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THE EXPLANATION OF ARTIFACT VARIABILITY

Michael Brian Schiffer and James M. Skibo

We furnish a theoretical framework for explaining that portion of formal variability in artifacts attributable to the behavior of the artisan. Major causal factors are the artisan's knowledge and experience, extent of feedback on performance in activities along the artifact's behavioral chain, situational factors in behavioral chain activities, technological constraints, and social processes of conflict and negotiation. In identifying the causal factors at work in a specific case, the investigator must focus analytically on activities—that is, on people-people, people-artifact, and artifact-artifact interactions—and on the performance characteristics relevant to each. Application of this behavioral framework allows abandonment of many cherished but unhelpful concepts, including style and function. Ceramic artifacts, the low-fired, clay cooking pot in particular, are employed for illustrative purposes.

Se propone un marco teórico para explicar esa porción de variabilidad formal en artefactos que es atribuible a la conducta del artesano. Los factores causales más importantes son el conocimiento y experiencia del artesano, el alcance de las evaluaciones sobre el desempeño del artefacto en actividades a lo largo de su cadena conductual, factores circunstanciales en las actividades de la cadena conductual, constreñimientos tecnológicos, y procesos sociales de conflicto y negociación. Se demuestra que, al identificar los factores causales activos en un caso específico, el investigador debe enfocar su análisis en actividades—en otras palabras, en las interacciones que ocurren entre gente-gente, gente-artefacto, y artefacto-artefacto—y en las características de desempeño relevantes para cada tipo de interacción. La aplicación de este marco conductual permite que se abandonen muchos conceptos atesorados pero inútiles, incluyendo estilo y función. Artefactos cerámicos, en particular la olla de cocina, se emplean para ilustrar estas ideas.

Archaeologists have long been fascinated by the endless variability—differences and similarities over time and space—in the characteristics of artifacts turned up by fieldwork. Until the mid-twentieth century, however, investigators were mostly satisfied to impose a time-space ordering on this artifact diversity; when explanations were offered, they usually invoked evolutionary change (e.g., "improvements" in hunting implements) or cultural affiliation (e.g., Anasazi vs. Mogollon pottery). With the advent of processual archaeology in the 1960s, behavioral archaeology in the 1970s, and evolutionary and postprocessual archaeologies in the 1980s, the explanation of artifact variability has been accorded a higher priority. As a result, the general problem has come under theoretical consideration, and many causal factors—from learning frameworks, to utilitarian and symbolic functions, to gender competition and asymmetries in social power—have been implicated in particular explanations.

Despite the heightened interest in artifact variability, theoretical treatments are at best fragmentary, and specific explanations remain crude and unconvincing. An even more troubling trend is that practitioners of different archaeologies cannot agree on what is an adequate theory or a rigorous explanation. Perhaps in our debates over style and function, in our disputes concerning technological organization, and in our arguments about social power, we have all lost sight of the past artisan striving to create products that embodied causal factors respecting no modern theoretical or analytical boundaries. Clearly, there is an urgent need to erect a theoretical framework that can integrate the many sources of artifact variability and establish standards of explanation.

Carr's (1995) recent paper, entitled "Building a Unified Middle-range Theory of Artifact Design,"

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poignantly demonstrates the need for a unifying approach. Reaching a Herculean 108 pages of fine print, Carr's theory, despite having much merit, is in the end almost entirely about "stylistic" phenomena, incapable of accommodating technological and utilitarian factors—as Carr (1995:229–230) himself comes close to admitting. On the other extreme is the authors' earlier formulation (Schiffer and Skibo 1987) that, although claiming complete generality, dwells on "technological" and "utilitarian" causes to the near exclusion of all others. To harmonize such divergent perspectives, we must return to first principles, rethink the nature and causes of variability in all artifacts, and discard some of our most cherished theoretical and analytical categories—style and function, utilitarian and symbolic causes, technological and cultural factors, and so forth. Without these conceptual shackles, perhaps it will be possible to fashion a framework that weaves all sources of artifact variability into a seamless whole.

In this paper we construct a theoretical framework that incorporates all causes of variability and establishes standards for specific explanations. This framework is unabashedly behavioral, grounded in the concrete interactions that take place in the activities constituting the life histories of artifacts and people (e.g., Schiffer 1992, 1995a; Skibo et al. 1995). Even so, by emphasizing interaction and performance in activities, our framework forges links to diverse theoretical perspectives on artifact variability (e.g., Braun 1991, 1995; Carr and Neitzel 1995; Conkey and Hastorf 1990; Dobres 1995; Dobres and Hoffman 1994; Jelinek 1976; Lechtman 1977; Lechtman and Steinberg 1979; Lemmonier 1992, 1993; Miller 1985; Neff 1992a; O'Brien and Holland 1995; O'Brien et al. 1994; Plog 1980; van der Leeuw 1991, 1984a). Although our examples come from ceramics, particularly the low-fired, clay cooking pot, we draw inspiration from studies on countless kinds of artifacts, including chipped and ground stone (Adams 1994; Dibble 1995; Goodyear 1989; Hayden 1977a, 1977b, 1987; Johnson and Morrow 1987; Kuhn 1994; M. Nelson 1991; Odell 1996; Sheets 1975; Torrence 1989; Young and Bonnichsen 1984), metal (Bleed and Bleed 1987; Keller and Keller 1996), architecture (Kent 1990; McGuire and Schiffer 1983; Nielsen 1995), clothing (Wobst 1977), and others (Binford 1979; Butler 1975; Gould 1990; Schiffer 1991; Schiffer, Butts, and Grimm 1994; Wiessner 1984). Thus, the general framework ought to apply to all products of human manufacture, including facilities and structures. We begin by presenting relevant behavioral definitions and principles.

