard hammer percussion using a *ya-winwin* hammerstone. This process is called *temena*. The core is held in the nondominant hand (in the event, all of the men studied were right-handed and held the cores in their left hands). A low frequency of platform preparation and hammerstone rubbing (discussed below) is associated with roughing out.

FIG. 5. *The selection* (top), *test-flaking* (center), *and discussion* (bottom) *of a potential boulder core.*

Roughing out occurs both at the quarry site and at the huts where the men spend nights between days on the river. As with blank production, in which several men may work the same boulder core, a single blank may be reduced by two or more men before reaching the rough-out stage. During a quarrying expedition, rough-outs accumulate in piles on the beach and are stored at night under the eaves of the hut being used. Some of these are taken by the individuals who produced them, usually senior craftsmen, but most are collected and redistributed by the head adze maker, who exercises authority over the stretch of the Ey River below Langda.

When quarrying is complete, rough-outs are carefully wrapped in leaves and carried back up to the plateau in net bags. Some rough-outs are taken by individuals to their homes, but many are stored at the hut of the head adze maker. *Ya-winwin* hammerstones are also stored under the eaves of the head adze maker's hut, and, at least during my stay in Langda, the head adze maker insisted that all knapping on the plateau be done in front of his hut.

In the final phase of knapping (called *talena*), rough-outs are reduced to a form called a *kil-ya* (fig. 9) that is ready for grinding and hafting. This involves an assortment of basic knapping operations and commonly takes about an hour, depending on the size of the core and the skill of the knapper. It is done squatting on the ground, most often with a line of other knappers all facing in the same direction. A premium is placed on reducing the core as closely as possible to the ultimately desired form because subsequent grinding is both laborious and tedious. As noted by Petrequin and Petrequin (1993:253), the emphasis on knapping over grinding seen in Langda and some other areas increases productivity but also requires more skill than the grinding that is the predominant mode of reduction in other Highland axe/adze industries.

As knapping proceeds there is a great deal of socializing, including discussion of the ongoing work. It is also traditional for adze makers to call out after a particularly successful flake removal. The most common exclamations are "harak" and "Alim-Ey," the latter being a reference to the mythical figure Alim Yongnum, who is revered as the provider of the tool-stone found in the Ey River. Sometimes the flakes (*ya-tokol*) produced are held aloft in display or passed along the line for examination. It is also common for knappers to observe and comment on the work of their neighbors (particularly if these neighbors are less experienced) and even to give aid by taking over for a while from another individual who is having difficulties.

Fine knapping (*talena*) is accomplished using an array of *ya-winwin* hammerstones kept conveniently by the feet. These hammerstones range in mass from about 250 grams to over a kilogram and represent a variety of shapes and stone types. I was informed that hammerstone substitution is not done in any consciously systematic way (switches are made in an experimental fashion as difficulties are encountered), although I did note a trend toward the use of smaller percussors as core size decreased. This trend was also reported by Toth, Clark, and Ligabue (1992).

During knapping, the rough-out is held cradled in the nondominant (left) hand, with particularly large rough-outs being supported by the forearm as well. The fingers of the left hand are placed directly underneath the intended flake removal. Experts in Langda state that this is an important part of proper technique and that the fingers serve the same function as the wooden anvils

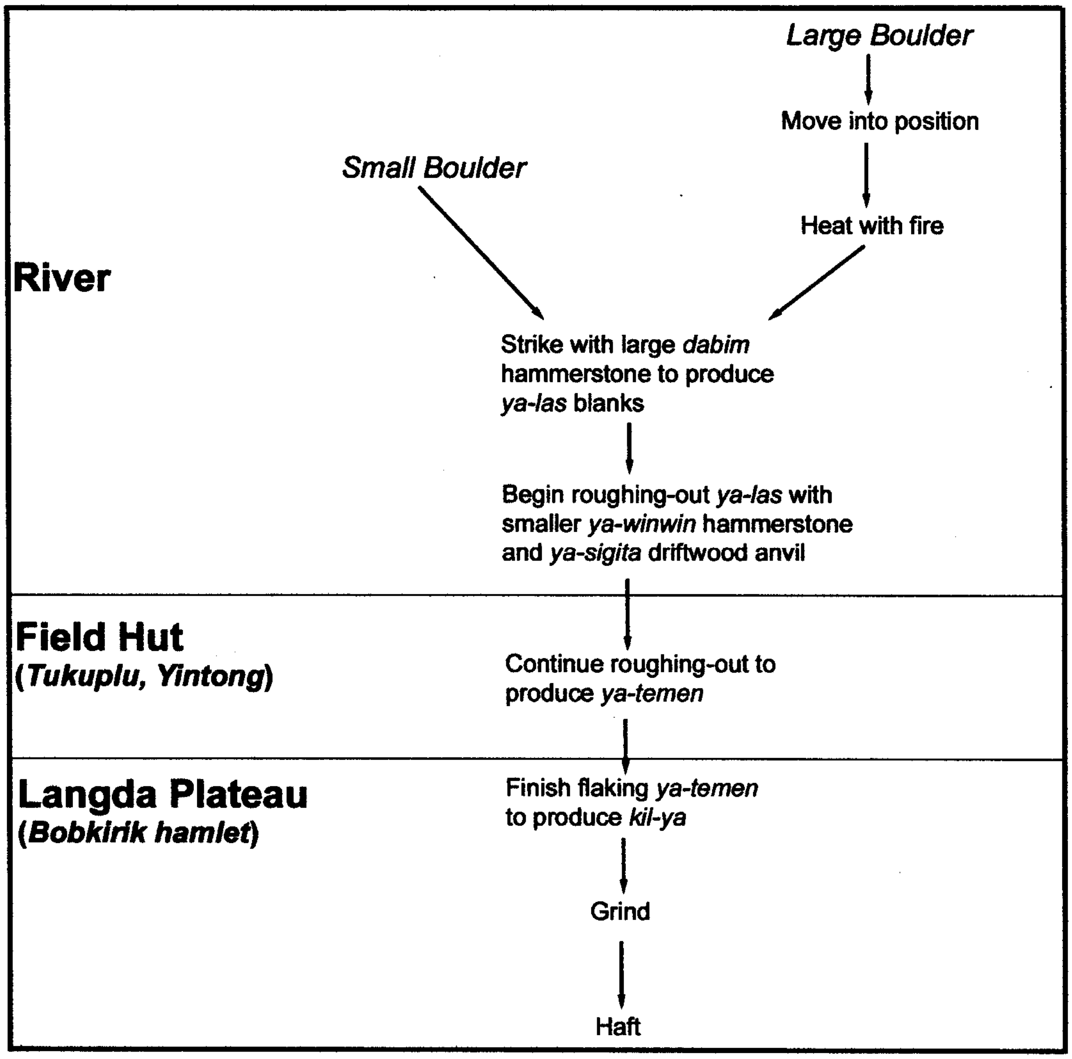

FIG. 6. *The generalized production sequence for stone adze heads in Langda.*

used during quarrying (i.e., to absorb shock and direct the force of the blow). The careful placement of the fingers may also help in aiming. After a successful strike, the detached flake is caught and discarded with a stereotyped flick of the wrist. Another aspect of successful flaking that the knappers of Langda are well aware of is the exploitation of core morphology. Thus, skilled knappers look for ridges (*magnana*) on the core that will conduct force and facilitate flake removal and strike at high points (*arayna*) along the edge being worked rather than at concave flake scars (*kwagna*).

Prior to attempting flake removal, the knapper almost always prepares both the striking platform (*kau*) and the percussor itself. Two kinds of platform preparation are practiced: pounding (*ungna-kiringna*) and microflaking (*hook dongaboka*). The edge of the intended platform may be pounded with a special basalt/andesite tool (*ungna*), usually a chunk from a broken rough-out. Blows are aimed directly into the body of the core and serve to remove small projections and overhangs. This is done "to keep the platform from breaking" upon percussion. Microflaking is done through a rapid succession of light, highly tangential blows with the hammerstone. The adze makers also pay attention to preparing the surface of the percussor they are using. This is done by rubbing (*krikun*) the hammerstone against the core in order to smooth the percussor's surface. Somewhat surprisingly, hammerstone abrasion does not seem to be used as a technique for platform preparation. As was also observed by Petrequin and Petrequin (1993:231), rubbing is done on any flat surface of the core and is in no way focused on the anticipated striking platform. The adze makers themselves report that the purpose of the abrasion is to prepare the surface of the hammerstone, particularly by generating a small flat area that will not "slip" on contact (Hampton 1999:267). This constant abrasion (before al-

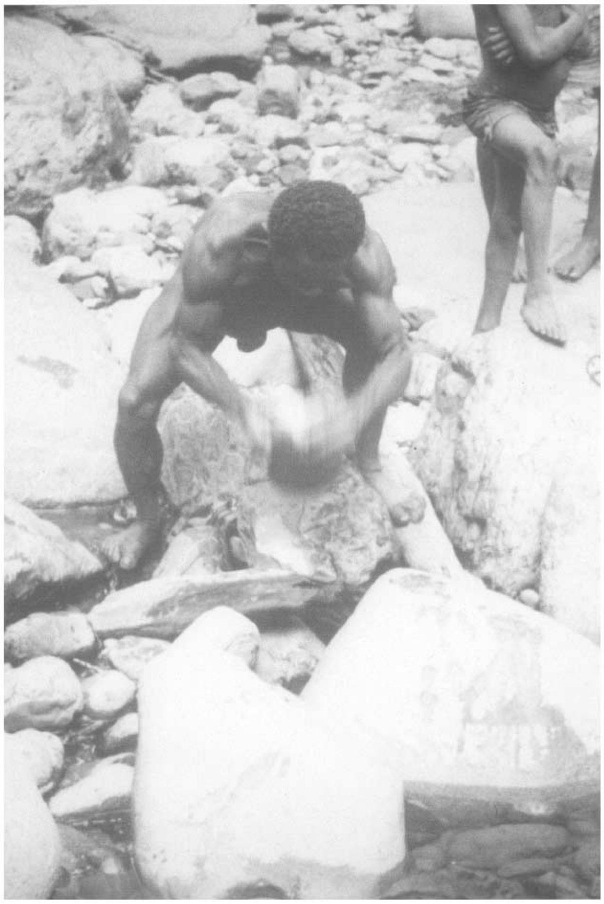

FIG. 7. *An adze maker using a large hammerstone* (dabim) *to strike flake blanks* (ya-las) *from a medium-sized boulder core* (ya-dup).

most every series of blows), combined with normal wear and tear, results in heavily modified hammerstones—with one extreme case being reduced to a near-perfect sphere.

After the finished *kil-ya* form has been achieved, the piece is ground and hafted. These stages of production are not the focus of the current investigation, but published descriptions are available in Toth, Clark, and Ligabue (1992), Petrequin and Petrequin (1993), and Hampton (1999). Briefly, the finished *kil-ya* is ground against a special sandstone slab (*ya-yok*) obtained in trade from the village of Bomela, about a day's walk to the west. Water, either from a stream or from a depression in the ground, is used as a lubricant. Grinding is commonly done in shifts and can take several hours for a large piece. The entire tool surface is ground, possibly in order to eliminate sharp projections that might damage the binding. Some of the deeper flake scars are usually left intact and may be painted with red and white pigments. These markings are both decorative and symbolically meaningful: Petrequin and Petrequin (1993) report on informants "giving life" to the adze by putting "blood" in its wounds, while my own interviews suggest that pigmented adzes are reserved for use by men only. The ground adze head, ready to be hafted, is known as a *kil-ya-ba*.

Adze handles are made from a particular variety of tree locally known as the *tilyi* and identified by Petrequin and Petrequin (1993:248) as belonging to the genus *Garcinia*. Adze-handle shafts (*ya-kala*) are made from proximal branch segments with the transverse haft itself consisting of a portion of the trunk. The blade socket is lined with small pieces of wood (*ya-suka*) that act as shock absorbers, and the blade is bound to the haft with rattan (*ya-tapu*).

