Loosening Our Chaînes: Cognitive Insights for the Archaeological Application of Sequence Models

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ABSTRACT
Sequential analysis has become a well established means of describing the operation of past activities. As their applications have expanded, the nature and implications of the models archaeologists have developed for the consideration of sequential activities have come into focus and debate. Difference in the steps used to produce microblades in two terminal Paleolithic sites in Japan exposes "breadth" and "depth" in routinized activities. Ideas from modern psychology can augment archaeological use of sequence models to reveal how technological information was organized and in that way help to address cognitive aspects of archaeologically observed behaviors.

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Treating routine activities in sequential terms has become an extremely popular archaeological research tactic. In particular, modeling the production and use of stone tools as a series of actions that can be recognized by distinctive materials has provided archaeologists with a powerful means of addressing issues such as how ancient individuals and communities made tools (Callahan 1979), managed raw materials (Kuhn 1991), moved across large and small landscapes (Blades 2003; Hofman 2003), and designed technical systems (Goodyear 1975). Beyond their analytical utility, archaeologists also have considered the theoretical significance of sequential models of behaviors (Bleed 2001; Mesoudi and O'Brien 2008; Shott 2003). In particular, the *chaîne opératioire* concept, an approach to sequence modeling developed by French archaeologists, has drawn great theoretical attention and has recently been the topic of a major synthetic presentation by Ofer Bar-Yosef and Philip Van Peer (2009). Given all of this, one might ask if anything more needs to be said about archaeological uses of sequence models.

A strongly positive response to that question is offered by Frederick Coolidge and Thomas Wynn (2009: 97ff) in their recent synthesis of Paleolithic archaeology presented in terms of cognitive science. In their view, the ability to manage sequential activities and to move routinely through series of decision points marks an important development of the hominin mind. This ability was the context of cranial growth and expansion of the motor cortex that marked the development of long-term memory capacity. Coolidge and Wynn's provocative consideration of a demonstrably powerful archaeological tool invites further consideration of the thought processes reflected by archaeological sequence models. This paper seeks to do that and sets the modest goal of suggesting that psychological research might expand the interpretive power of archaeological sequence models.

MODELS OF MICROBLADE PRODUCTION

To provide a specific archaeological example of how archaeological sequence models can address past behavior I will call on models developed for two Japanese microblade assemblages dating from the terminal Pleistocene in Japan. These assemblages come from the Kakuniyama and the Araya sites located in Central Honshu (Bleed 1996, 2008).

ARAYA

Araya was among the very first microblade assemblages recovered in Honshu and securely dated to the terminal Pleistocene (Bleed 1996; Sutoh 1990). It is located in central Niigata and sits on a terrace remnant that overlooks the confluence of two major rivers, the Shinano and Uono, which in pre-modern times supported major seasonal fish runs. Charcoal from the cultural layer of the site has been radiocarbon dated at 13,200±350 (GAK948) (Ono et al. 2002). High quality stone raw material is not available at Araya. The source of stone worked at Araya is not known, but since decortication flakes are rare, it appears to have been brought to the site either in the form of large flakes or palm-sized bifaces that were the starting point for production of wedge-shaped microblade cores. As summarized in Figure 1, the process of making cores at Araya involved what can be described as six steps.