Definitions and Basic Principles

There is a vast universe of archaeologically recovered clay cooking pots and sherds varying in formal, spatial, quantitative, and relational properties (on the four dimensions of artifact variability, see Rathje and Schiffer 1982:64–65; Schiffer 1987:13–23). This is much more variability than our framework can handle, and so the present inquiry is restricted to formal variability: an artifact's observable, often measurable, physical characteristics. Also excluded is formal variability resulting from post-manufacture modifications, such as use alteration (Hally 1983; Skibo 1992) and formation processes (Schiffer 1987).

Framing the Question: Explaining Design Variability

What remains to be explained, then, is all formal variability—through time and across space—generated by past artisans, the person or persons (Wright 1991:198), including those employed by corporations, engaged in the activities of producing an artifact. In the cooking pot case, the formal variability of interest includes orifice diameter, body shape, rim shape, capacity, temper (kind, size, amount), wall thickness, and interior and exterior surface treatments (incising, polishing, etc.).

Formal variability is caused, in a proximate fashion, by artisans executing different sequences of material procurement and manufacture activities, including materials preparation. For example, one jar's exterior surface has a matte appearance because the potter smoothed it with a piece of gourd, whereas another's is lustrous because it was polished with a pebble. Proximate explanations of formal properties arise from a sophisticated process of archaeological inference employing general principles—along with traces preserved in the artifact itself and in other lines of evidence—for establishing warranted statements about the artisan's behavior (for ceramic principles and examples, see Bey and Pool 1992; Bronitsky 1989; Franken 1971; Franken and Kalsbeek 1975; Kingery and Lense 1985; Kingery and Vandiver 1986; Mills and Crown 1995; Neff 1992b; Olin and Franklin 1981; Orton et al. 1993; Rice 1987; Rye 1981; Shepard 1965; Sinopoli 1991; van As 1984; Wardle 1992; Zedeño 1994).

Although invoking the artisan's activities does account for an artifact's formal properties, archaeologists today, moving to the next level of explanation, seek to understand *differences and similarities in the inferred activity sequences.* Why, inquiring archaeologists want to know, did a given artisan employ a particular sequence of activities (e.g., Gosselain and Smith 1995; van der Leeuw 1991)? Because artifacts produced by different activity sequences are said to differ in "design," a convenient label for the subject matter at this level of explanation is design variability (Bleed 1986; Carr 1995; Hayden et al. 1996; Horsfall 1987; Kingery 1984, 1989; Kuhn 1994; McGuire and Schiffer 1983; M. Nelson 1991). Our goal, then, is to present a theoretical framework that can guide the search for specific explanations of design variability.

The point of departure for building this framework is the premise that design is driven by performance; that is, the artisan's behavior is influenced by an artifact's performances in activities throughout its life history (for related views, see Rice 1984; van der Leeuw 1984a). Regrettably, there are precious few invariant relationships between artifact performance and specific procurement and manufacture activities. Thus, we devote much attention to elucidating the processes that intervene between artifact performance, especially in post-manufacture activities, and the artisan's behavior.

A Focus on Specific Activities and Interactions

In previous studies of artifact design, behavioral models have often been framed in terms of major life-history processes, such as procurement, manufacture, use, and maintenance (e.g., Bleed 1986; McGuire and Schiffer 1983; M. Nelson 1991; Schiffer and Skibo 1987). Although these coarse-grained processes have enabled us to offer "first-approximation" explanations, progress now requires analytical focus on individual activities. The entire sequence of activities in an artifact's life history is its behavioral chain (Schiffer 1975a, 1976:49–53). The concepts of convergent and divergent chain segments (Schiffer 1976:53) give the analyst tools for describing, respectively, the assembly of materials into a product and the creation of byproducts or waste products.

Individual activities in material procurement and manufacture processes are known as technical choices (Schiffer and Skibo 1987:599). The technical choices in a particular pot's behavioral chain might include the following abbreviated sequence of activities (adapted from Hodder 1982a:37, 1982b:73–77): collecting clay from ant hills, putting clay in a container, carrying the container to the potter's work area, spreading out the clay on a skin, pounding the clay (with a stone?), shaking the skin to sort out finer particles, mixing clay and water, hand forming the pot's base, making coils by hand, using hands to join and smooth the coils, use of a piece of calabash for smoothing and thinning, etc. By employing the term "choice," we presume only that for each activity (or sequence of activities) there were alternatives, enumerated by the modern investigator, that did not get chosen. Technical choices, it should be stressed, encompass all procurement and manufacture activities, whether carried out explicitly or implicitly, including those responsible for painted decoration. Flexibly defined by the investigator, technical choices are our framework's dependent behavioral variables.[1]

An activity consists of the patterned interactions between elements (e.g., people, artifacts, animals), at least one of which is an energy source (Schiffer 1972, 1976:45, 1979a, 1992:4, 78). Although "interaction" tends to have a mechanical implication, we emphasize that *an interaction can be based on any kind of matter-energy transaction*—mechanical, chemical, thermal, electrical, electromagnetic, visual, acoustic, etc. This expansive conception of interaction is illustrated by the seemingly simple activity of cooking stew over an open fire in a ceramic pot. Table 1 presents some of the major interactions that take

Table 1. Concept of Interaction as Illustrated by "Cooking Stew over an Open Fire in a Low-Fired Clay Cooking Pot."

Reference Element	Other Element(s)	Interactions	Temporal Pattern
Burning Fuel	pot	M, C, T	continuous
Stew	pot	M, T, C	continuous
Cook	stirring spoon	M	episodic
Stirring spoon	pot (interior surface and contents)	M, C	episodic
Cook	tasting spoon	M	episodic
Tasting spoon	stew	M, T, C	episodic
Cook	stew (on spoon)	M, T, C	episodic
Cook	burning fuel, pot, stew, stirring spoon, tasting spoon, etc.	V	intermittent
Cook	new fuel	M, V	periodic
New fuel	burning fuel	M, T	periodic
Other people	pot and stew	V, C	intermittent
Other people	burning fuel	V, T	intermittent
Other people	cook	V, A	intermittent

Note: Kinds of interaction are M = mechanical; C = chemical; T = thermal; V = visual; A = acoustic.

place during this activity, which range from the mechanical interaction between cook and stirring spoon, to the thermal interaction between pot and burning fuel, to the acoustic interactions between the cook and other people in the activity area. (The interactions listed in Table 1 are highly schematic; in actual case studies, interactions would be designated more exhaustively and in greater detail.) In the present framework, then, activities are sets of discrete people-people, people-artifact, and artifact-artifact interactions of any kind.