Apprenticeship and Socioeconomic Context

Perhaps because of the high value traditionally placed on stone adzes, a good deal of social control is exerted over the materials and skills needed to produce them. As has also been reported by Petrequin and Petrequin (1993) and Hampton (1999), different villages along the Ey River valley control access to quarry sites along adjacent stretches of the river. The head adze maker in each village has personal authority over quarrying activities in these areas. Hampton (1999) attributes this authority to a system of hereditary ownership.

The current head adze maker of Langda regulates the

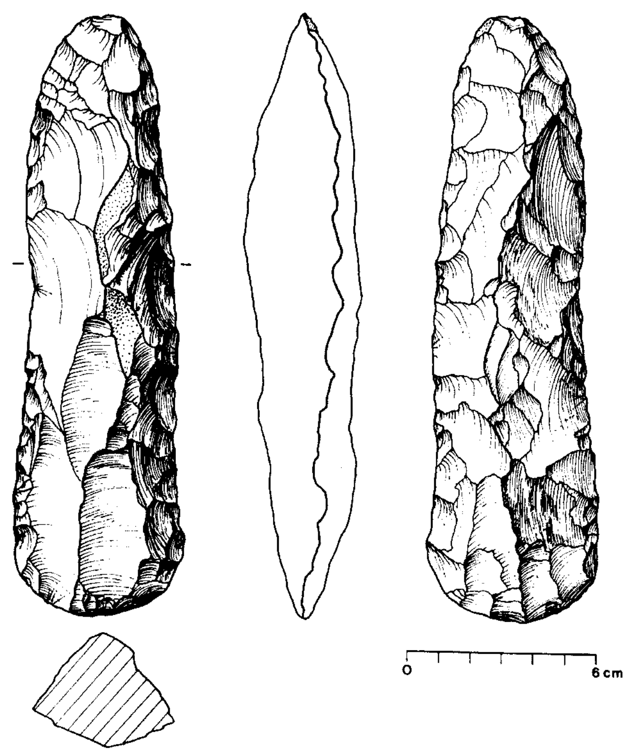

FIG. 8. *A rough-out* (ya-temen) *ready for final reduction.*

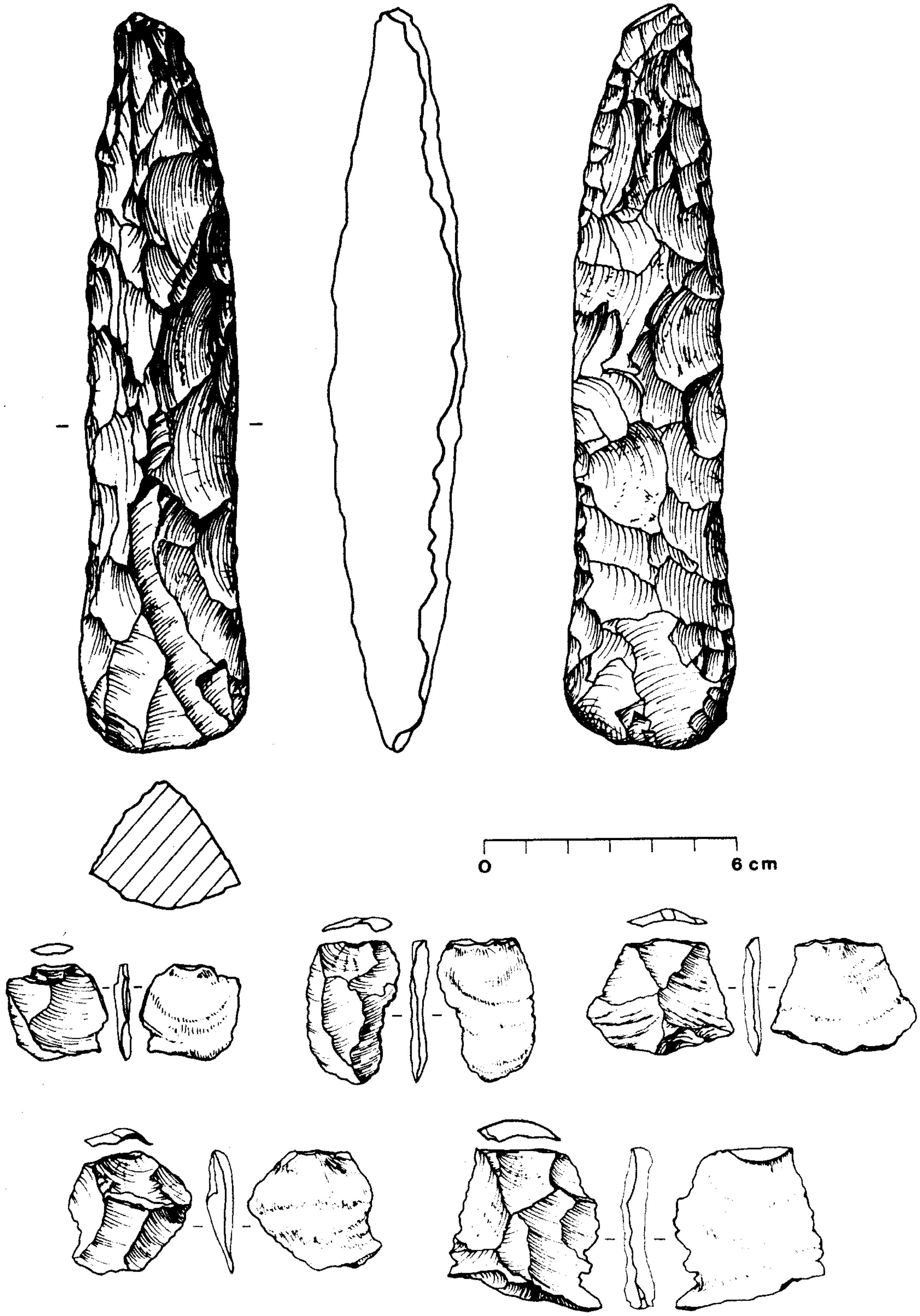

FIG. 9. *A finished adze-head* (kil-ya) *produced by a skilled craftsman, along with representative shaping flakes. Note the long, narrow flake scars emanating longitudinally inward from the bit of the adze head, a characteristic feature left from the removal of specialized blade-flakes* (utina).

quarrying process by collecting and redistributing the rough-outs produced during trips to the river. This process of redistribution is not a rigorous one, and men are often allowed to take home the same pieces that they produced, but the recognition of authority is clear. Back on the plateau, hammerstones and rough-outs are stored at the home of the head adze maker. He enjoys rights of ownership over these materials, and I was informed that in the past men had been killed for using such items without permission.

Some of the influence wielded by the head adze maker of Langda is almost certainly due to his own personality and charisma. As noted by Petrequin and Petrequin (1993) and Hampton (1999), he is both the head adze maker and one of the most influential headmen in his community, a combination that is by no means universal. Be that as it may, his authority also rests on traditional and hereditary arrangements that are consistent with the broader social and environmental context. This may be illustrated through comparison with the traditional adze industry (described by Petrequin and Petrequin 1993) of the nearby Phu River valley, located roughly 40 kilometers west-north-west of Langda.

In the past, inhabitants of the Phu Valley followed a cycle of itinerant agriculture that brought them near to sources of adze stone for roughly one month out of the year. These sources, large detrital cones along the Phu River, were treated as communal resources open for exploitation by all. Rights of ownership to stone blocks and large flake blanks simply went to the individual who collected them. Expert knappers were paid, usually with vegetables or pork, to work these blocks into a form ready for grinding, but ownership of the stone remained with the original collector. This is obviously very different from the situation in the Ey River valley, where hereditary quarrying rights are closely guarded by communities and individuals.

There are many potential explanations for this difference, including stochastic historical variation, but one major candidate is the difference in mobility and seasonality between the two groups. In Langda, raw-material sources are close at hand throughout the year, and adze manufacture may take place at any time. This favors the development of safeguards against overproduction and overexploitation and allows individuals to monitor access to quarry sites. In the Phu Valley, in contrast, lithic resources are only at hand for a small part of the year. This produces a situation in which not only must production be maximized for a short period but continuous monitoring of quarry sites is essentially impossible. In each case, the broader social and environmental context is reflected in the organization of the local adze-making industry. Although some of the authority exercised by the head adze maker in Langda may result from the force of his personality, a good part also derives from the traditional arrangements that have developed in the particular environmental context of Langda.

Another aspect of the adze industry in Langda that is subject to social control is skill itself. Entry into the community of adze makers occurs through a period of apprenticeship that can last five years or more. The Langda craftsmen report that, because of the great value of the skill, they will instruct only close relatives, usually "sons" (the Langda kinship system does not differentiate between sons and nephews). In general, a potential apprentice will express interest by attending to the knapping activities of the craftsman, perhaps bringing food or helping with menial tasks. For his part, the potential master will attempt to evaluate the seriousness and commitment of the student. He may even want to judge some early attempts at knapping before deciding to accept the apprentice.

Traditionally, apprenticeship began around the age of 12–13. In Langda today, however, the apprentices are generally in their mid-twenties. This is probably a reflection of the changes in the adze-making craft that have resulted from the increasing availability of metal tools. Demand for adzes to be used in everyday labor has fallen off dramatically, reducing the economic value of adze-making skill. For the adze makers, however, the craft remains as a source of pride and social identity. It seems likely that the changing significance of the stone adze in the social and economic life of Langda has altered the motivations for skill learning and caused more individuals to make the choice to pursue apprenticeship later in life.

Despite this shift, many traditional aspects of apprenticeship remain. Some are restrictive, such as the fact that any profits (in money, food, or goods) made by the apprentice must be given to the master. The apprentice is similarly restricted in the size of the rough-outs he is allowed to work on. During my research, I repeatedly attempted without success to persuade the head adze maker to allow an apprentice to reduce a large rough-out for the purpose of comparison. Such restrictions probably help to limit the potentially disruptive influences of novices (B. Graves 1989) by preventing competition with established craftsmen and regulating the use of valued resources.

Restrictions also play an important role in the learning process. For example, I was informed that it can take ten years or more to develop the skill needed to produce one of the largest adzes, which reach over 270 millimeters in length. In contrast, apprentices often produce pieces that are too small (~100 millimeters) ever to be used and are made solely for practice. Forcing apprentices to practice on small rough-outs suited to their level of experience helps to situate learning within an appropriate zone of development.

Social scaffolding for the learning process is also provided by the dynamics of the adze-making community itself. Virtually all technical operations in the production of stone adzes are conducted as group activities with a great deal of interaction among individuals. This includes discussion, observation, demonstration, and even direct assistance. It is quite common, for example, for one man to make suggestions to another about where to attempt the next flake removal or to comment on the quality of the material being worked. Similarly, a worker who is experiencing difficulties may ask another to try

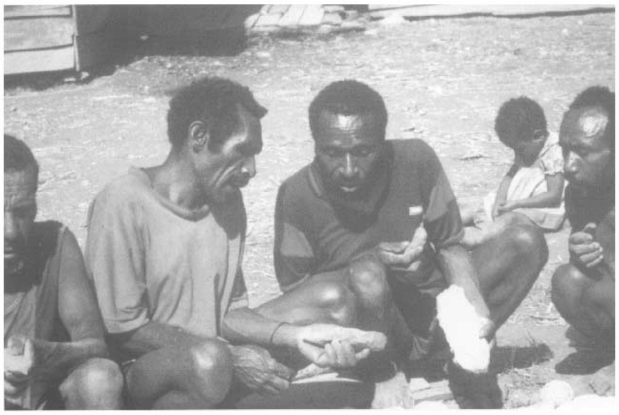

FIG. 10. *Two experienced knappers* (first and second from right) *providing instruction to an apprentice* (third from right).

his hand at the task. Such interaction occurs between peers but is most frequent between experts and apprentices (fig. 10). Experts also engage in more general exposition about proper stance, technique, and even attitude. Observed examples include apprentices' being told to work more slowly, to keep in mind the way in which the adze will be hafted while shaping the butt, to think before striking, and to strike the "high" or projecting parts of an edge first. Apprentices benefit from demonstration, instruction, assistance, and motivation from the entire community of craftsmen, not simply from their own nominal masters. Because of this communal dynamic, apprentices are able to participate in all stages of production, even those that they would be unable to accomplish by themselves. Furthermore, they are given assistance and advice during each stage that allows them to perform well beyond the unassisted level. This social facilitation of precocious performance is a practical realization of Vygotsky's zone of proximal development, in which structured support allows students to acquire skills more rapidly.

