The design space of stone flaking: implications for cognitive evolution

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The design space of stone flaking: implications for cognitive evolution

Mark W. Moore

Abstract

Stone tools emerged at least 2.5 mya in Africa and were manufactured continuously by early Homo species through the emergence of cognitively modern Homo sapiens. Aspects of hominin cognitive evolution, reflected in hominin intentions, may therefore be preserved in this durable aspect of the archaeological record. Stoneworking design space is cellular in structure and two levels of hominin intentions are apparent in modifying stone: the intention to remove a single flake and the higher-order intentions reflected in the ways that flakes are combined to produce effects. Archaeologists have traditionally interpreted early hominin intentions using the higher-order skills and experiences of modern knappers as analogues, an approach that is epistemologically flawed. Further, the tightly constrained structure of design space could have led early hominins inadvertently to produce what appear to be highly-designed tools or tool attributes in the absence of an intention to do so. Controlled experimental research is necessary to provide an empirical baseline for identifying higher-order intentions in the archaeological record.

Keywords

Stone flaking; stone artifacts; handaxe; Levallois method; hominin cognition; cognitive evolution.

Introduction

Stone-flaking to produce sharp-edged tools was exclusively a hominin activity that emerged in Africa at least 2.5 mya (Ambrose 2001). The non-intuitive and highly technical aspects of stone flaking – combined with the ubiquity and duration of byproducts in the archaeological record – make stone tools ideal for exploring aspects of hominin cognitive evolution (Nowell and Davidson 2010; Roux and Bril 2005; Wynn 2002). The process of stone flaking is exceptional because, unlike most other technologies, it involves reducing a mass rather than adding to it. The size of a stone becomes irretrievably smaller and its shape changes with each flake removed. Further, the success of a stoneworking blow is
conditioned by the physics that control fracture in brittle solids. These variables tightly constrain the design space of stone-tool manufacture.

Laboratory experiments are designed to explore fracture mechanics and how changes in input conditions correlate with changes in flake and core morphology (e.g. Dibble and Whittaker 1981; Pelcin 1997; Rezek et al. 2011). Modern stone knappers have a practical understanding of fracture mechanics and employ their experience to produce the effects they wish to achieve (Crabtree 1966; Patten 1999; Whittaker 1994, 2004). Archaeologists use modern knappers’ experience as a type of ‘middle range theory’ to gain insights into the ways that stone tools were made in the past.

This paper explores stoneworking at its most basic, showing how aspects of stoneworking design space are manipulated by modern knappers to produce simple features of tool morphology. The cellular structure of stoneworking is first discussed and a model is proposed for how stoneworking cells, or ‘flake units’, are combined to produce tools. Several ‘good tricks’ applied by modern knappers are described. The implications of the cellular model and ‘good tricks’ are then considered in light of hominin cognition. It is concluded that archaeologists presently lack a reliable empirical baseline for identifying higher-order intentions in the archaeological record. This weakness goes to the heart of our understanding of early stone tool-making and cognitive evolution.

The cellular structure of stoneworking

The design space of stoneworking is composed of the leeway available for stoneworkers to successfully articulate motor actions (‘gestures’) with the physics of stone fracture. Certain stoneworking gestures are irreducible in the sense that they must be done in combination or controlled stone flaking will not occur (Moore 2007, 2010). To produce a flake successfully, a stoneworker must be able to identify a geometrical configuration on the stone core composed of a platform surface on one face and a lump of mass on an adjacent face. The two faces must be oriented at an acute angle to one another. The stoneworker acts on this identification by rotating, turning and tilting the core to position the platform for striking. These gestures, usually conducted by the non-dominant hand, must be coordinated with the hammer stone swung by the dominant hand. Misidentification and/or poorly performed gestures result in stoneworking failure.

The design space of stone flaking is cellular in structure. A single ‘cell’ consists of the actions described above, organized to remove a flake. Stoneworking is an exceptional technological activity because the flake and flake scar are empirical records of a stone-flaking cell. A cell is called a ‘flake unit’ (Moore 2007, 2010).