Variation in activities can be described concretely by a set of components (adapted from Schiffer 1975a, 1976:49–52). Among the important activity components are (1) the number and nature of the elements, including the social unit of activity performance; (2) a behavioral description, that is, a precise listing of all discrete interactions and their temporal patterning within the activity; (3) the activity's performance time(s) and frequency; (4) the location(s) of performance, including relevant environmental parameters; and (5) energy consumption—measured in physical units or human effort. By focusing on components, one is able to distinguish between activities that might otherwise be lumped, such as the countless varieties of "cooking"; indeed, the investigator is forced to forgo abstract activity descriptions in favor of relentlessly empirical ones (Schiffer 1979a, 1979b). This degree of behavioral detail allows one to isolate the kinds of activity variability that affect artifact design.

Performance Characteristics of Elements

Each element in a given activity—whether person, artifact, or animal—has a set of interaction-specific capabilities known as performance characteristics (Braun 1983; O'Brien et al. 1994; Schiffer 1995b; Schiffer and Skibo 1987). For example, when a cooking pot and its contents are placed directly on the fire (Table 1), a number of performance characteristics come into play—i.e., are behaviorally relevant in that interaction—including heating effectiveness and thermal shock resistance.[2] In addition to the familiar performance characteristics dealing with mechanical, thermal, and chemical interactions, we call attention to a large family of sensory performance characteristics.

Sensory performance characteristics are based on the human senses of taste, smell, sight, touch, hearing, and pain. Visual performance characteristics, for example, might include an artifact's abilities to stand out from its surroundings and thus "catch the eye" of an observer (Schiffer 1992:135; see also Carr 1995:185–187), to direct the observer's attention elsewhere (Miller 1987:101), or to be seen at a distance (Wobst 1977)—performance characteristics that are behaviorally relevant in many marketing activities (e.g., Hawkins et al. 1992). Similarly, musical instruments have acoustic performance characteristics—e.g., those relating to loudness, frequency range, and tone—that are behaviorally relevant in activities of purchase, practice, tuning, and recital (for an archaeological study of acoustic performance, see Hosler 1994). In the stew cooking example, chemical properties of the stew sampled by the cook affect its performance characteristics of taste and smell. All senses, and thus all sensory performance characteristics, have a physicochemical basis (Coren et al. 1994). For example, visual performance characteristics depend upon electromagnetic radiation (in the human-visible portion of the spectrum) that an artifact reflects or emits (Brill 1980). Sensory performance characteristics also depend, of course, on human perception and cognition. Though still in its infancy in archaeology, the investigation of sensory performance characteristics is apt to become exceedingly important as we strive to put the study of all people-people and people-artifact interactions on a behavioral foundation.

Performance enables—or leads to—the progression from interaction to interaction of an element along its behavioral chain. Thus, on the basis of an element's performance(s) in a specific interaction, the next interaction takes place or is "cued" (cf. Miller 1985:181; Rathje and Schiffer 1982:63). Cuing may be explicit or implicit and also depends on the performances of other activity elements. Returning to the stew cooking case, an example is furnished by "tasting." In that set of interactions, the mechanical performances of the cook and tasting spoon along with the taste, smell, and visual performances of the stew sample typically cue either continued cooking or the initiation of serving activities. It must also be noted that the same artifact performance can cue different responses by different people, depending on their individual life histories—the specific sequences of activities in which they participated.

Relationships between Technical Choices, Formal Properties, and Performance Characteristics

Performance characteristics are strongly influenced by an artifact's formal properties, and the latter are determined by technical choices. Let us now consider, generally, these causal relationships.

Technical choices usually have tangible effects on an artifact's formal properties, and these effects can persist during subsequent ("downstream") activities. Thus, the technical choice of mixing equal amounts of sand temper and clay yields a coarse-textured and moderately porous paste. Those paste properties in turn influence the vessel's formal properties during post-mixing activities such as forming, firing, cooking, and maintenance. Technical choices that affect vessel shape and size have especially persistent consequences; similarly, properties imparted by slipping and painting are retained in most post-manufacture activities. Although formal properties can be modified—e.g., residues absorbed during cooking reduce a vessel's porosity (Mills 1984), heavy abrasion removes painted decoration, and extensive chipping alters rim shape—one can expect technical choices generally to influence an artifact's formal properties during downstream activities.

Through its influences on formal properties, *a technical choice can affect performance characteristics in many activities along an artifact's behavioral chain.* A case in point is vessels made with large amounts of fiber temper; compared to a sand-tempered equivalent, a fiber-tempered pot is more porous and less dense. As result of these formal properties, such vessels are, we suggest, less able to receive a smooth slip or a finely painted decoration, are more portable during transport (Skibo et al. 1989), have lower heating effectiveness in cooking over an open fire (Skibo et al. 1989), and are more susceptible to abrasion (Skibo et al. 1989; Vaz Pinto et al. 1987) in ladling and cleaning activities.

In recognition of further complexities, we affirm that *a given performance characteristic can be affected by many technical choices* (Schiffer and Skibo 1987). An example is furnished by thermal shock resistance during cooking. This performance characteristic, which is based on a host of formal properties ranging from porosity to vessel size, responds to technical choices in preparing the paste (Bronitsky and Hamer 1986; Rice 1987:366–368; Rye 1981:27; West 1992), shaping the vessel (Braun 1983; Rice 1987:368–369), applying interior and exterior surface treatments (Rice 1987:369; Schiffer, Skibo, Boelke, Neupert, and Aronson 1994), and firing (Rice 1987:106; West 1992). Similarly, visual performance characteristics, such as the ability of one potter's wares to be easily distinguished at a distance from the wares of another at a market, depend on the many technical choices affecting formal properties such as vessel size and shape, surface color, and painted decoration.