Social context also provides motivation and produces work-related values. A central value expressed by the adze makers is commitment to and immersion in the craft. Thus, I was repeatedly told that proficiency is acquired only through continual practice and that without it a man's hand will "grow heavy." Similarly, craftsmen compliment others by commenting on their single-minded commitment to knapping and speak of forgetting their wives, their gardens, and everything else while they are working. In addition to the traditional exclamations of "harak!" and "Alim-Ey!" while working, the craftsmen express their joy in their work by speaking of the flakes as "peeling off like sweet-potato skin" or sliding off as if on the "wet grass of a mountain slope." One man spoke excitedly of wanting to flake "every stone in the river." In sum, apprenticeship in Langda is a social institution that reflects the broader socioeconomic context of the adze-making craft while at the same time contributing significantly to the structured social environment in which learning takes place.

Conceptualization and Communication

Adze making in Langda is associated with a large body of terminology and other technological concepts. For example, stone adze heads are subdivided into many distinct parts identified by particular names (fig. 11). Similarly well-developed terminology exists to describe particular knapping techniques and strategies. This makes it relatively easy for the adze makers to communicate about the details of their craft, for example, when giving technical instructions to apprentices. Thus, an apprentice may be reminded to work edges bifacially (*dinar dina*) and to strike at high points (*arayna*) rather than concave flake scars (*kwagna*) so that the flakes removed will tend to follow ridges (*magnana*) on the core.

Such statements provide a window on the conscious reduction strategies pursued by craftsmen. For example, several experts told me that for large adzes it is particularly important to start work on the bit (*si*) first, then the butt (*bumyok*), and finally the middle section (*ting kwiribkun*). This is because premature thinning of the middle makes the piece more likely to break as the bit and the butt are shaped. It was also emphasized that special attention needs to be paid to shaping the dorsal ridge (*amyok*), because it is one of the most difficult areas to flake and often gives apprentices trouble (in the reduction strategies employed by skilled knappers this

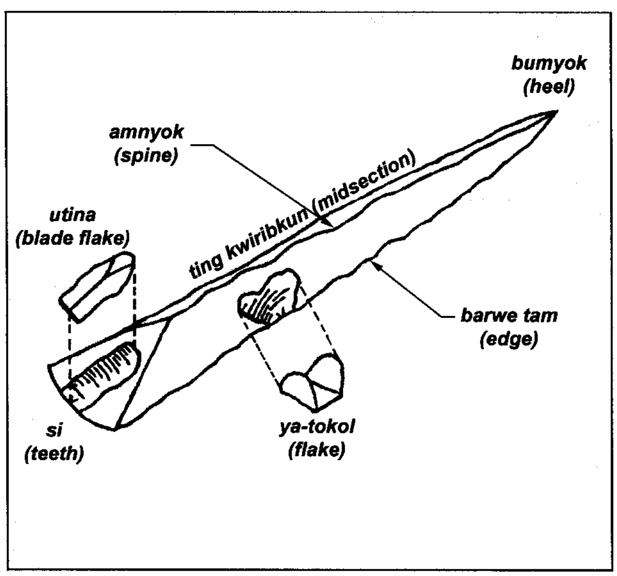

FIG. 11. *Some of the terms used to identify different parts of an adze and different kinds of flakes. Translations are in parentheses; note that many parts are described using anatomical metaphors.*

ridge is itself a third flaked edge and not simply an intersection of flake scars). Such comments reflect on the conceptual "thinking about knapping" that is as much a part of the Langda stone adze technology as actual knapping.

Further information about conceptualization comes from narratives describing particular reduction sequences. On one occasion, for example, an older craftsman explained to me that he had struck a flake from the side (*abum*) of the bit in an attempt to remove a step fracture (*kotangna*) left during a previous flake removal. This attempt had failed, he said, but he was then able to remove the step by striking a long blade-flake (*utina*) from the front of the bit. Such examples illustrate not only the adze makers' detailed knowledge of the materials, techniques, and strategies of their craft but also the problem solving and higher-level organization it involves.

knowledge of raw materials

A more complicated example of conceptualization and communication is the naming of adzes. Although the Langda adzes are all made in volcanic basalts/andesites of varying texture, the craftsmen use at least 14 different names to describe their lithic raw materials. In addition to these stone-type names, each adze head also receives an ancestor name and a place-of-origin name.

Stone-type names are generally assigned after careful examination of the stone's physical properties, usually in the context of group discussion. Naming first occurs at the quarry site, but the name may change as work proceeds. I was informed that grinding in particular reveals qualities helpful in naming an adze, such as the size, color, and uniformity of crystals or the presence of mineral bands. Such bands are considered to be important "signs" of a stone's name. The naming of hammerstones also seems to reflect stone characteristics such as color rather than size or shape, but additional research is needed on this topic.

The physical characteristics consulted in assigning a name to adze-stone are almost certainly associated with technically relevant variables such as ease of flaking and ultimate durability. In fact, I was informed that the two "special" or *bikrobya* types, *murkonye denlaru* and *lumkerye*, are valued specifically because they are stronger. It was also stated that these quality materials are much more difficult to find and cannot always be identified by the unskilled. In the observed quarrying activities, it was in fact the more experienced men who were responsible for locating most of the materials. Even for these experienced men, however, the naming of particular stones is not a trivial task.

When I asked three experienced men to name a random assortment of flaked pieces independently, they agreed in only 2 cases out of 11. This is not surprising considering that naming is normally part of the process of finding and working the stone and involves substantial interplay between individuals. The almost total lack of agreement observed in this artificial context suggests that naming, like so many other aspects of technological performance, is an inherently social phenomenon. Burton (1985) reports a similarly elaborate taxonomy of raw materials among the stone axe makers of the Wahgi Valley in Papua New Guinea. As in Langda, "no two informants gave the axe varieties in exactly the same order" (p. 60), and, when given museum specimens to identify, "they were too inconsistent in their identifications for the basis of the classifications to be clear" (p. 61). These parallels strongly suggest that the naming of raw materials was widespread in traditional Highlands adze/axe technologies and that it was often a social and symbolic rather than a purely classificatory process.

knowledge structure and context

As is illustrated by the naming of adzes, technological knowledge among the Langda adze makers is structured in a fairly complex way. One might be tempted to deal with this by distinguishing between "practical" technological knowledge of things like the physical properties of stone and more "symbolic" or socially relevant aspects of meaning. Such a distinction would, however, be somewhat artificial, being based on typically Western ideas regarding the separation of society and technology (Ingold 1997) rather than the understandings of the adze makers themselves. For these craftsmen the production of adzes is itself a social phenomenon.

This may be seen on several levels. For one thing, the adze makers view the stones they work with as living, intentional subjects. Thus, knappers will speak of stones' being "angry" if they fail to fracture as desired and will call out to them using their "secret names" as they search for them at the quarry sites along the river. The boulders themselves are believed to grow with age as people do (Petrequin and Petrequin 1993:226), with "old stone" (*wisy-ya*) being darker and stronger than "young stone" (*ya-babau*). Social relations with stone are an important part of production, and care must be taken to avoid angering pieces through improper practices such as placing finished pieces on the ground in an improper orientation (they should lie parallel, with the bit facing away from the craftsman). Similarly, Toth, Clark, and Ligabue (1992:92) report that when an adze breaks "the makers say they 'feel sorry' for their handiwork and take pains to bring it home for final discard."

Social relations with people (living, dead, and mythical) are also an important part of production. The first thing, entirely unsolicited, that adze makers generally wanted to relate during interviews was a list of their ancestors who had handed down the craft through the years. For the dominant Balyo clan, this list begins with Menminy Malyoman Balyo, who is said to have originated the technology. Another important figure, as we have seen, is the mythical woman Alim Yongnum, who "gives birth" to the stones in the Ey River and controls their availability (Louwerse 1990).

Relations with living individuals are embodied in the learning, instruction, cooperation, and exchange that are as much a part of the adze-making craft as is knowledge of reduction strategies. Craftsmen must always be aware of their relationships with others and the ways in which they are enacted and modified through adze production. The social, symbolic, and mythic ramifications of the industry are for them in no way external to the central goal of adze making. Knowledge in these spheres is one aspect of an overarching structure of knowledge that is unified by its practical and teleological focus.

Research on the subject of "everyday" or "situated" cognition has revealed that motivation, emotion, and task definition are important components of human mental performance. Keller and Keller (1996:23) elaborate this *practice perspective* with their concept of production *constellations* organized under goal-defining *umbrella plans.* Each such constellation embodies a "unit of ideas, tools, and materials" oriented toward the achievement of a particular step in production. In the case at hand, the umbrella plan is the production of adzes, and it is composed of individual constellations structured around raw-material procurement, roughing-out, grinding, and so on. In each of these constellations, information is distributed throughout a system that includes the affordances (J. J. Gibson 1979) of the physical and social environment as well as the performance characteristics (Schiffer 1999) of the craftsmen. In the raw-material procurement constellation, for instance, understandings about desirable stone characteristics, mythic significance, resource ownership, and extraction techniques are realized through purposeful interaction with the actual locations, stone resources, and individuals and groups involved in quarrying.

Manifestations of Skill

To evaluate variation in knapping skill, it is necessary to have a standard by which to judge performance. In the current study, general information about norms and standards provided by informants was augmented through analysis of actual knapping products. It was hypothesized that performance would vary with experience and that the adze heads produced by established craftsmen would reflect a higher level of skill than those produced by apprentices. In order to test this hypothesis, individual craftsmen were divided into two groups ("skilled" and "unskilled") according to social status (established versus apprentice). This simple division does not capture individual variation within groups, especially in terms of the developing skills of the apprentice craftsmen, but it does reflect large-scale patterns of difference.

Statistical comparison of the two groups revealed a clear pattern of differences between established and apprentice craftsmen, including significant differences in the size and shape of the adze heads and waste flakes they produced as well as in the organization of their operational sequences. One of the most robust and diagnostic differences was the greater mean size (length and weight) of adze heads produced by established craftsmen. This observation fits nicely with interview data indicating that larger adze heads are considered to be more difficult to produce and are more highly valued.

There is, however, one major exception to this pattern. In the field, it was noted that one established craftsman appeared to be performing at a lower level than his peers (i.e., making fewer, smaller, and less well-formed adze heads). Examination of the quantitative data confirmed this impression, revealing significant differences between the adze heads and flakes produced by this individual and those from the rest of the "skilled" sample. Although the pattern of differences described above is robust enough to be discerned whether or not this individual is included in the "skilled" sample, he is clearly an outlier from that group. In fact, he was found to display the same pattern of performance as the apprentice knappers and did not differ significantly from the "unskilled" sample in either adze head or flake metrics. The explanation for this interesting exception is unknown and may include loss of skill with advanced age, a lack of innate ability, and/or some unknown social dynamic. In light of this uncertainty and because actual performance was considered more directly relevant than social status to the questions being addressed, the individual in question was ultimately classified as "unskilled" in the analyses presented below.

As we have seen, adze production involves multiple stages and associated constellations. The information presented here will focus on final reduction from the rough-out to the finished form ready for grinding.

KIL-YA: PRODUCTS OF SKILL

In the Langda adze industry, the ultimate objective of stone knapping is to produce well-formed adze heads that are ready to be ground (to become *kil-ya-ba*) and then hafted with a minimum of effort. Not surprisingly, it is in the achievement of this central goal that some of the most striking differences between skilled and unskilled craftsmen emerge.

As part of the observation of the knapping process, core measurements were taken both before and after final reduction. This yielded a sample of 25 finished adze heads (prior to grinding), including 18 made by five skilled craftsmen and 7 made by five unskilled craftsmen. Because of the relatively small size of the sample, measurements from different adze heads made by the same individual were treated as independent data points. Use of only a single adze head per individual produces qualitatively similar results but neglects many of the available data. [See appendix B in the electronic edition of this issue on the journal's web page.] Use of mean values for individuals would eliminate the variance that is the object of study in the first place.