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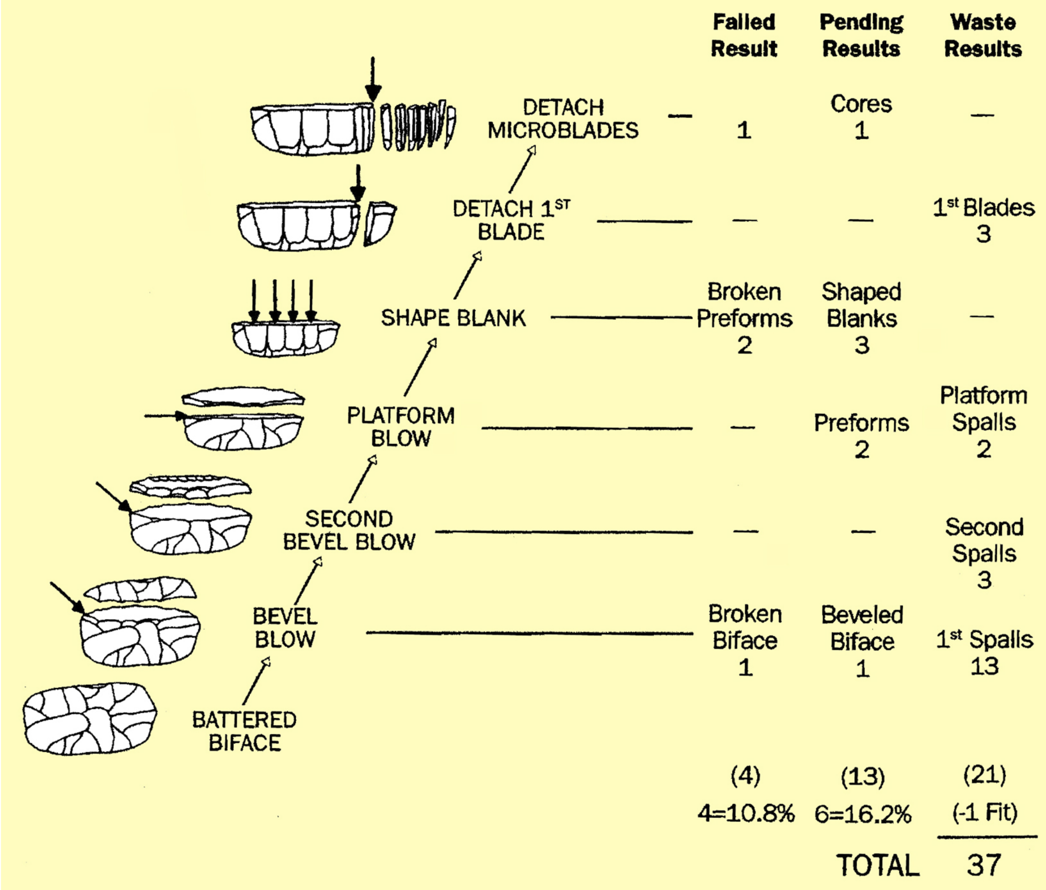

Figure 1. An Event Tree Model of microblade manufacture at Araya. Steps in the production sequence are shown at left. Numbers show the waste results, failures, and unfinished pieces generated by each step. The proportion of pieces abandoned before completion or broken during production define the "failure rate."

1. A <u>bevel blow</u> to the margin of a biface seems to have started the process even if it appears <u>not</u> to have been immediately aimed at the production of microblades. The first bevel blow removed a long flake from the side of a biface. These flakes have a bifacially retouched ridge on the dorsal surface and they were detached oblique to the transverse axis of the core to leave a beveled rather than transverse margin on the biface. This margin would have been very sharp, of course.
2. After the initial bevel blow, one or more <u>second bevel removals</u> were detached from the beveled margin of a biface. Following earlier bevel blows, these flakes have a trapezoidal cross section with the major scar on the dorsal surface parallel to the ventral side. They renewed acute margins along the side of biface. These acute margins show battering indicating that before the bevel blows were detached, the acute margins of the bifaces had been used as choppers.
3. After one or more bevel blows, a <u>platform blow</u> was detached from the biface. This was done with a removal that changed the oblique beveled margin into a surface that crossed the biface transversely. Platform removals have a distinctive "triangular" cross section with a dorsal face that is oblique to the ventral surface.
4. The biface portion that resulted from the process had a "wedge-shaped" cross section. This microcore <u>blank was shaped</u> by the removal of flakes from both sides of the flat surface that had been formed by the platform removal. This shaping adjusted the width and regularity of the biface fragment, and turned it into a regular core preform.
5. Once width of the split biface had been adjusted, one narrow end of the preform was detached with a distinctive large "<u>1st blade</u>." These are flakes with a flat, right angle striking platform and a bifacially retouched dorsal surface.
6. With the core shaped in this way, <u>microblades were removed</u> from the surface left by the 1st blade using the surface created by Step 3 as the striking platform.