The complex effects of technical choices on performance characteristics, mediated by formal properties, impose technological constraints. That is why the artisan can rarely contrive a set of technical choices that achieves high values of all behaviorally relevant performance characteristics. Thus, any artifact design (i.e., a set of technical choices) is based on trade-offs or compromises in performance (Bleed 1986; Blinman 1993; Braun 1983; Horsfall 1987; McGuire and Schiffer 1983; O'Brien et al. 1994; Rands 1988; Schiffer and Skibo 1987). We return below to the issue of compromises in artifact design.

The Correlate Matrix

The specific effects of technical choices on formal properties and of formal properties on performance characteristics in the activities of an artifact's behavioral chain are described by principles called correlates (Schiffer 1975b, 1976:12–14, 1988). Correlates are experimental laws (Nagel 1961) and low-level theories that we, as modern scientists, formulate (Schiffer and Skibo 1987). Correlates include what is elsewhere called "techno-science" (Schiffer and Skibo 1987), "socio-science" (Schiffer 1992:136-137), and "ideo-science" (Schiffer 1992:137-138). Schematic examples of correlates can be found in the previous section. Needless to say, a firm grasp of relevant correlates is necessary (though far from sufficient) for explaining design variability. Although ethnoarchaeology, crosscultural studies, theory, and experiments are bringing to light countless correlates of many traditional technologies, correlates treating sensory—especially visual—performance characteristics have been slow in coming. Insofar as the clay cooking pot is concerned, principles of mechanical and thermal performance dwarf the few dealing with other kinds of interactions. In the following discussions, then, we are forced sometimes to contrive examples and to draw on other ceramic artifacts in demonstrating the framework's generality.

Eventually it should be possible to assemble and systematize the set of correlates for any kind of artifact; these codified principles would comprise a correlate matrix. We cannot yet provide a correlate matrix for the clay cooking pot (it would consist of hundreds of principles), but the abstract concept is still useful, for *a correlate matrix represents the totality of principles relevant to understanding all interactions in an artifact's behavioral chain activities*. Employing a correlate matrix, the investigator can (1) specify which technical choices were available, in principle, to the artisan for solving a particular performance problem, and (2) delineate the effects of any technical choice, through formal properties, on performance characteristics in behavioral chain activities.

Feedback to the Artisan on Artifact Performance

No artisan could have been aware of most principles in a correlate matrix. Through trial-and-error and other learning processes, however, the artisan discovers how particular technical choices affect an artifact's interaction- and activity-specific performances. Thus, on the basis of feedback from performance, the artisan learns the consequences of specific technical choices. This brings us to the pivotal principle of our framework: *any activity on an artifact's behavioral chain can, through feedback to the artisan about performance, lead to changes in the nature and sequence of technical choices*. This principle can also be phrased in selectionist terms: behavioral chain activities are the "immediate selective context" for technical choices (Schiffer 1996). (Selectionist discussions of technology are furnished, for example, by Neff 1992a and O'Brien et al. 1994.) As will become apparent below, this deceptively simple principle permits us to integrate myriad sources of design variability.

The effects of a technical choice may be most immediately discernible in downstream activities of procurement and manufacture processes. For example, a potter might discover that use of a certain clay causes the pot to warp and crack during drying (Blinman 1993; Vitelli 1984). On the basis of this rapid and reliable feedback, the potter can try out other technical choices, such as use of a different clay or the addition of sand temper. Similarly, a novel painted decoration may occasion ridicule from other members of a potter's work group, perhaps cuing the potter to destroy the vessel instead of firing it.

Whether an artisan obtains equally salient feedback on artifact performance in post-manufacture activities depends in part on the behavioral chain's social heterogeneity—the degree to which the social unit of activity performance undergoes changes from one activity to the next. Adding to social heterogeneity is differentiation in the social unit of particular activities, especially use. When social heterogeneity is low, as in the manufacture of pottery by a household for its own consumption, there is immediate feedback of high quality because the potter uses and maintains the same vessels that she or he made (Skibo and Schiffer 1995). Attached specialists (e.g., Costin 1991) may receive feedback from patrons on some post-manufacture performance characteristics of their products, but information on precise interactions is unlikely to match that available when artisan and user are one. As a behavioral chain's social heterogeneity grows even greater, the immediacy, quality, and quantity of feedback can decrease drastically. For example, craft potters in the modern United States who distribute their wares through galleries and specialty shops may obtain little feedback on the actual uses of their wares, much less on how well they perform in post-purchase activities. Industrial societies have the most socially heterogeneous behavioral chains, which can include many large corporations. Obtaining actual feedback in these cases, especially when the product has diverse use activities and user groups, is very difficult. Modern corporations seeking solutions to the feedback problem may employ laboratory simulations, focus groups, marketing surveys, and limited release of prototypes—all of which yield ersatz feedback of variable quality.

For certain artifacts, like vernacular structures, social heterogeneity is quite low, but owing to the artifact's long use life, feedback on performance has delayed effects on design (McGuire and Schiffer 1983); in these cases, users often remodel the structure to improve its performance. Feedback from post-manufacture activities may also be limited when the manufacture span of the artifact is very short, as in the annual models produced by many present-day corporations.

In an ideal world, feedback would enable the artisan to arrive at a suite of technical choices resulting in high values of all behaviorally relevant performance characteristics in all behavioral chain activities. In the real world, however, many factors beyond inadequate feedback contribute to design variability. One of the most significant is the artisan's knowledge and experience.