Seven linear dimensions, four angular dimensions, and weight were recorded for each core. Linear measures taken included the length along the midline of the long axis and both width and thickness at each of three points along this length: (1) at the shoulders of the bit, (2) in the middle at half the length, and (3) at the butt at nine-tenths the length. Angular measures were taken of the bit angle of the blade, the slope of left and right sides at half the length, and the point of the butt. Comparisons of absolute and relative (ratio) values between these groups were made using Pearson's two-tailed *t*-tests, while the relationships of variables within the groups were explored using simple linear regression.

The most striking differences between adze heads produced by the skilled and unskilled groups are the greater mean length and weight of the skilled pieces (table 1). Even from casual observation it is obvious that established experts routinely produce larger adze heads than apprentices (fig. 12). Whereas the longest adze head produced by the unskilled group measured 165 millimeters, roughly 80% of the adze heads produced by skilled craftsmen were greater than 170 millimeters in length.

Of course, apprentices are allowed to work only with relatively small rough-outs, usually of less than 200 millimeters in length. In contrast, skilled workers may start with rough-outs as long as 300 millimeters or more. Expert adze makers assert that the production of larger adzes is simply beyond the ability of apprentices, but it was impossible to test this directly because no instances of apprentices' attempting to work larger cores were permitted. Some indirect support for the assertion is provided by differences in shape between adze heads made by the skilled and the unskilled groups. Although the former are significantly longer, they are not thicker or wider. In fact, when width and thickness measures are expressed as proportions of length, their mean values are significantly less for skilled pieces at all measured points (fig. 13), despite the fact that there are no significant differences in the proportions of the rough-outs used by apprentices and experts.

The shape differences between adzes made by the skilled and the unskilled groups are not simply an allometric artifact of size. When width at midpoint is plotted against length (fig. 14), it is clear that, whereas skilled craftsmen are able to maintain a constant relationship between length and width across a large range of sizes, these dimensions are completely unrelated in pieces produced by the unskilled group.

These observations indicate that less developed knapping skills are reflected in an inability to control the proportions of the finished product even if it is small and that this problem arises mainly from difficulty in narrowing the piece. The inability of unskilled knappers to shape even small adze heads strongly supports the hypothesis that they would be unable to work larger pieces effectively.

Explanations for this difference in ability may be sought at different levels. For example, there is the global reduction strategy employed by less skilled workers, who direct little or no attention to flaking along the dorsal ridge of the piece. Differences in motor skill may also help to account for variable success in individual flake removals and in the ultimate achievement of knapping goals. Exploring the relative contribution of such inter-

TABLE 1
Absolute Metrics for kil-ya *Produced by Skilled and Unskilled Knappers*

Measure and Sample	*N*	Mean	Range	Standard Deviation	Significance of Difference between Means
Weight (g)					
Skilled	17	300	125–620	130	
Unskilled	7	203	146–240	35	0.010**
Length (mm)					
Skilled	18	201	136–271	40	
Unskilled	7	150	123–165	14	0.0005**
Width at head (mm)					
Skilled	18	43	34–52	5	
Unskilled	7	41	36–48	5	0.299
Width at half length (mm)					
Skilled	18	35	32–41	3	
Unskilled	7	38	31–41	4	0.124
Width at butt (mm)					
Skilled	18	21	19–28	3	
Unskilled	7	23	21–26	2	0.100*
Thickness at head (mm)					
Skilled	18	20	14–39	5	
Unskilled	7	19	17–22	2	0.589
Thickness at half length (mm)					
Skilled	18	28	20–36	5	
Unskilled	7	25	20–30	4	0.098*
Thickness at butt (mm)					
Skilled	18	15	8–22	3	
Unskilled	7	15	12–21	3	0.848

*Significant at 90% level.
**Significant at 95% level.

FIG. 12. *Finished adze heads produced by skilled* (three on left) *and unskilled* (three on right) *craftsmen. The pieces produced by the skilled group are not only longer and relatively narrower but also more regular in plan form.*

related factors is a major step in determining the nature of adze-making skill in Langda.

STRATEGIC SKILLS

At the highest level of organization, there are the overall strategies that guide reduction. Some aspects of strategy are embodied in general rules of thumb such as the need to shape the bit first or to work evenly along the edges of the piece. These general rules do not, however, encompass the complexity and variability of the strategic decisions that must be made when working idiosyncratic stone cores (Pelegrin 1993). In order to gain a more detailed appreciation of the strategic choices made by the knappers of Langda, we must carefully examine the actual patterns of technical performance through which these choices are enacted.

Video recordings were made of 18 individual sequences of reduction from rough-out to finished form. Of these, 12 were selected as being suitable for analysis (relatively free of interruptions, piece successfully worked to completion, work done by a single individual, etc.), resulting in a sample of 5 reduction sequences by four skilled knappers and 7 sequences by five unskilled knappers. The question of independence once again arises, but reduction of the sample to only one sequence per knapper does not meaningfully alter the results.

Each recording was carefully reviewed and scored for the occurrence, sequence, and location on the core of the five major technical operations employed by the Langda knappers: (1) *talena*, a forceful blow with a *ya-winwin* hammerstone, directed into the body of the core and intended to detach a flake; (2) *ungna-kiringna*, pounding of an intended platform with a small basalt block (*ungna*) to remove irregularities and projections; (3) *hook dongaboka*, light, tangential strokes with a *ya-winwin* hammerstone, used by experts to prepare platforms through microflaking; (4) *krikun*, rubbing of the *ya-winwin* hammerstone against the core to smooth the hammerstone's surface; and (5) *dung d'ona*, refitting of detached flakes and fragments onto the core (usually done for inspection only but occasionally used to complete the removal of snapped flakes using the proximal end as a punch). In order to score the location of an action, cores were divided into the five regions recognized by the knappers themselves (fig. 5), namely the bit (*si*), sides (*ting kwiribkun*, including left and right together), butt (*bumyok*, posterior fifth of the piece), and dorsal ridge (*amnyok*). Elapsed time was recorded at five-minute intervals with some deviations reflecting continuity or pace of work.

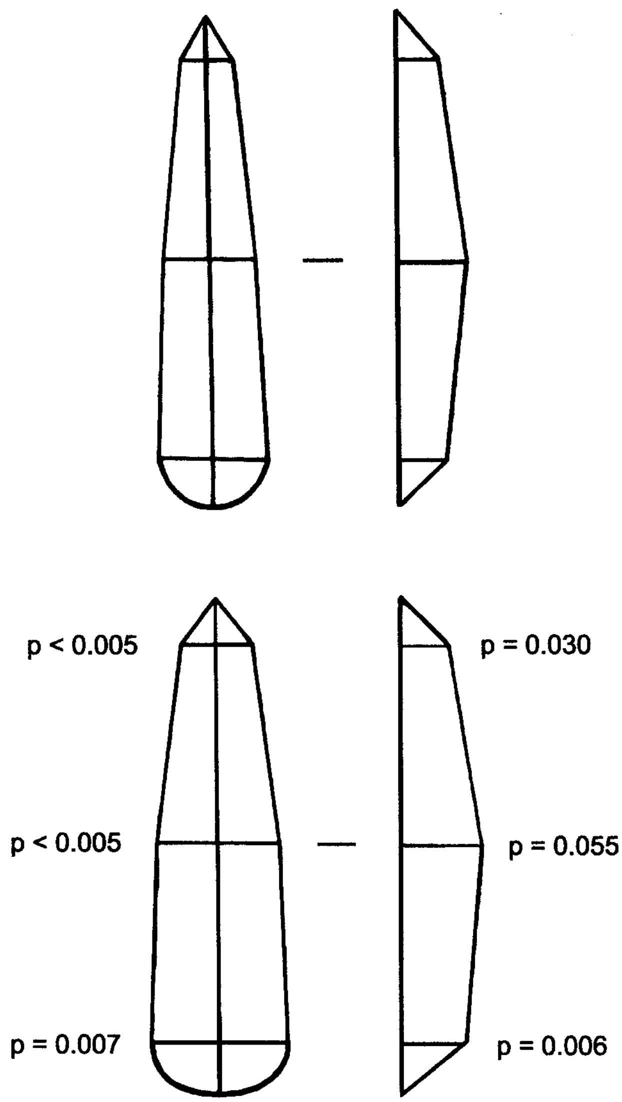

FIG. 13. *Relative proportions of adze heads* (scaled to length) *produced by skilled* (top) *and unskilled* (bottom) *craftsmen. The significance* (p) *of the difference in proportions for each measured dimension is indicated alongside the lower diagram.*

The data produced were once again divided into "skilled" and "unskilled" groups; trends and differences were explored using simple bivariate (two-tailed Pearson's) correlation and Student's *t*-tests. The significance of differences in the variability of data between the two groups was assessed using Levene's test for equality of variances.

Rules of thumb regarding the sequence in which different parts of the adze should be shaped are only weakly expressed in actual patterns of reduction activity. Among skilled knappers, the general rule that the bit should be shaped first is reflected by a significant but weak negative correlation between knapping time elapsed and the proportion of blows directed at the bit ($r = -0.401, p = 0.031$). Similarly, the mean percentage of blows directed by experts at the sides is significantly greater ($p = 0.049$) during the last quarter of the reduction sequence (53%) than during the first three (37%). The only such difference among unskilled knappers is an increase in the proportion of blows directed toward the butt during the final quarter of the reduction sequence ($p = 0.057$). In this case, the actual knapping practices of unskilled individuals are at odds with the expressed rule that the blade and butt should be finished before the middle section.

There is thus some evidence for differences in the temporal organization of knapping strategies in skilled as opposed to unskilled craftsmen. However, this evidence is relatively weak, and many potential comparisons not reported here do not show such patterning. It appears that, for the most part, decisions regarding which part of the core to work on at any particular time are characterized more by homogeneous variability than by adherence to any uniform sequence.

Strategic differences between skilled and unskilled craftsmen are more clearly visible in the global patterning of blows directed against different parts of the adze over the entire course of reduction. Most obvious is the almost complete lack of attention paid by apprentices to the dorsal ridge (fig. 15). The difference between experts and novices in the percentage of dorsal-ridge strikes is highly significant ($p < 0.005$), with skilled workers averaging 24% and unskilled workers a mere 2%. Conversely, unskilled workers directed an average of 66% of their blows to the sides of the cores while skilled workers averaged only 44% to this region ($p = 0.060$).

As may be seen in figure 15, the strategies pursued by unskilled knappers are far more variable than the relatively stable strategy of skilled knappers. This is further reflected in the higher standard deviations for unskilled workers in every region except the uniformly neglected dorsal ridge. The lesser variance of skilled data in each of these regions is significant at $p = 0.100$ or better. Although skilled workers do not work on the different parts of the core in an immutable sequence, they do make uniform decisions about how much overall attention to devote to each region. This is not the case for unskilled workers, whose global strategies show little if any consistent pattern.