Since only one of the core-related pieces from Araya is represented by a pair of refitted elements, it appears that much of the work on the individual pieces was done elsewhere. All stages of core manufacture were undertaken at the site, but there are many more 1st, 2nd, and platform spalls than finished cores. This indicates that more cores

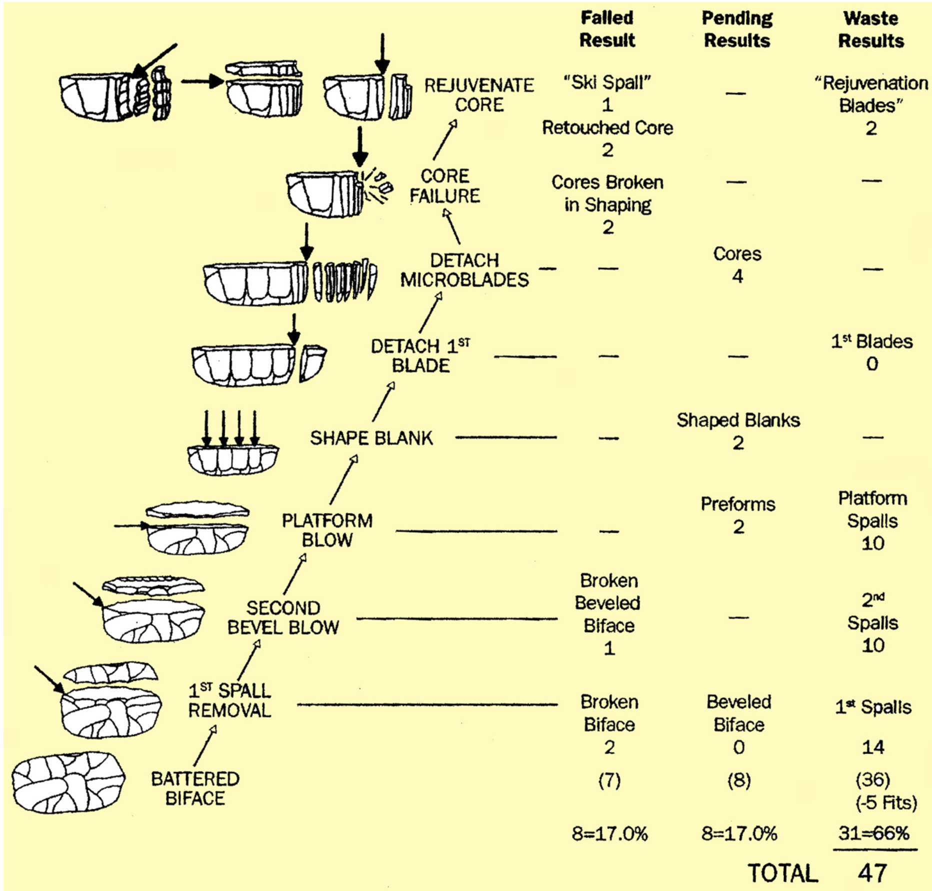

Figure 2. An Event Tree Model of microblade manufacture at Kakuniyama. Steps in the production sequence are shown at left. Numbers show the waste results, failures, and unfinished pieces generated by each step. The proportion of pieces abandoned before completion or broken during production define the "failure rate."

were started at Araya than left there. All of these facts suggest that cores were used in the context of mobility.

KAKUNIYAMA

Kakuniyama is located in northern Yamagata Prefecture, some 200km east from Araya (Bleed 1996; Uno and Ueno 1983). Like Araya, it is located above a river confluence that certainly had good fishing potential in pre-modern times. Proximity to raw materials, however, is a major difference between Kakuniyama and Araya. Cobbles of high quality hard shale available immediately below Kakuniyama were used for essentially all of the tools worked at the site. The assemblage includes many hammerstones, as well as decortication flakes, angular shatter, and tested cobbles.