Knowledge and Experience of the Artisan

The influence of the artisan's knowledge and experience on design has been examined in studies of individual differences (Carr 1995; Hill and Gunn 1977), learning frameworks (e.g., Arnold 1984; Deetz 1965; Graves 1985; Hill 1970; Longacre 1970; Plog 1980, 1983; Smith 1962), perception and decision making (van der Leeuw 1984a), teaching frameworks (Schiffer and Skibo 1987), cultural transmission (Neff 1992a), technological style (Lechtman 1977), and technological tradition (Rye 1981:5; Schiffer, Skibo, Boelke, Neupert, and Aronson 1994). Moreover, in earlier generations of culture-historical research, many "explanations" involving migration, diffusion, or "influence" tacitly invoked knowledge factors.

It is possible to put knowledge and experience into more explicit behavioral terms (for additional discussions of knowledge in technology, see e.g., Keller and Keller 1996; Schiffer 1992:Chapter 7; Schiffer and Skibo 1987; van der Leeuw 1984a; Young and Bonnichsen 1984). To wit, differences in knowledge and experience can be treated as properties of artisans that arise from differences in their life histories. Thus, the sequence of activities in an artisan's life history influences his or her performance characteristics relevant to assessing feedback and, especially, creating and carrying out procurement and manufacture activities.[3] The result is that artisans have different repertoires of potential technical choices. This behavioral formulation clearly accommodates differences of the sort usually called individual expression or style, as well as similarities—at various social and spatial scales—in artisan performance (see Rathje and Schiffer 1982:Chapter 4).

In further developing this behavioral treatment of knowledge and experience, it is useful to adopt the vantage point of the artisan, in the present case, a potter. For traditional societies we identify several idealized possibilities:

1. The artisan learned the potter's craft in another community and already makes cooking pots.
2. The artisan manufactures ceramic objects, but not yet cooking pots.
3. The artisan makes no pottery, but uses pots from other communities as inspiration and models.
4. The artisan has neither experience in, nor a model for, working with clay, and so invents pottery making de novo. In this case, however, the aspiring potter may draw models and inspiration from different technologies that he or she commands or that are practiced by other artisans in the community.

Case 1 leads us to expect that, even in one village, potters who originally learned their craft in diverse communities or regions can employ quite different technical choices when making cooking pots. In cases 2, 3, and 4, artisans, beginning from rather varied starting points, learn experientially how, using new materials and techniques, to construct pots that perform acceptably in behavioral chain activities. The result will be sequences of technical choices, each of which doubtless differs in detail from that employed by any other potter. Clearly, differences in knowledge and experience owing to life-history variation can lead to differences in artisan performance—that is, to different sets of technical choices.

A possible example of the influence of the artisan's knowledge and experience on artifact design comes from early historic ceramics of the southeastern United States. On the basis of archaeological finds in South Carolina, Ferguson (1978) has inferred that the distinctive Colono ware—a coarse, unglazed pottery sometimes fashioned in European forms using non-European techniques—was made and used by rural slaves of African origin. Comparative research has shown that Colono ware may have incorporated technical choices from West African pottery-making traditions (Ferguson 1992; Orser 1990). (On the retention of Spanish Medieval and Renaissance pottery technology in New World traditions, see Lackey 1989.)

Regrettably, attributing variability to the artisan's knowledge and experience in the absence of historical or ethnoarchaeological evidence is fraught with difficulties, as generations of culture-historians discovered (Binford 1968). A common problem is that investigators, when invoking migration, diffusion, or influence as an "explanation," often focus on formal properties, not on technical choices. However, with new analytical techniques and principles now available for inferring technical choices and locations of artifact manufacture, this difficulty is diminishing. A more persistent problem is the failure to control for situational sources of variability. Our framework, which exploits many insights of ceramic ecology (e.g., Arnold 1985, 1993; Kolb 1988, 1989; Kolb and Lackey 1988; Matson 1965; Rice 1987; van der Leeuw 1984b; van der Leeuw and Pritchard 1984), is especially sensitive to the situational factors affecting design. Let us now consider these important factors in some detail.

Influence of Situational Factors

Situational factors are defined as the behavioral, social, and environmental externalities that impinge on the activities of an artifact's behavioral chain and are embodied in each activity's specific components. For example, a group's religious practices are responsible for where, when, with whom, with what, how, and how often a particular vessel is used in a given ceremonial activity. *Situational factors, through their effects on activity components, determine the ideal values of particular performance characteristics.*[4] Ideal values can range continuously from low to high, but for simplicity's sake we employ the dichotomy of weighted vs. unweighted; a weighted performance characteristic, then, is one that situational factors indicate should reach a high value. It must be stressed at the outset that ideally weighted performance characteristics are not always weighted in a design; in a later section we discuss the factors that affect actual weights.

Dispersed throughout this section are additional correlates not present in the correlate matrix; some are well established, but others are offered as hypotheses. With such correlates the investigator can link activity components to ideally weighted performance characteristics. As examples, we hypothesize that a pot subjected to daily abrasion by a sandy cleanser ought to be abrasion resistant; pots with water-saturated walls that are often exposed to freezing temperatures during storage should have resistance to freeze-thaw damage; vessels manufactured for sale to tourists who have limited transport capability ought to be portable (DeBoer 1983; Neff 1992a); and in the display activities of modern galleries, pots made by different artisans should perform in a visually distinctive manner (cf. Ehrich 1965:15). Future work in experimental archaeology, ethnoarchaeology, historical archaeology, and comparative ethnography will doubtless expand the corpus of such correlates.

The following discussions demonstrate with diverse examples how the investigator can use situational factors and correlates to construct expectations about ideal weights of performance characteristics. By drawing on the correlate matrix, we also indicate some of the technical choices available to an artisan for achieving higher values of performance characteristics. In conducting specific studies of design variability, one must follow an artifact's entire behavioral chain, interaction by interaction. For convenience of presentation, however, this section—organized on the basis of major life-history processes—omits many interactions.

Procurement of Raw Materials

In traditional societies, transport capabilities for acquiring potting materials commonly amount to what a person can carry in a basket. Moreover, when clay and temper procurement are embedded in other activities, such as visiting agricultural fields (e.g., Gosselain 1994), the latter constrain the distances a potter can travel in exploiting raw material sources. As a result of these situational factors, raw material accessibility should be weighted.