In the ‘basic unit’ of stoneworking, gestures are organized to remove one objective flake. A ‘complex unit’ involves applying one set of basic flake units to remove anticipatory flakes to create a platform for the blow that removes the objective flake. This is expressed empirically by a flake with a multi-faceted platform, and anticipatory/objective scars can often be identified on cores. An ‘elaborated unit’ involves a separate set of gestures to abrade a platform created by anticipatory flaking; this is identifiable empirically by an abraded platform on the flake (Moore 2010).
The application of a flake unit (no matter how internally complex) can be visualized as a simple two-step algorithm:

identify high mass → apply the flake unit.

The simplest way of combining flake units is to link them in a chain, like this:

(identify high mass → apply the flake unit) → (identify high mass → apply the flake unit) → (identify high mass → apply the flake unit). . . etc.

The knapping process begins anew in each application of the algorithm and the ‘identify high mass’ element drives the progressive reduction of the stone. The arrangement of high mass changes with each flake removal: removing one area of high mass ‘deflects’ new areas of high mass along the lateral and distal margins of the flake scar. The flake scar itself is a concavity on the face of the core. Thus the reapplication of a flake unit is always to a novel situation, one that is conditioned by the way prior flake removals intersect.

A stoneworker can predict the ways that the removal of a flake reconfigures the locations and shapes of high mass. A ‘reduction sequence’ describes the way that stoneworkers combined flake units to achieve effects. Flake units can be arranged in chain-like series, much as bricks are placed side-by-side to construct a footpath. This is stoneworking at its most simple. In contrast, a stoneworker can achieve complex effects by acting in relation to predictions made about mass reconfiguration. Mass is intentionally manipulated across multiple flake removals to achieve specific effects on a core itself or the flakes struck from it. This reflects hierarchically organized, ‘higher order’ intentions because future results are contingent on past actions; flake units are ‘stacked’, much like bricks are hierarchically combined to produce walls (see Moore 2007). Hierarchical construction is a hallmark of behaviorally modern *Homo sapiens* (Gibson 1990; Greenfield 1991). Archaeologists often describe complex reduction sequences in relation to progressive stages of core manipulation; this is a schematic way of portraying the sorts of predictions made by the stoneworker.

**Seven ‘good tricks’ for reducing stones**

The experiences of modern experimental knappers demonstrate how the restrictions of knapping design space caused past stoneworkers to repeatedly discover similar approaches. In reduction sequences that reflect higher-order intentions, ‘good tricks’ like these are employed strategically to achieve various effects. Seven good tricks are briefly described here to illustrate the flavor of stone-tool design.

*Straight edges*

The production of many types of stone tools relies on the ability to create a straight core edge. Two design space phenomena are exploited to do this. First, the ventral surface of a flake is convex and its corresponding scar is concave. When a concave flake scar is
introduced on a convex core edge, the edge becomes relatively straight (Fig. 1). Second, the ‘wings’ of the concavity created on the core edge are naturally positioned roughly in line with the high mass zones deflected to either edge of the flake’s scar – an ideal platform configuration for removing them. Striking flakes from those platforms removes the wings and this, combined with the concavity effect, is how a stoneworker can impose a straight knapped edge.

Core symmetry

Because feather-terminated flakes are thicker at the proximal (bulbar) ends, flaking from one core edge inevitably heightens mass near the opposite edge. When this high mass is targeted and another straight edge created, plan symmetry is imposed on the core (Fig. 2).

Core elongation

A part of the edge of a core is removed with the flake and, as zones of high mass are removed from either edge of a core and straight edges imposed, the core becomes progressively elongated (Fig. 2). Callahan (1979: 38) suggests that the highest skill level in biface manufacture is demonstrated when a knapper progressively removes mass from both core edges while simultaneously controlling edge attrition and edge straightness and therefore core symmetry.

Mass enhancement

Striking feather-terminated flakes from opposite edges of a core will enhance the mass along the core face’s midline (again because flakes tend to be thicker at the proximal ends). This mass might be strategically reduced or displaced through the application of complex or elaborated flake units applied at the core edges (Callahan 1979; Patten 1999; Waldorf 1993; Whittaker 1994), but might also be targeted by one or more flakes oriented from the end of the core face, called ‘end thinning’ (after Callahan 1979) (Fig. 3). Some technologies involve the deliberate enhancement of the midline mass to manipulate the shape of the flake that removes it. The target might be the flake itself (e.g. Pelegrin 2009) or the scar it produced (e.g. Bradley 1993; Crabtree 1966).