In typological terms, the microblades were produced at Kakuniyama with exactly the same process as at Araya. As elucidated with an event tree in Figure 2, however, there are two differences in how the people of the two communities made microblades. First, the process of beveling, rebeveling, and flattening a biface at Kakuniyama was rather less routine than the lock-step sequence used to reduce bifaces to core blanks at Araya. Second, after the initial shaping steps, Kakuniyama microblade makers used a variety of core rejunivation techniques to extend the use-lives of their cores. This activity is simply not seen at Araya. As at Araya, residues of the early steps of biface beveling and shaping far out number finished cores at Kakuniyama.

HOW LINEAR WAS MICROBLADE PRODUCTION AT ARAYA AND KAKUNIYAMA?

Through careful typological and refit analysis, Japanese archaeologists have been able to define a number of highly patterned techniques for making microblades and have used them for the study of the terminal Pleistocene cultures of central and northern Japan (Nakazawa et al. 2005; Sato and Tsutsumi 2007). These techniques are invariably presented as linear sequences and it is hard to see them as anything but highly routinized behavioral, cultural, and cognitive activities. Making microblades at Araya and Kakuniyama exemplifies those techniques. They involved an array of highly dissimilar forms, a series of at least six major steps, perhaps hundreds of specific actions, and a large variety of tools and facilties. Executing the steps and creating the residues observed at these sites had to rest on well-developed motor skills. The fact that the activity was shared by separate communities indicates that it was a widely share cultural institution. Connecting all of the acts that went into this production sequence had to rest on cognitive structure. People had to "know" how to do this complex routinized task.

At the same time, it is clear that these tool production sequences also encompassed a range of behaviors. First, as similar as these sequences were, the Araya and Kakuniyama production processes were not identical. The Kakuniyama knappers, for example, resorted to a variety of rejuvenation techniques that the Araya microblade makers got along without. Since these differences parallel the availability of raw material, they suggest that skill is a technological variable that could develop in response to local conditions (Bleed 2008). With its relative abundance of flakable stone, Kakuniyama may have been a place where knappers practiced the skills and learned the process of microblade production. Learning to understand and execute a complex technical process like this would have required practice. It is also possible that the production process was managed so that the most skilled microblade makers were involved in the process in sites like Araya, where raw material was scarce and failure, therefore, costly. Second, at both Araya and Kakuniyama, there is more evidence of the early stages of the sequence than there is of final stages of microblade production. As in other biface technologies (Kelly 1988), early stage biface forming produced useful flakes which were themselves retouched into a variety of scrapers and burins. This part of the sequence, in other words, appears not to have been solely about microblade production. Microblade production was enmeshed in other stone working activities. By emphasizing microblade production, linear models may cause us to overlook other important activities and to misunderstand how stone working tasks were actually organized.

TASK STRUCTURES

Cognitive and applied psychologists have developed ways of describing the organization of tasks similar to the activities archaeologists observe with sequence models. They have also addressed material, behavioral, and cognitive aspects of such activities. To design or understand such activities, a common psychological approach is to describe them in terms of how their subdivisions relate to one another (Norman 1988: 119). These relations can be described as "**narrow**"—if each potential action in the activity leads to another single action in a direct, linear series. By contrast, in "**wide**" activities, every action presents the operator with a number of potential options.

Wide and narrow activities have different occurrences in modern life. Since each step in a wide activity requires thought and a decision, carrying them out cannot be "learned." They are problems that have to be solved. Experience, knowledge, and information can support completion of wide activities, but they always require thought and decision making. In our world, wide activities are relatively rare. They tend to be difficult or at least challenging. By contrast, most of the activities of everyday life are "narrow." They can be done in a straight forward manner. One step leads directly and only to another one. They follow a routine. If there are alternatives and variations, they are not significant. Once mastered, narrow activities require little planning or thought. They need not be easy, but people can learn them. That is, we can remember how to carry them out. In fact, based on well established memories, some of these activities can be done unconsciously.

COGNITIVE MANAGEMENT OF SEQUENTIAL TASKS

Most archaeological sequence models, and certainly most lithic reduction sequences, seem to fit the description of narrow activities, but that generalization deserves evaluation. Lithic technology may have inherent constraints that confined reduction sequences to narrow sequences of actions. Stone tool making is strictly reductive and errors are irrevocable. These conditions may make lithic technology less flexible than, say, making a pot or a basket. Beyond that, it is possible that linear thinking of modern observers may serve to make production of stone tools appear narrower than it may have been. Activities that fail to follow the single sequence we perceive or expect may be hard for us to recognize. In that case, our models may serve as blinders. Archaeologists need to have conceptual means of dealing with both narrow and wide activities.