These strategic differences are best understood as indicative of different levels of skill. Skill emerges from the dynamic coordination of perception and action with respect to organismal, environmental, and task-related constraints (Newell 1996). Skill learning can occur on different spatiotemporal scales and may thus be characterized as more or less "conceptual" in nature, despite the fact that it always concerns goal-oriented action. Skilled knappers in Langda learn to coordinate large-scale patterns of perception and action in their treatment of the various parts of the core. Overall strategic regularity emerges from knapping patterns that are necessarily variable on a smaller scale and reflects the perception of larger relationships in the emerging form of

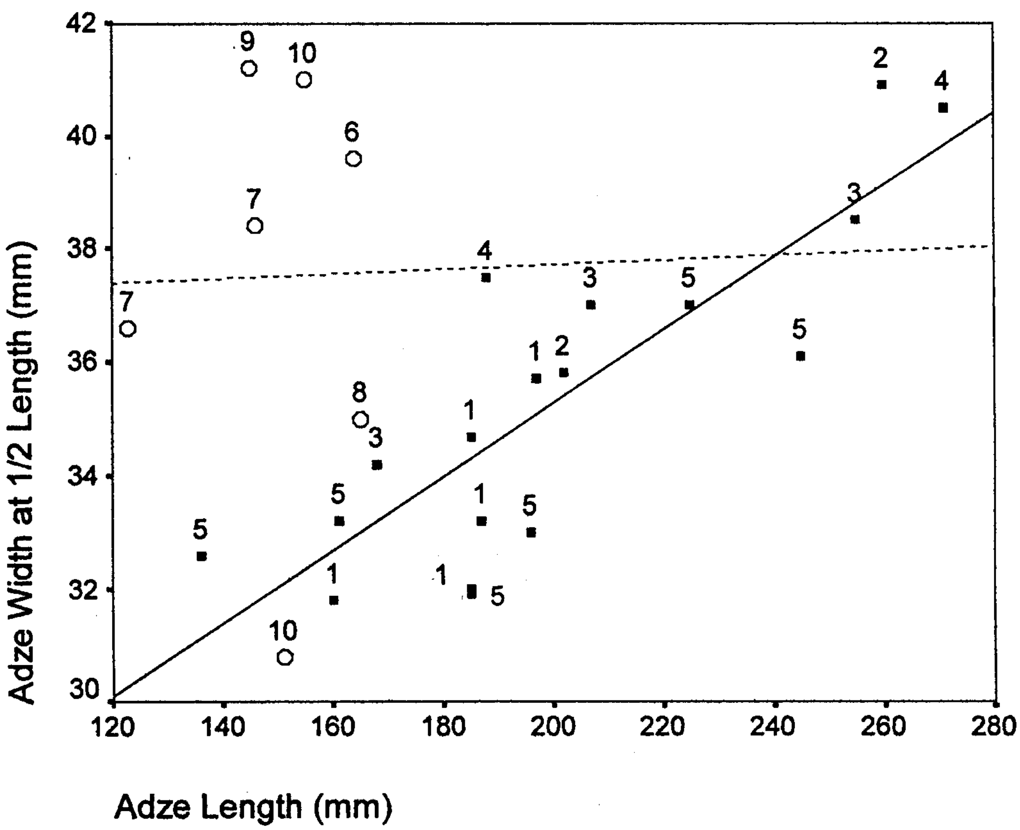

FIG. 14. *Length versus width for adzes produced by skilled* (solid line) *and unskilled* (broken line) *craftsmen. Numbers indicate the individual craftsmen responsible for each adze head.* R^2(*skilled*) = *0.7098,* (*unskilled*) = *0.0002.*

the adze. Unskilled knappers are still exploring these relationships and fail to exhibit such strategic regularity.

Experts display an understanding that, although embodied in practical action, may be considered conceptual in scope. Depending on the spatiotemporal level of description adopted (Keijzer 1999), an active knapper may be said to be either moving his arm, removing flakes, shaping the dorsal ridge, making an adze, or attempting to increase his wealth and prestige. In fact, he is doing all of these. Actions such as the pursuit of an overall knapping strategy take place toward the higher end of this scale and are more closely analogous to what are conventionally termed "cognitive" behaviors or skills. There is even evidence that such large- versus small-scale actions tend to involve different neuroanatomical substrates (Green 2001).

Obviously, these different levels of organization are intimately (though not simply nor linearly [Keijzer 1999]) related to each other. For example, the basic physical difficulty of striking flakes from the dorsal ridge of the core, which requires the use of large and even obtuse exterior platform angles, almost certainly plays a role in apprentices' neglect of this region. It may also be that the propensity of unskilled individuals to strike less invasive flakes (see below) makes it difficult for them to achieve a workable angle along the dorsal ridge.

PERCEPTUAL-MOTOR SKILLS

Because of the essential continuity between the cognitive and the perceptual-motor skills involved in adze production, it is neither possible nor desirable to dichotomize the two. It is, however, beneficial to differentiate skills along a continuum from small-scale perceptual-motor actions to large-scale cognitive/conceptual actions. To investigate the perceptual-motor end of this continuum, I collected and analyzed flake waste from novice and experienced craftsmen.

A 100% collection was made of the debitage produced during observed reduction sequences. Waste products from different individuals and from different cores worked by the same individual were collected, analyzed, and recorded separately. All pieces were counted, and those greater than 20 millimeters in maximum dimension were classified and analyzed. The sample presented here consists of all of the whole flakes from the final reduction (rough-out to finished adze head) of 14 cores. This includes 453 flakes from 8 cores made by the skilled

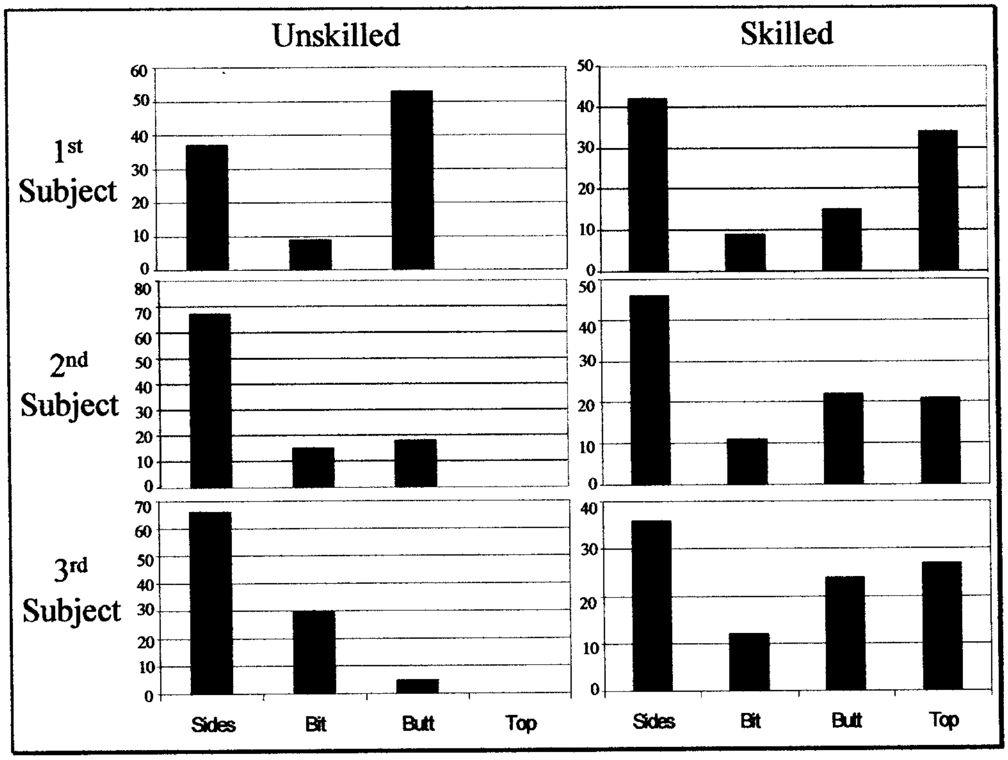

FIG. 15. *Percentage of total blows directed against various parts of the core during six individual reduction sequences by three unskilled and three skilled knappers.*

group and 189 flakes from 6 cores made by the unskilled group.

Numerous attributes were recorded for each whole flake. Ratios between overall flake dimensions (length, breadth, thickness) and between platform dimensions (breadth, depth) were also calculated in order to produce dimensionless shape variables. A principal-components analysis using Varimax rotation was conducted in order to identify the major dimensions of variability within the overall sample; component scores for the skilled and unskilled samples were then compared using Student's *t*-tests.

Principal-components analysis using 12 flake size and shape variables yielded five components accounting for 84% of the observed variance (table 2). On the basis of the factor loadings obtained, these components may be described as corresponding to (I) absolute size, (II) relative thickness, (III) relative elongation, (IV) platform shape (relative depth), and (V) platform angles. *T*-tests revealed significant differences in component scores between flakes made by skilled and unskilled groups on components I, II, III, and V. Inspection of the mean score values for each component in light of their factor loadings reveals the direction of these differences. For example, component V (platform angles) loads positively on internal angle and negatively on external angle, so that the lesser mean value of skilled flakes on this component indicates smaller internal angles and larger external angles (i.e., both are closer to 90°). Overall results indicate that the flakes made by the skilled group are absolutely larger, relatively thinner, and more elongated and have steeper platform angles than those made by the unskilled group. These interpretations may be corroborated in a more direct fashion through a careful inspection of pairwise comparisons between the two samples (table 3).

Multiple factors must be considered in order to understand the observed differences in flakes produced by skilled and unskilled craftsmen. To begin with, intentional production of larger, thinner, and longer flakes would be useful for the exercise and maintenance of control over core form. Longer flakes allow access to core areas farther from a working edge, while relatively thinner flakes allow even shaping of an edge without gouging.

Before accepting this intentional explanation, however, we need to consider the potential constraining effects of core size. Experts tend to work larger cores, and this might plausibly contribute to differences in flake size and shape. In fact, component I (flake size) is correlated with core length ($p = 0.004$), but this accounts for very little of the observed variation ($r^2 = 0.06$). The same is true of components II (thickness) and V (platform angles). Components III (elongation) and IV (platform shape) are not correlated with core length. Core size ex-

TABLE 2
Principal-Components of Variation in Flake Attributes

Variables	Components				
	I Absolute Size	II Relative Thickness	III Elongation	IV Platform Shape	V Platform Angles
Flake dimensions					
Length	0.766	−0.022	0.584	−0.038	−0.015
Breadth	0.909	0.013	−0.280	−0.038	−0.038
Thickness	0.706	−0.621	−0.020	−0.148	−0.018
Maximum	0.948	−0.020	0.114	−0.064	−0.029
Platform dimensions					
Breadth	0.663	−0.100	−0.350	0.114	0.104
Depth	0.526	−0.205	−0.177	−0.625	0.132
Exterior angle	0.030	−0.143	0.072	0.305	−0.804
Interior angle	0.038	−0.159	0.077	0.217	0.803
Flake shape					
Length/breadth	−0.146	−0.051	0.932	−0.017	0.025
Length/thickness	−0.134	0.788	0.534	0.110	−0.060
Breadth/thickness	0.020	0.927	−0.256	0.132	−0.036
Platform shape					
Breadth/depth	0.069	0.125	−0.092	0.888	0.020

erts a weak influence on some flake attributes but does not account for the overall pattern of differences between the flakes made by skilled and unskilled knappers.

Skilled knappers produce larger, flatter, and more elongated flakes with more oblique platform angles but without any significant difference in platform depth or thickness. According to the controlled fracture experiments of Dibble and Pelcin (1995), flake mass increases deterministically with platform thickness. Looking to the current data, we find that platform thickness is closely correlated with platform depth ($r^2 = 0.935$, $p < 0.005$) and that both are correlated with flake thickness ($r^2 = 0.350$, $p < 0.005$ and $r^2 = 0.332$, $p < 0.005$, respectively). The mechanical properties of the stone medium thus allow skilled knappers in Langda to produce longer and broader flakes without increasing thickness by choosing steeper exterior platform angles while holding platform depth constant.

This strategy imposes an added burden on the perceptual-motor skills needed for flaking. As observed by Dibble and Pelcin (1995:437–38), increased exterior platform angles allow the production of larger flakes but require greater control on the part of the knapper. More specifically, experts are faced with the need to increase both the magnitude and the accuracy of the striking momentum they employ. According to Fitts's (1954) law of psychomotor behavior, such an increase in striking momentum without a corresponding increase in target size produces a logarithmic increase in task difficulty. The flakes produced by skilled knappers in Langda thus provide evidence of increased task difficulty and of correspondingly greater perceptual-motor skill.

All other things being equal, the experts' greater perceptual-motor skill would allow for the production of relatively thinner flakes. However, all other things are not equal. Core morphology plays a large role in determining the shape of any particular flake that is detached. The experienced knappers of Langda are well aware of this and will make specific comments about phenomena such as the tendency of flakes to propagate along ridges on the core. It is quite likely (though difficult to test) that one of the major factors underlying the differences between the flakes (and finished adze heads) of skilled and unskilled knappers is the greater ability of experts to exploit and manipulate core morphology.

One important example is the blade-flakes (*utina*) (fig. 16) produced by experts while shaping the bit of the adze head. Even though these flakes are not significantly different from others in platform shape (breadth/depth) or exterior angle, they are roughly twice as elongated (flake length/ breadth = 2.0 compared with 0.9). This difference is achieved by manipulating core morphology in order to create long ridges running perpendicular to the bit, a technique that is broadly analogous to the preparation of a blade core (e.g., Whittaker 1994:119–21). The ridges produced serve to guide the propagation of flakes inward, preventing the lateral dissipation of force.