Figure 1 Schematic model (platform view) showing how a rounded core edge (A) becomes straightened (B) by reduction. Each flake removes part of the core’s platform edge, and flakes 2–4 were struck down zones of high mass created by preceding removals. When concave flake scars are introduced on a convex core edge, the edge becomes relatively straight.
Bifacial edges

A conchoidal flake’s interior platform angle is obtuse and the corresponding platform angle on the core is acute (Fig. 4). The acute edge can be flaked to either core face (Fig. 5). This naturally reproduces and enhances exploitable core platform angles (cf. Shipton et al. 2009: fig. 4) (Fig. 6) and, along with asymmetrical reduction, is a key design space phenomenon that facilitates complex and elaborated flake units. When zones of high mass are removed to either face from the acute-angled edge, a bifacially flaked core is created.

Figure 2 Schematic model showing the creation of a symmetrical, elongated core. A flake is struck from a natural high mass configuration on a circular stone, laterally offsetting the zones of high mass (A). Next, the offset zones of high mass on either side of the first flake scar are removed (B). This raises the mass between the two flake scars, which is then removed (C). Flakes are relatively thick at the proximal ends, so flaking on the core’s left edge offsets mass towards the right edge. This is removed by a similar series of flakes from the right edge (D).

Figure 3 Schematic model showing the process of core end-thinning. Mass is targeted first from one edge (A). This enhances the mass on the opposite edge, which is removed (B). Reduction from opposite core edges concentrates a mass zone on the center of the core face, which is removed from the end of the core (C).
Asymmetrical reduction

Similar-sized flakes can be struck from both faces of a stone with a symmetrical cross-section because the exploitable portions of adjoining core faces are roughly the same size.

Figure 4 Schematic core and flake cross-section showing the relationship between a flake’s exterior and interior platform angles. Laws of fracture mechanics dictate that the interior platform angle (2) is obtuse on conchoidally initiated flakes. Thus removing a flake from an acute-angled platform (1) reproduces an acute-angled platform on the core face (3).

Figure 5 Schematic core and flake cross-section showing how an acute platform angle on a core can be flaked to either face. Striking both flakes creates a bifacial edge.

Figure 6 Schematic core and flake cross-section showing how removal of a flake to one face can improve the platform for removing a flake to the opposite face. In this case, the platform edge angle is acute but the core edge is rounded (A). Removing flake 2 is difficult because of the core mass relationships. Flake 1 is removed instead (B) and this creates an easily exploited platform for reducing the opposite face (C).

Asymmetrical reduction

Similar-sized flakes can be struck from both faces of a stone with a symmetrical cross-section because the exploitable portions of adjoining core faces are roughly the same size.
On stones with asymmetrical cross-sections, larger, more invasive flakes can be produced from larger core faces than from smaller core faces (Figs 7 and 8). Facial asymmetry can be an obstacle if a symmetrical core cross-section is desired (cf. Waldorf 1993: 33–4) but modern human stoneworkers often exploited asymmetry to focus reduction on one core face (e.g. Akerman 1976; Bordes and Crabtree 1969; Flenniken 1987; Moore 2004; Titmus and Clark 2003; Tixier 1972).

Flake predetermination

The shapes of zones of high mass influence the ‘rupture points’ of the flakes that remove them (Van Peer 1992; cf. Pelcin 1997; Rezek et al. 2011). For instance, an elongated flake is produced by removing an elongated mass (Fig. 9). Flake shapes can be ‘predetermined’ (Inizan et al. 1999) by prior flaking that manipulates the shape of the high mass (e.g. Boëda 1995; Crabtree 1968; Flenniken 1978; Pelegrin 2005, 2006).

Figure 7 Schematic core and flake cross section-showing reduction of an asymmetrical stone. The core platform angle is acute (A), providing a potential platform to both faces. The flakes modeled here have the same interior platform angle, and the flake removed from the strongly convex surface (B) is less invasive than the flake removed from the flatter surface (C).