Dean Arnold's (1985) cross-cultural studies on procurement distances for clay and temper indicate that raw material accessibility is, indeed, weighted in most traditional societies. In a sample of 111 societies, Arnold (1985:38–51) found that although the distance traveled to a clay source extended to 50 km, in 33 percent of the cases clay within 1 km was exploited; what is more, 84 percent of the societies obtained their clay within 7 km. Insofar as temper is concerned, Arnold (1985:51–52) ascertained in a sample of 31 societies a similar pattern of local procurement: the extreme distance for obtaining temper was 25 km, but in 52 percent of the cases the distance traveled was only 1 km or less—and 97 percent of the societies secured temper within 9 km. In most nonindustrial contexts, then, weight is placed on exploiting clays and tempers that are easily procured.

The procurement of raw materials for slips and paints in traditional societies is a different matter. Because these materials are used in smaller quantities and obtained less frequently than clay and temper, ease of procurement should not be weighted. What is more, people might expend considerable effort in acquiring such materials when, for example, visual performance during post-manufacture activities depends on vessels having a certain color or a particular painted decoration. As expected, Arnold's (1985:52) comparative research has shown that slip and paint materials are often secured from sources that are tens—even hundreds—of kilometers away.

Manufacture

The manufacture process involves a host of situational factors that affect the ideal weights of sundry performance characteristics. For example, natural clays differ greatly in chemical and physical properties relevant to manufacture-related performance characteristics, such as plasticity, wet strength, drying shrinkage, and greenware strength (e.g., Bronitsky 1986; Rice 1987:54–78; Rye 1981:29–40; Shepard 1965:12–19). Thus, in areas where the clay lacks sufficient plasticity to be formed into vessels, paste plasticity should be weighted. Plasticity can be improved by technical choices such as aging or weathering the clay (Leach 1976:47) or adding organic matter (London 1981; Shepard 1965:52–53).

By influencing ideal—and often actual—weights of performance characteristics, forming techniques are also a potent source of variation in the manufacture process. Indeed, different forming techniques require weighting of different paste-workability performance characteristics (Rhodes 1957:27–45). For example, in the construction of very large, hand-built vessels, the paste should have a high drying rate (Rhodes 1957:28); similarly, a paste appropriate for making *raku* vessels—small, glazed pots that are fired very rapidly—ought to be highly resistant to thermal shock (Leach 1976:55–56; Rhodes 1957:192–193). Temper choice can enhance both paste-drying rate (Skibo et al. 1989) and thermal shock resistance (West 1992).

Another manufacturing factor expected to influence ideal weights of performance characteristics is the vessel manufacture rate. If the potter makes vessels often, especially in large quantities, then performance characteristics pertaining to ease of manufacture ought to be weighted. It is under these conditions, of course, that technical choices such as employment of the fast wheel or a division labor is likely to be adopted (see Costin 1991; Nicklin 1971; Rice 1981; van der Leeuw 1984b; Wright 1991).

The size and composition of the social unit of pottery manufacture also influence which performance characteristics are ideally weighted. For example, certain visual performance characteristics of vessels should be weighted when potters work together. A case in point comes from Zuni Pueblo, in New Mexico, where present-day potters striving to re-create traditional vessels assess each other's painted decorations, rejecting those that do not perform visually as "Zuni" (Hardin 1991). Where social heterogeneity is low, feedback from other members of work groups and potting "communities" (Arnold 1984) contributes importantly to the local-scale patterning in technical choices—and to the resultant similarities in artifact properties, especially painted decoration—that is so familiar to archaeologists worldwide.

Transport

Transporting pots from the production locale to the place of sale, exchange, or use is an activity that can vary in mode, distance, frequency of trips, number of pots moved, and kinds of terrain covered. Transport activities can affect the ideal weights of performance characteristics such as ease of carrying, impact resistance, nestability, and stackability (Rice 1987:240). If a large number of vessels is usually carried for long distances by people or pack animals, for example, then stackability or nestability ought to be weighted. Stackability and nestability can be enhanced by technical choices pertaining to body and rim shape (e.g., Rice 1987:240; Whittlesey 1974).

Distribution

The components of distribution activities vary greatly; sometimes the potter immediately becomes the pot user, whereas in more socially heterogeneous behavioral chains the potter and pot user are separated by the activities of traders, wholesalers, and retailers (see Majewski and O'Brien 1987). In distribution activities, which can include feasts, fairs, and shows, pots are usually displayed to prospective exchange partners or customers. On the basis of the visual, acoustic, and tactile performances of displayed pots (and sometimes their contents), exchange partners or customers make their selections (e.g., Aronson et al. 1994; Neff 1990).

Patterns of vessel acceptance and rejection furnish strong feedback to the potter on distribution-related performance (Foster 1965:52–55) and influence the ideal weights of performance characteristics (Majewski and O'Brien 1987). For example, Stark (1993:186–189) describes how Kalinga potters in northern Luzon, in the Philippines, have found that certain nontraditional forms—effigies in particular—perform well visually in distribution activities, and so are purchased; not surprisingly, potters have responded by increasing the manufacture of forms having great visual novelty (for Mesoamerican examples, see Neff 1990). In distribution activities involving participants from diverse communities, visual performance of vessels may allow purchasers to identify the potter's home community (Longacre 1991), which can in turn cue vessel selection. In the Lake Baringo area of East Africa, Hodder (1982a:43–44) reports that a Karau potter selling to Njemps people had to make pots that were visually identical to those of Njemps manufacture.

Archaeologists have doubtless underestimated the influence of distribution activities on artifact design (see the papers in Bey and Pool 1992);

even in nonmarket societies, visual performance during gifting and other exchange activities can lead to ideally weighted performance characteristics, furnish feedback to the artisan, and ultimately affect technical choices.