People need three sorts of information to complete linear activities like most stone tool production sequences. First, a flintknapper needs the motor skills required to accomplish the steps of the activity. Second, a worker needs the intellectual knowledge of how to accomplish each individual step. Finally, with that motor and cognitive knowledge, the operator needs to understand the sequence of steps required for completion of an activity. This involves knowing the steps, knowing where they are in the sequence, and what step comes next. Many archaeologists have addressed the motor skill of stone tool making (Whittaker 1994: 87ff). Understanding the cognitive aspects of sequential activities has been less studied, but it may be aided by consideration of what is known about how people learn and operate narrow activities.

Analysis of refitted sections of late Paleolithic tool making residues demonstrates that modern human flintknappers were able to manage their sequences in a variety of ways (Bleed 2002). They could execute them in an unbroken series or leave them unfinished and pick them up at a midpoint. This kind of management of steps and actions involved in even rather complex reduction sequences could have been remembered by "rote" (Norman 1988: 67ff). That is a non-technical term that describes execution of an activity made up of arbitrary information. We can cite examples of arbitrary series we manage as rote—computer adjustments or fragments of verse. These tasks are no more complex than the series of steps that went into making microblades at Araya, but rote learning is uncommon in everyday life. Memorization of arbitrary information is difficult and time consuming. Activities that depend on this kind of learning tend to be associated with frequent errors. And when an error occurs in a sequence remembered by pure rote, it is hard to know what went wrong. For all of these reasons, modern designers try to avoid creating tasks that depend on this kind of memory. They can do this be-cause there are alternatives to arbitrary memorization that can significantly enhance mastery of sequential activities.

In fact, most activities modern people do, and most of the remembered actions we use in everyday activities, do not depend on rote. Instead, the regular activities people carry out more or less routinely are guided by cognitive structures that the operator uses to link individual actions. As approached by psychologists, these "mental models" are ideas people hold about the people and things with which they interact (Norman 1988: 17). On the surface they may seem similar to the archaeological concept of a "mental template" (Deetz 1967: 45ff; McPherron 2000). But unlike the template concept that assumes people carry conceptual standards for their actions and creations, mental models are viewed as ideas that offer cognitive guidance for remembering how to carry out activities. It appears that humans have a well developed capacity of approaching activities in cognitive terms and that the sequential—as opposed to cyclical—thinking is a distinctively human quality (Burke and Ornstein 1997: 17ff). In that sense viewing an activity as a sequence of steps can serve as a mental model that facilitates execution of the steps it involves. Mental models can be much more specific. Jacob Bronowski (1978) famously called attention to the ways that ritualization could support technical undertaking. Stories and myths can guide technical activities, but it appears that people prefer and perform better when the mental models that guide their actions are practically connected to the operation they must complete. That is, we do best when we see a meaningful relationship between the steps of an activity (Kieras and Bovair 1984). A common way of organizing information is with an explanation of the operation (Norman 1988: 70). Even if explanations are flawed, inaccurate, or irrational (Norman 1993: 122), seeing meaningful relations between actions is the best way of remembering how to perform activities like the ones that were involved in archaeological sequence models. It also seems that thoughtful consideration of why and how activities operate is a product of skill development. "Elaborate rehearsal" describes a level of practice that deeply engrains actions. This kind of practice—at violin playing, golf, or stone tool production—is marked by recollection that involves the meaning of the information involved in the activity (Aschcraft 2006: 226). Simply put, it seems that if modern humans do something long enough, they become interested in its underlying basis.

Like *chaînes opératioires* or other reduction sequences, mental models are inferential. None of them is subject to direct observations. Psychologists can address mental models by observing the behavior of people, but the link between behavior and cognition is inferential. With the hard residues of behavior, archaeologists may not be any more removed from cognition than psychologists. Archaeological evidence may preserve concrete behavior sequences that are comparable to what is available to psychologists.