Figure 8 Chert cobbles shown before (left) and after (right) hard-hammer flaking to illustrate how asymmetry influenced flake invasiveness. The flake scar on the steep cobbles edge is non-invasive and the flake scar on the flatter face covers the entire surface.
Modern human knappers and hominin intentions

Archaeologists rely on modern knappers to provide the ‘middle range’ explanations that link stone artefacts with the knapping strategies that produced them. The ‘good tricks’ described previously are a small sample of the technical knowledge used by modern knappers to replicate stone tools and explain the by-products; the cited studies are informed by those authors’ practical stoneworking knowledge. The replication literature demonstrates that the physics of fracture are predictable and by acting on those predictions – by deliberately manipulating the core using ‘good tricks’ organized according to higher-order intentions – a knapper can create complex tools.

Of course, the replication-informed literature shows how a modern human knapper (the flintknapper replicator) goes about achieving effects. Uniformitarianism is a possible rationale for linking modern knappers’ intentions to the intentions attributed to cognitively modern *Homo sapiens*, and higher-order intentions are evident in complex stone technologies made by arranging flake units hierarchically (Moore 2010). However, in the context of pre-modern hominins, invoking uniformitarianism presupposes that...
pre-modern cognition, as reflected in stoneworking, functioned like modern cognition (Davidson 2002; Holloway 1969; Wynn 2002). Our knowledge about the cognitive significance of early stone tools, when filtered through the experience of modern knappers, may be logically suspect. We will now return to the cellular structure of stoneworking, which further complicates assessments of hominin intentions.

**Hominin intentions and design space structure**

As we have seen, a zone of high mass must occur on the core face for successful knapping, but each flake removal reconfigures the arrangement of high mass. In hierarchical knapping organized according to higher-order intentions – where a knapper works towards a preconceived goal – the reconfigurations of high mass are predicted and acted upon. But, because reconfiguration of mass is inevitable when a flake is removed, it is possible progressively to knap – and change the form of the core – with no more intention than is inherent within the flake unit itself (the intent to remove one flake). Stoneworking in this case is driven by the inevitable reconfiguration of the high mass on the core face by the prior flake removal.

Since zones of high mass are inevitably reconfigured – and flake units are inevitably linked together – a hominin stoneworker could have, in theory, reduced a stone without ‘thinking ahead’ and predicting how removing a flake would reconfigure the mass. Each application of the flake unit could have been perceived as a new beginning. Crucially, however, removing a flake redistributes mass non-randomly: high-mass zones are always deflected laterally and distally to the scar’s periphery. This non-random process, combined with the ‘mindless’ application of the flake removal algorithm, could have channeled different core reduction events in similar directions. The result may be morphological clusters of archaeological by-products that appear to have been, by their repetition, deliberately designed according to higher-order intentions.

A bifacial handaxe, for instance, might be produced mindlessly through inadvertently combining the effects underpinning the ‘good tricks’ of design space described previously. The process begins by removing a flake from a high mass zone on one face of a stone. Removing a flake reproduces an acute edge angle and improves potential platform angles for reducing the opposite face. Acting on this phenomenon inevitably creates a bifacial edge; an intention to produce a bifacial edge is not required. The removal of a flake results in a decrease in the width of the core and the removal of multiple flakes can incrementally straighten the core edge. This edge regularization is a flow-on effect of distributing flakes along one core margin, itself driven by the geometrical identification internal to the flake unit – not necessarily an intent to produce a straight edge. Reduction along one edge of the core can deflect mass distally towards the opposite side of the core. When this mass is targeted, the opposite edge of the stone is straightened and the core becomes elongated and often symmetrical – again, without an intention to produce a symmetrical, elongated core (see Moore 2010: fig. 2.9). Aspects of the Levallois method might unintentionally occur through a similar process. The proximal ends of flakes are to be thicker than the distal ends; thus removing a flake deflects the zone of high mass on the core distally, often enhancing core face convexity. The high mass is then removed from a platform at one end.
of the core, creating a ‘predetermined’ flake without a special intention to do so (cf. Sandgathe 2004). Asymmetrical core reduction – with the larger ‘predetermined’ flakes removed from only one face of the core – can develop unintentionally from differences in the sizes of adjoining core faces. Asymmetry might be conditioned by the shape of the starting cobble (or flake blank) or can develop inadvertently during core reduction.