The diagnostic blade-flakes that are produced in this fashion are almost entirely absent from the debitage produced by the unskilled group. Although these blade-flakes are an extreme example, they do indicate that the selection of advantageous targets and the manipulation of core morphology are important components of the knapping skill demonstrated by experts. In one sense, such technical choices are made on a relatively conceptual level of organization, but they are also grounded in the perceptual-motor skills needed to realize concrete plans in a difficult stone medium.

Discussion

Adze making in Langda is a skilled technical activity that exists as one aspect of a broader socioeconomic

TABLE 3
Pair-wise Comparison of Attributes of Flakes Produced by Skilled and Unskilled Knappers

Attribute and Sample	*N*	Mean	Student's *t*-test *p*≤	Kolmogorov–Smirnov *p*≤	Mann–Whitney *p*≤
Length (mm)					
Skilled	153	30.2			
Unskilled	189	25.7	0.0005**	0.0005**	0.0005**
Breadth (mm)					
Skilled	453	33.7			
Unskilled	189	31.3	0.042**	0.146	0.025**
Thickness (mm)					
Skilled	453	4.9			
Unskilled	189	4.7	0.446	0.647	0.821
Maximum dimension (mm)					
Skilled	453	42.7			
Unskilled	189	37.8	0.0005**	0.0005**	0.0005**
Platform breadth (mm)					
Skilled	438	17.8			
Unskilled	186	15.5	0.004**	0.021**	0.002**
Platform depth (mm)					
Skilled	444	3.4			
Unskilled	188	3.4	0.964	0.614	0.592
Platform thickness (mm)					
Skilled	421	3.4			
Unskilled	186	3.2	0.292	0.573	0.661
Exterior platform angle (°)					
Skilled	422	82			
Unskilled	186	79	0.0005**	0.001**	0.001**
Interior platform angle (°)					
Skilled	422	100			
Unskilled	186	102	0.015**	0.001**	0.0005**
Length/breadth					
Skilled	453	1.0			
Unskilled	189	0.9	0.017**	0.130	0.278
Length/thickness					
Skilled	453	7.2			
Unskilled	189	6.3	0.001**	0.0005**	0.0005**
Breadth/thickness					
Skilled	453	7.8			
Unskilled	189	7.3	0.031**	0.010**	0.011**
Platform breadth/platform depth					
Skilled	438	8.2			
Unskilled	186	5.6	0.004**	0.017**	0.012**

**Significant at the 95% level.

whole. For this reason, adze-making skill may best be understood as a series of production constellations (Keller and Keller 1996) with diverse material, technical, economic, social, and symbolic dimensions. The example provided by Langda contributes to our understanding of the nature of modern human technology and, in so doing, helps to provide a foundation both for the interpretation of archaeological remains and for the reconstruction of human cognitive evolution.

IMPLICATIONS FOR THE ARCHAEOLOGY OF HUMAN ORIGINS

How may these findings regarding the nature of knapping skill in Langda be applied in evaluating the skill of prehistoric knappers? Obviously, the adze-making craft of Langda is not an exact analogue for any particular prehistoric industry or assemblage. The specific combination of production goals, techniques, and raw materials used in Langda are particular to one time and place. Despite this, the craft does display areas of overlap with a number of different prehistoric technologies (Toth, Clark, and Ligabue 1992).

In the most general terms, the adze industry of Langda provides an example of a skill-intensive flaked-stone technology designed to produce well-shaped and extensively worked large core forms (which in this case are subsequently ground). Archaeological examples falling within this very broad category include the later Acheulean handaxes and cleavers known from sites like Kalambo Falls, Zambia (Clark 1969, 1974), Bodo, Ethiopia (Schick and Clark 2000), Lion Spring, Jordan (Copeland 1991), St. Acheul, France (Howell 1966), and Boxgrove, England (Bergman and Roberts 1988), as well as Middle Stone Age core axes like those from the Central African "Lupemban" industry and Mesolithic and Neolithic

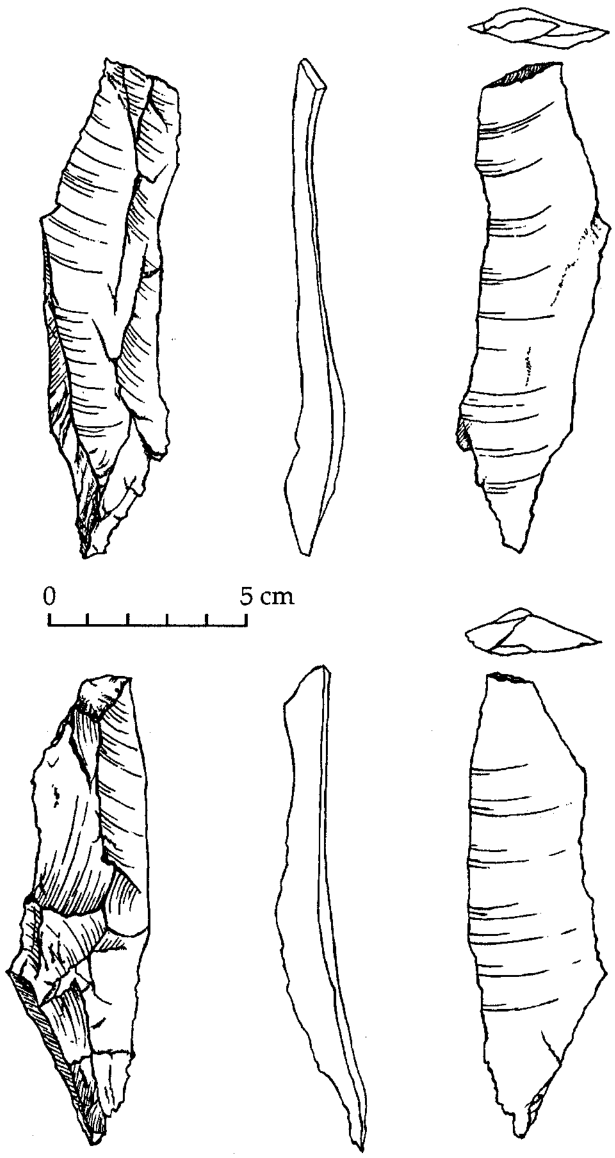

FIG. 16. *Two blade-flakes* (utina) *produced by a skilled knapper during adze-bit shaping.*

celts in which the basic form was achieved through knapping rather than grinding. Obviously, this list includes a huge amount of technological variation. Within the later Acheulean of Africa alone, a great diversity of raw-material types, sizes, and shapes were exploited using a range of techniques including the Kombewa, "proto-Levallois," and Talabalat/Tachengit methods (Clark 1994).

Despite this diversity, the unifying goal of producing regular core forms from inherently variable blanks or nodules does lead to certain general convergences. For example, it is a simple matter of geometry that thick, short flake removals will reduce only the immediate edge being worked, steepening edges and leaving the interior of a face untouched. Flakes must extend at least half the distance between working edges if uniform reduction of a face is desired (Callahan 1979), and this basic constraint applies whether the desired core form is a bifacial handaxe or a trihedral adze.

In discussing the manufacture of Acheulean-style bifaces, Schick (1994:584) lists some common errors made by beginning knappers, including (1) excessive narrowing of the piece without sufficient thinning, (2) failure to maintain the piece in a flat plane, (3) production of an uneven outline shape, and (4) failure to impose a bifacial edge on more obtuse areas of the blank. Although these observations are made with respect to a particular technology, they illustrate general difficulties in the production of any well-shaped core form. Difficulties with thinning, for example, are clearly related to the problem of striking sufficiently invasive flakes discussed above. Callahan (1979:35) describes thinning as a major stumbling block in the replication of both Acheulean- and Clovis-style bifaces.

Control over outline shape, though partly a product of higher-level planning, also relies upon the more basic ability to remove trimming flakes in such a way as to avoid gouging and overcorrection. This requires the production of relatively thin, spreading flakes such as the typical biface trimming flakes of the Acheulean (Schick 1994). In general, the striking of "large, relatively flat and thin flakes with small bulbs of percussion" is essential in order to produce large, extensively worked tools with straight edges (Whittaker 1994:185). This is because thicker flakes leave deeper flake scars with more pronounced negative bulbs of percussion and thus tend to produce wavy and irregular edges.

To the extent that such general constraints and requirements apply across diverse technologies, lessons learned from the knappers of Langda may be (cautiously) applied to the evaluation of archaeological material. In any such evaluation, careful analysis of the archaeological evidence itself, ideally including experimental replication with authentic raw materials, will be a prerequisite. Ethnographic analogy can provide important insights of a general nature, but application of these to any specific case is appropriate only with reference to idiosyncratic technological and environmental conditions.

Before invoking knapping skill as an explanation for the observed characteristics of stone artifacts, more parsimonious alternatives should always be considered. Even in the current ethnographic case, for example, some differences in flake size and shape were related to differences in core size. At the same time, when analysis and replication indicate that tool characteristics are underdetermined by constraint and least-effort explanations, we should not be afraid to credit their makers with the requisite level of knapping skill.

With this in mind, the following general guidelines for the evaluation of knapping skill in the archaeological record, *relative to local conditions*, may be proposed:

1. Insofar as variation in raw materials may be controlled, it requires more skill to detach increasingly large

but relatively thin flakes. One way to produce flakes that maximize area but minimize thickness is to exploit platform angles approaching 90°, a strategy which requires the combination of increased knapping force with preserved striking accuracy. Strategic skill in the manipulation of core morphology, although more difficult to quantify, also plays an important role in the production of appropriately shaped flakes (e.g., the *utina* of Langda). Removal of large relatively thin flakes is essential to the production of well-formed and extensively worked core forms and is reflected in the smooth linearity, as opposed to a sinuous "scalloping," of the edges produced.

2. Where artifact shape is not determined by raw-material form or reduction intensity, the consistent production of uniform shapes from nonuniform raw materials reflects the exercise of knapping skills. In Langda, for example, expert knappers display much less variability than novices in the relative proportions of the adzes they produce. Relative to the particular technology being considered, more highly standardized artifacts provide evidence of greater levels of skill.

3. Consideration of the evidence from Langda and elsewhere shows that certain production goals are particularly difficult to achieve. As a general rule, it is difficult to produce core forms that maximize one dimension relative to another. Thus, in the Langda material, skilled knappers may be distinguished by their ability to produce adzes that are greatly elongated relative to width and thickness. Similarly, skill in the manufacture of Acheulean-style bifaces is reflected in the ability to produce pieces that are broad but thin.

4. Finally, raw-material procurement in Langda is a highly demanding aspect of production involving quite a bit of expertise. Whenever possible, consideration of raw-material availability should be part of the interpretation of archaeological occurrences. In particular, we should ask how selective the toolmakers were and what problems they may have faced in locating, identifying, and exploiting desired materials.

As long as due attention is paid to local conditions and alternative explanations, it is possible to make sound inferences about the relative skill of prehistoric stone knappers. Such inferences are particularly valuable because the manifestation of skill is intimately related to a wide array of cognitive, social, and economic considerations. In Langda, we see an example of a sophisticated and skill-intensive lithic technology. Even in the structured and nurturing learning environment provided by the community of craftsmen, skill acquisition can take years of diligent effort. Learning and production are conditioned by linguistic terminology, social relations, symbolic meaning, and metaphor that situate technical performance in a humanly meaningful context. Particularly important are the dynamics of task definition and motivation and the way in which they shape task-related cognition.

Although the adze industry of Langda is just a single example, it does provide a useful source of questions to be asked about prehistoric chipped-stone technologies. For example, how much time and effort were required to develop the necessary knapping skills, and what might this have meant in social and economic terms? Similarly, what might the distribution and availability of raw materials have meant for relations within and between groups? Approaching the issue of cognition more directly, how were knapping tasks defined and motivated? The enormous potential role of social and symbolic meaning in the acquisition and expression of sophisticated knapping skills is underlined by the Langda example but remains to be demonstrated in other specific cases. Consideration of this issue opens further interesting questions regarding the hypothetical cognitive capacities/propensities that might support a comparable level of skill in the absence of a comparable social and symbolic scaffold.