Use

Vessel design is especially responsive to situational variables of cooking, serving, and other use activities (e.g., Arnold 1985; Ericson et al. 1972; Hally 1986; Henrickson and McDonald 1983; Kingery 1990; Kobayashi 1996; Linton 1944; Miller 1985; Mills 1984; B. Nelson 1991; Rice 1987; Smith 1983, 1985). In terms of specific activity components, "cooking" exhibits enormous variation; even in one community, different cooking episodes (or "meals") can involve varying types and quantities of food (Kobayashi 1996) as well as differences in the size and age-gender-class affiliations of cooking, serving, and consuming groups. One can also expect intra- and intercommunity differences in what is cooked, for how long, and how often. Situational differences in meals can in turn affect the relationship of fuel and pot, mode of heating (e.g., boiling, simmering, steaming), extent of stirring, use of lids, the practice of pouring or ladling, the frequency of cooking, whether the pot is moved when hot, the amount of each food cooked at one time, the number of pots used simultaneously, and so on (Kobayashi 1996).

Differences in the components of cooking activities affect the ideal weights of many performance characteristics. For example, if fuel is scarce or costly and food is boiled for long periods several times a day, then heating effectiveness ought to be weighted (Schiffer 1990; Skibo 1994). To increase heating effectiveness, a potter can add more mineral temper (Skibo et al. 1989), change interior and exterior surface treatments (Schiffer 1990; Young and Stone 1990), or reduce wall thickness (Braun 1983). If food is usually ladled, then easy access through the vessel's mouth should be weighted; accessibility can be enhanced by enlarging the orifice (Rice 1987:241; Smith 1983:121–122) and adjusting rim shape. Empirical research has shown that the mechanical and thermal performance characteristics ideally weighted in use activities often do strongly influence cooking pot design (e.g., Hally 1986; Henrickson and McDonald 1983; Kobayashi 1996; Smith 1983, 1985).

Visual interactions can also figure importantly in a vessel's cooking and serving activities, and thereby influence ideal weights of performance characteristics. For example, when different foods are heated simultaneously in several pots, visual performances should indicate what each pot contains. Such visual discriminations may continue to be behaviorally relevant in the activity of transferring the pot's contents to serving vessels or to individual bowls or plates (De Cunzo 1995:72). To render the contents of a food-specific vessel identifiable at a glance, the potter can turn to technical choices that create differences in size, shape, or surface properties such as color or texture.

Visual performance characteristics are often ideally weighted in vessels taking part in religious rituals. Miller (1985) describes the participation of pottery in various Hindu ceremonies in central India. In weddings, for example, a set of 20 specific vessels (some of them used only in weddings) are placed in four stacks, outlining a sacred space in which to carry out an important ritual (Miller 1985:127–128). Needless to say, without the visual performance of these vessels to cue the ritual, a proper wedding ceremony could not take place (for examples from Classical Greece, see Weinberg 1965).

Similarly, when a vessel's use includes display in social activities, visual performance characteristics should be weighted (Skibo 1994:124). An example is maiolica tablewares from Renaissance Italy, whose ornate mythic scenes, painted on a specially prepared white ground (Kingery 1993), doubtless performed visually to visitors in a home's public areas, helping to cue people-people and people-artifact interactions. European porcelain is another good example (Lackey 1988).

To this point it has been assumed that the social unit of pottery use is relatively homogeneous. However, use activities themselves may involve more than one user group, with the result that use-related performance characteristics can receive varied ideal weights. For example, many families in Western societies have a set of tableware, the "good china," used mainly for feasts involving relatives and friends. On these ceremonial occasions, adults and children all eat from identical plates, but each age group differentially weights the plates' performance characteristics. In adult interactions, visual performance and difficulty of replacement (as in expensive or heirloom sets) should be weighted (Ehrich 1965:14–15); in children's interactions, more mundane performance characteristics ought to be weighted such as the plate's ability to prevent different foods from merging. Under some circumstances, of course, feedback to the artisan leads to the differentiation of designs (e.g., Kobayashi 1996; Miller 1985). Infants, for example, do not in modern times eat from the "good china," but have their own impact-resistant plates, bowls, and cups. We emphasize that an artifact's user groups may be differentiated on the basis of age, sex, gender, class, caste, place of residence, and various life-history variables—each with varied ideal weights of performance characteristics (Schiffer 1995b).

Storage and Retrieval

Ideal weights can also be influenced by situational variability in storage and retrieval activities intervening between use episodes. For example, cooking pots in some societies are stored adjacent to the hearth, whereas in others they are stored with noncooking pots in a specialized storage place. In the latter storage situation, if cooking vessels are retrieved frequently, then visual or tactile contrast ought to be weighted so that the cook can easily discriminate cooking pots from all others (which prevents, in some cases, an unpleasant taste that can arise from inadvertent mixing of flavors—e.g., Kobayashi 1996). Technical choices affecting size, shape, and exterior surface (texture or color or painted decoration) influence vessel distinctiveness.

The nature and availability of storage space, perhaps related to dwelling size, can also affect ideal weights of performance characteristics. For example, if storage space is severely limited, but many pots are stored together, then compactness, nestability, or stackability should be weighted; higher values of these performance characteristics can be achieved through technical choices that alter a vessel's shape and size. If the storage area has a hard surface, then pots resting on their rims—and retrieved often—could experience frequent chipping; under these conditions, a vessel's resistance to rim damage should be weighted. The potter can improve resistance to rim damage by adopting technical choices that influence the rim's shape, size, or orientation.

Maintenance and Repair

Maintenance activities are also a source of situational variation in artifact design. Cooking pots themselves are usually cleaned, but cleaning activities vary in frequency, manner of performance, and in other components. A pot cleaned often with sand and water, for example, should require a greater abrasion resistance than one washed in water alone. Abrasion resistance can be raised by altering the interior surface treatment, firing the vessel at a higher temperature, changing the kind or quantities of temper, and so on (Schiffer and Skibo 1989; Skibo et al. 1997; Vaz Pinto et al. 1987).