**Conclusion**

Mindless repetitions of the flake removal algorithm, combined with the channeling effect of stoneworking design space, could unintentionally reproduce the ‘good tricks’ discussed here. Since stone flaking is cellular, considerable skill might be reflected in the removal of individual flakes, but ‘mindless’ linking of units might converge on cores with straight edges, elongated shapes, bifacial edges, and symmetry, as well as traits such as mass enhancement/end thinning, asymmetrical reduction and ‘predetermined’ flake morphology. All of these traits have been used by archaeologists to argue for the emergence of higher-order intentions in early hominin evolution because modern knappers demonstrably employ them, in a deliberate and strategic fashion, to achieve effects (e.g. Edwards 2001; Jones 1994; Madsen and Goren-Inbar 2004; Newcomer 1971; Pelegrin 1993; Pitts and Roberts 2000; Schick and Toth 1993; Shipton et al. 2009; Toth 2001).

We have seen how aspects of handaxe manufacture and the Levallois method might have been unintentionally produced by non-modern hominins. They may, in fact, be stoneworking ‘spandrels’ – arrangements that exist empirically but were not deliberately designed (see Gould and Lewontin 1979). However, few archaeologists would argue that complex Levallois reduction methods and hyper-symmetrical handaxes resulted from ‘unintentional’ knapping. These relatively sophisticated products occur comparatively late in cognitive evolution; thus, assuming that these later products reflect relatively advanced cognition, the key question is how and when inevitable aspects of design space – ‘good tricks’ – were deliberately combined by hominin stoneworkers to achieve these sophisticated effects, and how these higher-order intentions might be recognized empirically in the archaeological record.

Researchers have focused on specific aspects of these more advanced methods – similar to the ‘good tricks’ discussed here – and concluded that they were significant steps on the way to more fully developed expression (e.g. DeBono and Goren-Inbar 2001; Delagnes and Roche 2005; de la Torre et al. 2003; Pelegrin 2009; Sharon 2009; Wynn 1995). An alternative explanation is that the ‘good tricks’ that appear in isolation among assemblages made by early hominins occurred unintentionally. Two scenarios can be inferred: a gradualist scenario where hominin stoneworking developed incrementally and over a long time span as ‘good tricks’ were recognized and added to technical knowledge; and a punctuated scenario where ‘good tricks’ were assembled en masse, and over a brief time interval, to achieve an intended effect. The starting point for evaluating these scenarios is to determine empirically what by-products might be expected, and in what proportion, in ‘mindless’ stoneworking.

Issac (1986: 225–6) recommended the ‘method of residuals’ in analyzing early stone tools, where variation in assemblages is first evaluated in reference to ‘least-effort’ flaking.
and unexplained residual variation is carried over to the next highest level of explanation. Aspects of ‘least-effort’ flaking can be considered in light of design space constraints like those discussed here. Since stone flaking is cellular, the removal of single flakes can be randomized without resulting in the breakdown of the reduction process. It is presently unclear what the by-products of truly random ‘least effort’ flaking – undirected by the actions of modern knappers – might look like, but experimental efforts directed at discovering this could provide the empirical baseline required by Issac’s method. It is predicted that these random by-products would include occasional examples that illustrate each of the ‘good tricks’ described here. The abundance and nature of their expression in the archaeological record were likely influenced by the sizes and shapes of the starting cobble and allometric changes that occurred through the knapping process (cf. McPherron 2000; Toth 1985).

The closeness of the boundaries of design space led hominin stoneworkers into some well-trodden areas. Trajectories through design space were confined into channels – some broad, some narrow – as stoneworkers struggled with the medium’s various physical constraints. It is these well-used channels – forced by design space boundaries – that offer the key to interpreting the emergence of complex combinations of the ‘good tricks’ of stoneworking in early hominin evolution. The first step, however, is to define empirically the technological baseline reflected in the mindless assembly of flake units in simple chains.

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References


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