IMPLICATIONS FOR HUMAN EVOLUTION

All of this is particularly interesting when considered in the broader context of human cognitive and brain evolution. The Langda example is valuable not as a direct analogue for premodern behavior but as a model for the exploration of general issues surrounding the relationship between cognition and lithic technology. Such exploration is an essential step toward the generation of productive hypotheses regarding the role of stone technology in human cognitive evolution.

Researchers interested in the relationship between prehistoric stone tools and cognition have often emphasized the imposition of arbitrary form (Holloway 1969) during tool making and the shared mental or procedural templates that this is thought to imply (Gowlett 1996). In the modern adze industry of Langda, shared ideas and sophisticated planning are essential aspects of production. The invariant proportions of adze heads produced by skilled knappers clearly reflect the imposition of an "appropriate" (Wynn 1995) form, while analysis of actual operational sequences illustrates the planning involved in the concrete realization of this form. Just as important, the impressive perceptual-motor skill displayed by expert knappers in Langda calls attention to this oft-neglected aspect of human mental uniqueness. It is appropriate to ask to what extent these characteristics, evident in at least one modern example, are present in particular prehistoric technologies.

Prehistoric tool-making skill must also be situated in its broader social context. As observed by Holloway (1981:288), stone tools represent "*clues* to the more complex social processes that were under direct selection pressures." Human technology is distinguished by its complex interdependence with social structure (K. Gibson 1993), an evolved condition that should figure prominently in any exploration of human uniqueness. Evidence of acquired skill is one of the more powerful clues to "complex social processes" that can be provided by the study of stone tools.

Research in Langda reveals that the acquisition of sophisticated knapping skills is far from trivial, even for motivated modern humans with an elaborate system of social support. To the extent that various premodern hominids might have possessed less elaborate mental abilities and/or social support, the acquisition of knapping skills would have been a proportionately greater challenge. Of course, Paleolithic stone technologies like the Oldowan and earlier Acheulean are notable for their simplicity and ease of manufacture. The refined later Acheulean core forms that emerge ca. 500,000 b.p., however, represent more demanding technologies that may be replicated by modern researchers only after lengthy practice (e.g., Callahan 1979:35). The presence of such well-developed skills in prehistory raises questions about socioeconomic context and attendant mental sophistication, even if the toolmakers were not fully modern *Homo sapiens*.

The advent or elaboration of mechanisms for the social facilitation of skill acquisition clearly must have represented a watershed in the course of hominid evolution, and it may well be that a good part of that which is unique about the human species relates to our reliance upon complex, socially facilitated skills. Kaplan et al. (2000) have constructed such an argument around the complexities of modern human hunting skills. To this may now be added the evidence presented here regarding the acquisition and performance of modern human stone-knapping skill.

Conclusion

Research in Langda has provided an example of a modern human lithic technology that is remarkable for its sophistication and complexity. The manufacture of adze heads by the craftsmen of Langda requires well-developed skills ranging from basic motor coordination and movement accuracy to higher-level strategic planning and conceptualization. Acquisition of these skills is a lengthy and labor-intensive process that is inextricably linked with the broader social and economic context in which adze manufacture takes place.

In Langda, the manufacture of adzes is a social phenomenon. Task definition and motivation are provided by participation in the community of craftsmen and by personal relationships with trading partners, resource owners, mythic figures, and the personified stones themselves. The community also acts as a social scaffold for the acquisition of skill by apprentices. Structuring rules and norms, as well as instruction and assistance, provide a framework for the arduous process of skill learning.

These findings suggest important questions to be asked about prehistoric stone technologies. Chief among these are questions regarding the time and effort required for skill acquisition and the potential social implications of these requirements. Attention is also called to the mental demands of raw-material procurement.

The broad theoretical issues raised by research in Langda underline the importance of identifying skilled performance in the archaeological record. Although this task is greatly complicated by raw-material variation and difficulties in divining the intent of prehistoric toolmakers, the analysis of lithic products from Langda has provided some useful insights. These include an appreciation of the relative difficulty of producing core forms that maximize one dimension relative to others and of striking large, thin flakes. The careful adaptation of such general principles to specific archaeological examples should provide a means to approach some of the broader questions raised in this study.

The observed complexities of adze production in Langda add to our understanding and appreciation of human uniqueness. The complex interdependence of social structure and technology and enhanced capacities for the social facilitation of skill acquisition in general are defining components of the human adaptation. Stone tools provide hard evidence of skilled performance that will be invaluable in determining when and how these capacities emerged.

Comments

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As Stout says, "traditional social contexts in which to study lithic technologies are very rare in the modern world." In fact, it is only in New Guinea and India that stone knapping is still performed on a sufficiently large scale for the systematic study of different levels of expertise and of the learning process. A group of French archeologists and motion researchers has conducted fieldwork in Khambhat (India) aimed at characterizing the skills involved in stone knapping (Roux and Pelegrin 1988–89, 1989; Roux, Bril, and Dietrich 1995; Bril, Roux, and Dietrich 2000). In Khambhat, stone knapping employs a different technique (indirect percussion) from the one described by Stout among the Langda, but the results of the two studies show remarkable convergence.

Both studies compare skilled and unskilled knappers on the basis of the finished products (in New Guinea adzes, in Khambhat beads) and the actions involved in their manufacture. Both in New Guinea and in India, the finished products distinguish the two groups; the less expert craftsmen produce shorter and smaller pieces overall. In terms of strategic skills, Langda unskilled craftsmen pay almost no attention to the dorsal ridge of the core, according to Stout because of the basic physical difficulty of striking proper invasive flakes. A similar technical situation in Khambhat leads to similar behavior on the part of nonexperts. The ridges of quadrangular rough-outs must be shaped to remove long flakes, and this shaping requires the production of transversal invasive flakes. Less skilled craftsmen pay no attention to this operation. This suggests that in both cases the less skilled lack the control of the elementary action (that is, positioning the stone and directing the blow) that is required for mastery of strategic skills.

Apprenticeship also shows strong similarities between Langda and Indian craftsmen. It is a progressive process: learners begin with small pieces and only gradually move on to work on larger ones. It can take ten years to develop the skill needed to produce the largest pieces, whether adzes or beads. This seems to be a general feature of expertise. Another example may be found in the work of Roux and Corbetta (1989, 1990), who carried out a field experiment with potters in India. Here again, full mastery of the wheel-throwing technique takes ten years to acquire. More generally, a period of ten years of apprenticeship seems to represent a rule of thumb in other categories of motor and/or cognitive activity (Erickson and Lehman 1996).

Stout refers to a perception-action perspective to explain the differences between skilled and unskilled craftsmen. He concludes from the characteristics of flakes and finished products that these differences probably reflect "the greater ability of experts to exploit and manipulate core morphology." From a perception-action perspective, the demonstration of such a proposition would require an analysis not only of the finished products and overall strategies but also of the elementary action. In the Khambhat study, recording of the hammer acceleration by means of an accelerometer showed that experts displayed a finer adaptation of the acceleration to the size of the flake. This result is consistent with a perspective that emphasizes the necessary fine-tuning of the perception-action cycle. We concluded in our 1995 paper that "what must be learned is not the movement per se, which is quite simple, but the optimal adaptation to the constraints of the environment" (here, the morphological and geometrical properties of the stone and the weight, dimensions, and material of the hammer).

Stout raises the question of the relevance of the Langda case to the study of prehistoric knapping skills. However, uncovering pieces of the puzzle will require the consideration and comparison of existing ethno-archeological and experimental studies. Only in this way will it be possible to highlight the invariant underlying mechanisms at work in complex situated action in general and knapping in particular.

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Stout's work in an Irian Jayan village provides a great deal of information on the technical competence developed by artisans who make stone adzes. It shows that this competence is not simply a matter of motor and cognitive conditions but also depends heavily on the economic and social context, from the selection of the raw material to the hafting of the shaped and polished adze head. However, the morphometric study of these adze heads, interesting as it is, is somewhat disappointing in that the results obtained only confirm what intuition has already suggested: the dimensions of the adze heads, their proportions, their regularities, their sophistication are associated with the degree of skill of the artisan, the most accomplished adze heads being the work of the experts as opposed to the apprentices. The requirements for developing these abilities are many, and I will confine myself here to those that may have important archaeological implications.

The period of apprenticeship required to acquire these stone-working skills is very long (minimum five years), and the richness of the linguistic and technical exchanges between the skilled and the unskilled (discussion, observation, demonstration, and even direct assistance) is remarkable. Talking about actions is, however, far from universal. Cases of apprenticeship by imitation alone are legion, judging from the ethnographic evidence, and do not affect the richness of the technical vocabulary, especially in oral-tradition societies: vocabulary can be rich and precise without being employed in apprenticeship as such. It serves less to teach than to comment, on occasion, on what is being taught by imitation.

The archaeological implications suggested by Stout are interesting. He suggests that the production of bifaces implies the possession of the social and mental structures necessary for apprenticeship and the production of such tools since the terminal Acheulean (500,000 years ago). If one agrees with him that it is the interaction among tool kit, language, and society that would have produced the skills necessary for the production of such stone adzes, this would mean that the acquisition of language took place very much earlier than anthropologists have supposed—as early as the first bifaces. This possibility can be considered, but two objections to it can be raised. First, we have seen that the transmission of knowledge does not require language. Furthermore, a long period of apprenticeship for the acquisition of technical skill is not unique to humans. In groups of chimpanzees that crack nuts with hammer and anvil, young chimpanzees spend several years learning how to do it. The kind of apprenticeship is of course not the same (the mother chimpanzee rarely guides her infant and has no recourse to any verbal explication), and the motor problems involved are different, but the fact remains that animal socialization suffices to create the conditions for a long apprenticeship. We must therefore be cautious with regard to the kind of socialization that the production of bifaces implies for the Acheuleans.

Stout also suggests a new way of approaching the question of the origin of flint knapping and of hominization in his attempt to determine at what point in evolution the motor, cognitive, social, and economic conditions for the emergence of stone-working skills came together. Although his argument is appealing, it is preliminary and raises a number of questions. I look forward to learning how Stout envisages testing his model with regard to the first hominid stone workers and their skills.

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The analysis of Langda technology presented by Stout forms a very valuable case study, especially in its tracing of social context and careful documentation of technical features and their significance at the individual level. Each such study is precious. Those available already show great variety in the factors interacting to shape technological production, as Stout notes—from the entirely practical approach of the Galla, whose scrapers must be shaped to fit their wooden handles (Gallaher 1977), to the example given by Paton (1994) for northern Australia, where the entire purpose of leilira blade production appears to be symbolic and, presumably, functional constraints would no longer apply.

As Stout observes, it is therefore difficult to triangulate from modern evidence to premodern humans, but in comparisons there is some scope to consider the social embeddedness of chimpanzee technology (McGrew 1992) and also to analyse consistencies and inconsistencies in the production of ancient assemblages. As the tree of hominid origins becomes bushier, it becomes a question of choice whether our major purpose is to clarify the distinctiveness of modern humanity or to make some effort to map behavior onto the various past hominid representatives.

Stout clearly traces the range of factors contributing to the final form of a tool, giving an explanation of size variation that may be specific to the Langda and perhaps related peoples. Size variation has been explored for the Acheulean, but with little explanation for its social or functional context. The various factors of variation make the word "template," which many of us use, seem too hard or immutable. One can attempt alternatives such as "schema" or "instruction set," but the point emerges that we have very little knowledge of *how much* factors such as raw material, functional need, or the standing of the particular knapper affect the form of the output (in a way which might even vary from day to day). Even so we can see from the Acheulean—where, paradoxically, we have larger comparative datasets than for the present, though difficulty in unravelling the message—fairly regular length variation in bifaces from about 8 to 25 cm. Why does this recur over large areas and through great depths of time? I have always been struck that one sees this range even if one finds a only dozen bifaces in a landscape. Studies such as Stout's provide some insights into possibilities and suggest approaches that will allow us to aim to see, say, Acheulean assemblages as the products of communities of individuals and attempt to disentangle some of the factors bearing upon them.

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Stout usefully applies the Vygotskian notion of the thought/action dialectic in his attempt "to develop productive hypotheses about the psychological implications of prehistoric stone tools." But to treat the conceptual facet of this dynamic interrelationship simply as "thinking" fails to take advantage of the information that his otherwise insightful description provides. He presents evidence for a considerable range of cognitive processes in the production of the stone adzes in question.