The kind of regularity archaeologists have traced over long periods of time can reasonably be the basis for inferring well developed cognitive structures. The nature and basis of those models may not be apparent, but the people who carried them out must have had a conceptual way of linking the steps, probably in a meaningful way that reflected studied understandings. This may have been accomplished with mnemonic devices which are preestablished memory aids (Ashcraft 2006: 213ff). They have to be learned, but once mastered, they help people perform tasks. They can do this by structuring mental models or somehow reminding the operator of what to do. Many mnemonics are verbal or semantic, but they also may be material arrangements that could be observed archaeologically.

In that regard, it is worth pointing out that archaeologists have observed detailed elaborations and carefully executed small steps within reduction sequences. Ground striking platforms and carefully prepared proximal margins might be examples of these kinds of elaborations. Modern flintknappers can understand how such careful actions might aid flake removal. Still, modern replications also indicate that not all of the observed elaborations are functionally necessary. Elaborations that can be observed in ancient production systems may be reflections of highly routinized behaviors that knappers undertook as mnemonics to guide themselves through the production process. The point is that archaeologists might wish to be open to the possibility that reduction processes reflect cognitive behaviors.

If the support offered by mental models and mnemonics are likely to be archaeologically ephemeral, there is one element in learning routine tasks that certainly can leave an archaeological record. Developing facility in an activity and reaching a level of mastery at its execution involves rehearsal (Ashcraft 2006: 223ff). Defined as deliberate practice of activities intended to be remembered, rehearsal of technological activities is a means of both committing the steps of a procedure to long-term memory and developing the associated motor skills. Technological rehearsal will obviously leave material remains. Given that performance (i.e., production) and rehearsal have different goals, they should leave a distinctive signature. The residues of practice, for example, should show signs of growing skill. The results of practice can be expected to be used—or not used—in ways that are different from production. Finally, instead of creating the residues of an entire process, rehearsal may focus on parts of a technological activity that offer challenge or that demand special attention. Residues of those steps would, then, be disproportionately presented at rehearsal sites.

As explained earlier, executing the sequence of acts that archaeologists observe as sequence models is more than simply knowing the actions to take. Carrying our complex procedures involves knowing how to do each step and being able to know when a step is done. Archaeologists tend to emphasize the motor activities or materials residues associated with the completion of steps. To address the mental basis of procedural actions, psychologists conceive of them in terms of "means - ends analysis" (Ashcraft 2006: 545). In this view, problem solvers move mentally back and forth between judgments about the state of a task and decisions about taking actions that will produce some goal.

This is how computer simulations of problem solving operate. And there is empirical support for the premise—called ACT for 'adaptive control of thought'—that while solving a problem, people make use of observations and errors as the move toward a desired outcome (Anderson and Douglass 2001). Anderson (1990) suggests that just as sequences of actions can be learned, stores of "*if-then* pairs" can be mastered and put into human memory. This "production memory" is not the same as rote and becomes an important part of an activity like tool production and use. Current understanding suggests that there are few if any material reflections of this kind of cognition. The best evidence that can be offered in support of the existence of "mean-ends" cognition during the execution of tasks is that problem solving skills can be taught; people can develop their problem solving ability (Ashcraft 2006: 555).

The cognitive aspects of sequential activities discussed so far—rote, mental models, mnemonics, rehearsal, and production memory—are all common human activities. People do these things and they are basic features of lots of human behaviors. Modern designers have increasingly appreciated, however, that tools can be made to support cognitive activities (Norman 1988, 1993). Modern technologies make extensive use of cognitive tools. Machines tell us how to use them, what steps we need to complete, and the order we must follow (Hutchins 1995). Even simple technologies can incorporate cognitive aids. Habitualized work stations and postures, for example, offer a stoneworker both a physical and mental context for how to proceed. They allow a worker to get right to work. Likewise, organized tool kits—especially those carried in a special container—relieve an operator from remembering where things are. They provide answers to questions like, "Where did I put…?" or "Where do I find ….?" Specifically crafted or even well-worn tools serve as behavioral guides for procedural questions like, "How do I hold this?"