Reflection, in the form of recalling past actions and considering options for future operations, takes place during both periods of active knapping and intervals of inactivity. Identification of various stages in the production process and construction of a shared terminology are indications of reflection by individuals and collective communication among the adze makers. Reflection on the success or failure of previous knapping episodes also guides the master stone worker in his selection and allocation of boulders for flaking.

Integration of diverse technological and social information takes place throughout the manufacturing process as personal and group relations, social norms, and mythic significance influence the attitudes and procedures employed. The scaffolding provided by the community of practice allows the construction of expertise by the apprentices and provides resources for the more adept when problematic conditions arise. The situated nature of the activity adds other practitioners to the ideas, tools, and materials that make up the production constellations employed.

Monitoring the progress of each piece requires constant comparison of mental images of the goal form, as well as appropriate intermediate shapes, with the actual state of the work piece. The fact that the products of experts differ in their proportions from those of the apprentices is an indication of the critical role of mental imagery in guiding motor behavior. Skill is grounded as much in sophisticated imagery as in manual dexterity, and the complexity of its construction contributes to the length of the apprenticeship that novices serve.

Planning takes place before the desired sequence of core reduction steps is initiated and continues during the operation. The emergent qualities of the process are revealed as each flake removal is evaluated and subsequent actions are considered. Failure of a planned removal results in the application of corrective measures derived from a repertoire of solutions based on individual experience and a shared stock of knowledge.

Understanding of ethnographic information or the remains of a prehistoric atelier can be enhanced by considering cognition as a set of processes rather than a monolithic unit.

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Any ethnographic description of stone knapping has intrinsic value, if for no other purpose than to check understandings derived from studies of nontraditional stone knapping. However, as Stout illustrates, ethnographic studies can also supply an account of the social context of stone knapping. Such accounts are few and therefore very valuable both for our understanding of technical activity in general and for the archaeology of human evolution.

My reaction to Stout's analysis is that it is overly cautious and conservative. Stout casts his theoretical net very widely, invoking the ideas of Vygotsky, Gibson, Ingold, Keller and Keller, and others. Instead of distilling these ideas into a single coherent account of technical action and cognition, he brings them to bear in a piecemeal fashion. As a consequence, it is difficult to appreciate how his account of Langda stone knapping enriches our understanding of stone knapping and technical action in general. This is, of course, the point. What can Stout now tell us about the cognitive context of stone knapping (and technique in general) that we did not know before? Simply referring to the "zone of proximal development" or "constellations of knowledge" does not quite do this. It is perhaps too much to expect him to construct a new grand theory, but even tentative attempts to formulate a single and consistent account of analytical concepts might have yielded new insights.

Stout is a bit bolder in his discussion of the implications for archaeology and human evolution. He proposes four guidelines for the assessment of knapping skill, and while these may strike some as obvious they acquire analytical value precisely because they derive from the ethnographic evidence (as opposed to the musings of the researcher or even studies of replication). What I would like to have seen is a bit more venturesome approach to the archaeological record itself. Stout suggests, for example, that the advent of "social facilitation of skill acquisition" represented an evolutionary watershed. When does he think this occurred? He implies that he favors a Late-Acheulean time frame (but perhaps my bias colors my reading). This would be a very important contribution to the archaeology of human evolution, which is Stout's stated ultimate goal, and I wish he had devoted more than a few sentences to the hypothesis.

My final point is based on an interpretation of the text that Stout perhaps did not intend, but as it bears on an important methodological issue it is worth airing. He suggests at the beginning of his text that "our interpretation of the lithic evidence must ultimately rely upon models developed from actualistic research." If we take this to mean that our understanding of the past is dependent on our understanding of the present, this statement provokes no quarrel. However, if it means that understanding of prehistoric stone knappers can only derive from actualistic studies of modern stone knapping or even that such studies must be granted priority, then I must disagree. It seems to me that all studies of skilled activity can provide potential analogues and that more general accounts of human and nonhuman cognition can provide important insights (as Stout himself has done in citing Vygotsky, Gibson, etc., none of whom knew a thing about stone knapping).

Reply

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I thank the commentators for the time and effort that they have invested in responding to this article. Space is a real constraint when dealing with a subject that touches on such a diverse body of method, theory, and evidence, and I am grateful for the opportunity to elaborate on particular points that the commentators have found interesting and/or troublesome.

Both Wynn and de Beaune consider the analysis I have presented somewhat disappointing, although for different reasons. For example, whereas de Beaune regrets that the analysis of artifacts "only confirm[s] what intuition has already suggested," Wynn points out that these results have value "precisely because they derive from the ethnographic evidence" rather than from "the musings of the researcher." Here I agree with Wynn. In fact, the primary goal of my research in Langda was to contribute to a more methodical and empirical approach to the subject of stone tools and cognition. Perhaps this is why, despite our points of agreement, Wynn considers my analysis overly conservative.

It is difficult to respond to Wynn's general theoretical criticisms without knowing what specific deficiencies he has identified, so I will settle for simply attempting to clarify my perspective. Much previous research on the subject of stone tools and cognition has been guided by a theoretical perspective that I would characterize as computational and essentialist. Cognition is viewed as an abstract system of formal computations carried out in the brain, with sensation and action being treated as little more than peripheral input/output channels. The psychological significance of stone tools is thus to be understood in terms of essential cognitive operations such as "hierarchical combination" (Greenfield 1991, Matsuzawa 1996) or "spatio-temporal substitution" (Wynn 1989) rather than in terms of overtly variable tool behaviors. For example, such apparently dissimilar behaviors as bifacial Oldowan flaking and the stripping of sedge stems by chimpanzees might be seen as essentially equivalent examples of an underlying "property of boundary" (Wynn and McGrew 1989).

This approach produces important insights on one level but could benefit from greater attention to the concrete details of performance. To this end, I follow Roux, Bril, and Dietrich (1995) in adopting a perception-action approach to stone knapping. This is not the appropriate place to review the substantial body of theory and research in dynamic systems and ecological psychology that contributes to the perception-action approach (see Thelen and Smith 1994, Reed and Bril 1996, Smitsman 1997, van Gelder 1998, Lockman 2000), but the basic argument is that skilled behaviors such as stone knapping emerge through the effortful coordination of perception and action rather than simply devolving from an abstract internal system of formal cognitive operations.

Bril and Roux have provided a useful summary of research among the stone bead knappers of Khambhat, India, that, in conjunction with my own work in Langda, highlights the fundamental role of perceptual-motor coordination in the emergence of knapping skill. In both cases, optimization of the motor synergies involved in effective flake removal provides the necessary means for the realization and stabilization of larger-scale knapping patterns (strategies). Less skilled craftsmen "know" about the operations needed to produce high-quality beads or adze heads but do not really comprehend them in the same experiential way as do more skilled knappers. For modern humans at least, it is much more difficult and time-consuming to acquire knapping skill than it is to develop a theoretical knowledge of the appropriate stages of reduction.

For this reason, consideration of the context and dynamics of knapping skill acquisition should figure prominently in psychological interpretations of stone tools. As Wynn points out, there is nothing new in the concepts of situated learning and distributed cognition that I have employed in explicating the Langda example. Wynn himself (1995) has drawn on similar ideas, and Tomasello (1999) has written at length about the "cultural origins of human cognition." The value of my case study in Langda is in providing a concrete example of the relevance of a cultural psychological (Bruner 1990) perspective to stone knapping. Of central importance is the observation that, although the behavioral experimentation needed to achieve knapping skill is an individual activity, it is motivated and enabled by an elaborate system of cultural meanings and social relations.

In Langda this system includes linguistic communication, but this need not have been the case with premodern technologies. I do not agree with de Beaune that my argument implies that the acquisition of language took place "as early as the first bifaces." As an anonymous reviewer of my original manuscript pointed out, Langda provides a prime example of the ostensive use of language "as a means of drawing listeners' attention into the world." This can also be achieved by nonlinguistic means. Donald (1991), for example, provides a speculative but intriguing account of what a prelinguistic, *mimetic* culture might have looked like.

The important point is not the necessity of language but the cultural nature of technical learning and practice. Although de Beaune contends that "cases of apprenticeship by imitation alone are legion" and that "apprenticeship for the acquisition of technical skill is not unique to humans," I would favor a more restricted use of the term "apprenticeship." For humans, apprenticeship implies participation in a structured and meaningful community of practice (Lave and Wenger 1991) that supports and motivates learning. Such communities grow out of routinely *intersubjective* (Quine 1960) social relations in which the understanding of others as intentional agents creates a medium for shared meaning, attention, and action, including true pedagogy.

In contrast, de Beaune notes in her example of chimpanzee nut-cracking that "the mother rarely guides her infant" (see also Inoue-Nakamura and Matsuzawa 1997). She speaks of teaching "by imitation," and while it may seem a quibble to point out that imitation is a means of learning rather than of teaching (the pedagogical counterpart would be demonstration), such distinctions with respect to intentionality are actually pivotal. Ape societies do provide a certain degree of scaffolding for skill acquisition, but I would contend that this scaffolding differs in critical ways from human apprenticeship, especially with respect to the prevalence of shared meanings. Over the course of human evolution, a distinctive, cultural mode of skill acquisition has emerged, and I am inclined to follow Tomasello (1999) in suggesting that it has its foundations in the saturation of everyday social interactions with intersubjective awareness.

For this reason, I feel that a focused and empirical program of research into the archaeological evidence of hominid knapping skill has much to contribute to the study of human cognitive evolution. It would appear that Bril, Roux, and Gowlett share this feeling. In fact, Bril and Roux take me to task for failing to provide a kinematic analysis of the elementary knapping action. I have argued that the artifact attributes I report do provide indirect evidence of the elementary action (evidence that would also be observable in the archaeological record), but I would certainly like to expand my research in this direction in the future.

De Beaune is interested to know how I envisage testing my ideas regarding skill and social facilitation in early hominid stone knappers. Although these ideas represent more of a research orientation than a set of testable hypotheses, I would advocate focused archaeological case studies conducted in conjunction with experimental investigations of knapping skill acquisition. I agree with Gowlett's comments regarding the importance of variation in lithic technologies and feel that given the current state of our knowledge we are more in need of specific examples than of sweeping syntheses.

Wynn is disappointed that I have not been more venturesome in my interpretation of the archaeological record, but I would contend that any substantive new interpretations will require further primary research. I have ventured to note the general sophistication of later Acheulean knapping and to argue that such "well-developed skills" raise questions about "socioeconomic context and attendant mental sophistication." However, answering such questions will necessarily be an exercise in specifics. A perception-action perspective demands that the psychological interpretation of stone tools be firmly rooted in the details of knapping behavior, and I would reemphasize that the detailed evaluation of knapping skill can occur only with respect to specific local conditions. Given the analytic value of specificity, I would argue, contra Wynn, that research on stone knapping per se should indeed be a priority for cognitive archaeologists, although I agree that studies of "any skilled activity" are valuable.

I am particularly grateful to Keller for discussing the issue of diversity in knapping-related cognitive processes, an important (and extensive) subject that I have largely glossed over in this article. Keller speaks of three kinds of cognitive activity: reflection, mental imagery, and planning. With "reflection" he appears to be highlighting the same distinction between "doing" and "thinking about doing" that I have picked up from the work of Thelen and Smith (1994). Although I would stress that reflection and performance are both kinds of action, they generally occur on different spatio-temporal scales and probably involve different (overlapping?) neural substrates and dynamics (cf. Green 2001).

Although Keller's comments reveal the value of Langda as an example of knapping-related cognitive processes, controlled experimentation will be important in further dissecting these processes. For example, Keller maintains that "skill is grounded as much in sophisticated imagery as in manual dexterity." Preliminary functional brain-imaging research (Stout et al. 2000) with Oldowan-style knapping, however, shows that brain regions classically associated with mental imagery (Kosslyn, Ganis, and Thompson 2001) are not heavily recruited during this activity. Such experimental approaches will represent an important supplement to introspection in assessing the role of cognitive processes such as "imagery" and "planning" in specific knapping techniques.

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