Tools that have to be used together also can provide an operator with information. Microblade makers at Araya appear to have had fairly precise ideas about the size and shape of their cores. Remember that lateral trimming of the striking platform was an essential step in changing a split biface into a core. Either knappers carried that standard in their memory, or answers to questions about the right size and shape of cores were determined by the physical dimensions of the grip or vice that held the cores while blades were detached. Assuming those grips were like other hand tools, they very likely also had information about how they were to be used. This information might be no more than signs of use, but they may have had shaped surfaces made to fit the hand. In any case, such features freed the blade maker from "deciding" how to grip the core and what posture to adopt while using it.

Designers use the term "affordance" to describe the perceived and actual properties of objects that determine how they can be used (Norman 1988: 9ff). Shapes and materials afford some uses more than others. Operators have to learn these uses, so they are at least partially cultural, but once incorporated in technology, affordances can guide actions and designs. By relieving operators of decisions and the need to remember every aspect of a task, they form part of the cognitive basis of actions.

Before leaving the subject, one more aspect of archaeological applications of mental models warrants attention. Some psychologists and especially educational psychologists have described strict adherence of conventional patterns as "linear" or "vertical" thinking (de Bono 1976; Mosleley et al 2005: 119ff). In this view, behavioral rigidity can result from uncreative use of established frameworks. That rigidity is in contrast with creativity and innovation and a type of thinking that has been labeled "lateral" or "critical" thinking. Educators and designers see training that is narrowly based on specific situations (de Bono 1976: 50) as inhibiting creativity and have proposed a variety of strategies that enhance creative thinking and innovation. Whatever we might do to flex our creativity, archaeologists using *chaînes opératioires* or other sequence models would do well to remember that the expectations we bring to those models may shape what they show us. If we rigidly expect linear patterns and believe ancient stoneworkers to have inflexibly moved through the series of steps we recognize, we may miss part of what our subjects were doing. The processes used to make microblades at Araya and Kakuniyama show that sequences followed by stoneworkers could be both long (in that they could involve many steps) and wide (in that they could involve diverse strategies as they progressed). If we narrowly conceive of the sequence models we use, and rigidly follow them only where we think they lead, these models could confine our explorations of past behaviors.

CONCLUSIONS

Sequence models have grown as archaeological ideas usually do, through a series of careful observations, borrowing from other disciplines, and expanding interpretations with middle range investigations. Theses models afford a powerful means of addressing behaviors and social patterns that were associated with stone tool production and use. In part, this strength reflects distinctive features of stone tool technology which leaves very durable and distinctive residues of the production process. This factor certainly explains why sequence models have been most successfully applied to stone tools as opposed to other media. The theoretical strength of these models does not rest solely on physical factors, however. The large number of archaeologists who have practiced or observed flintknapping have created a great reservoir of interpretive insights that have supported sequence analysis. The theoretical interest of many archaeologists in work, work patterns, and mobility also has supported refinement of sequence models.

If a mixture of material and theoretical factors contributed to the growth of sequence models, emergence of new archaeological questions and theoretical issues exposes their limits and points to new ways that they can be made stronger. The goal of this paper has been to suggest that there is information on the cognitive behaviors that were behind the activities that are addressed by sequence models. Much of this information is concrete and objective and a great deal of it is based on social scientific research. Much of it also has the potential for being reflected in material terms within the archaeological record. All of this means that it should be accessible to archaeologists interested in expanding the power and applicability of sequence models. Most of the insights about mental elements of routine activities comes from psychology and its applied affiliates. Making use of these insights will be difficult since the field is huge and not well synthesized (Wynn 2002: 390). There are unlikely to be any "plug and play" observations that archaeologists can use to expand sequence models to address mental behaviors. Methods borrowed from other disciplines—ecology, physics, geology, and various biological fields—have repeatedly been adapted to archaeology, so that finding and applying specific insights on the cognitive basis of tool production should not be impossibly difficult. The basic position developed here is that looking into the cognitive basis of sequential activities like tool production and use should be possible with thoughtful expansions of existing sequence models.

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