If pots are frequently lugged a long distance between locations of use and maintenance, portability should be weighted. Technical choices that enhance ease of carrying include the use of lower-density pastes and less paste per vessel, shaping the base so that it can rest on the bearer's head, and affixing handles. If several vessels are carried simultaneously by one person, then stackability or nestability ought to be weighted.

Ceramic artifacts—even cooking pots—are sometimes repaired (e.g., Senior 1995), but we are unable to contrive any expectations about ideal weights of repair-related performance characteristics. In the study of other kinds of artifacts, however, strong arguments have been made for the influence of repairability on design (e.g., Bleed 1986; Goodyear 1989; M. Nelson 1991).

Reuse

Reuse of ceramics—whole vessels, partial vessels, and sherds—is common, and so feedback from these activities could affect ideal weights. Ethnoarchaeological data suggest that vessels and partial vessels are reused in diverse activities, from storage of construction materials to burial of placentas (e.g., Deal and Hagstrum 1995), but we do not expect such varied interactions to influence ideal weights of performance characteristics. Rather, it is common for the reuser to remodel the ceramics by chipping and grinding (e.g., Deal and Hagstrum 1995:123–124). Even so, we hypothesize that if a particular reused artifact is channeled at high rates to only one new use, interactions in that use could affect ideal weights. For example, if most broken pottery is routinely recycled into temper, ease of grinding-up sherds should be weighted; firing vessels at a lower temperature is one technical choice that can enhance sherd "grindability."

Curate Behavior

For present purposes, the concept of curate behavior, introduced by Binford (e.g., 1979), is defined narrowly as the transport of a used item from one settlement to another. Among residentially mobile groups, pots are sometimes curated in anticipation of future use (Reid 1989; Skibo et al. 1989). If pots are frequently transported long distances by people-power alone, portability ought to be weighted. (See Maintenance and Repair, above, for technical choices that increase portability.)

Disposal

Many vessels, including cooking pots, reach the end of systemic context in activities of ritual deposition (Walker 1995). If particular pots commonly played a part in mortuary rituals and were deposited as grave furniture, performance in these rites—especially visual performance—should be weighted, even if the vessels had prior uses (e.g., Bray 1982). Thompson (1984:9) recounts how potters of ancient Athens placed offerings of their painted vases—"some of the finest black-figure and red-figure ever produced," including some with scenes of potters at work—at the Acropolis. Under these conditions, visual performance should have been weighted, and apparently was.

It is doubtful that ordinary (nonritualized) discard activities would affect ideal weights of ceramic performance characteristics. However, for other kinds of artifacts, especially in industrial societies, discard activities can influence ideal and actual weights. An example is biodegradable plastics that, alas, do not degrade in many landfills (Rathje and Murphy 1992).

Discussion

The situational factors embodied in the components of behavioral chain activities exhibit enormous variation. In the case of the cooking pot, situational factors range from the kinds and distributions of clay and temper resources, to variation in meals, to the composition of pottery-making and -using groups. Through their influence on activity components, situational factors determine which performance characteristics ought to be weighted in an artifact's design. We stress that *ideally weighted performance characteristics can pertain to any kind of interaction—thermal, mechanical, visual, etc.—in any behavioral chain activity.*

As already noted, however, in a given artifact design, ideally weighted performance characteristics are not always actually weighted. We now turn to two sets of intervening processes that influence actual weights: (1) the process of navigating the correlate matrix and (2) the compromise process.

Navigating the Correlate Matrix

In responding to feedback on performance, the tinkering artisan creates routes through the correlate matrix, exploiting the opportunities and respecting the constraints that the correlates delimit. In order to shed additional light on navigating the correlate matrix, we introduce a simple model, involving primary and secondary performance characteristics, that facilitates discussion of performance priorities.

Primary Performance Characteristics and Primary Technology

Because any technical choice can affect artifact performance in many behavioral chain activities, much experimentation may be required to reach a satisfactory sequence of technical choices. We propose that the artisan is guided through this process, at least initially, by the need to attain threshold values of certain primary performance characteristics. A primary performance characteristic is an ideally weighted performance characteristic whose threshold value must be reliably reached in order to permit or cue *any* interaction during downstream activities. Thus, there is an important sense in which downstream activities set threshold values. What is more, the order of primary performance characteristics on an artifact's behavioral chain dictates the order in which the artisan confronts—and has to solve—performance problems.

The correlate matrix permits us to appreciate that, in principle, several technical choices are usually available to the artisan for solving a specific performance problem. Each solution, however, can create new problems because of a technical choice's effects on other performance characteristics. Indeed, if a technical choice adversely affects one or more primary performance characteristics, then the artisan is obliged to continue experimenting with alternatives. What is more, as each performance problem is solved in turn, the artisan may have to tinker with previous technical choices. A successful artisan—and not all succeed—eventually hits on a sequence of technical choices that results in an artifact whose primary performance characteristics all reach threshold values. The set of integrated technical choices that arises from this trial-and-error process can be termed the primary technology.

Provisionally, we recognize six primary performance characteristics for a low-fired, clay cooking pot used on an open fire and having a socially homogeneous behavioral chain:

1. Paste workability. The paste must be sufficiently workable so that the potter can form a vessel of suitable shape and size.
2. Vessel dryability. After the pot is formed, it must be capable of drying without warping, excessively shrinking, or cracking.
3. Vessel firability. Vessels must survive firing without cracking badly or exploding.
4. Resistance to disintegration. The pot must hold liquid without decomposing into its constituent raw materials.
5. Thermal shock resistance. Vessels must survive repeated heating without shattering, cracking, or spalling badly.
6. Cooking effectiveness. The pot is capable of achieving an internal heating regime appropriate for cooking its contents.

Thus, in order that his or her pot progress from one interaction (and activity) to the next, the potter must attend diligently to achieving threshold values of these six primary performance characteristics.

Though perhaps lacking concepts like vessel dryability and thermal shock resistance, the artisan could nonetheless observe the tangible effects of inappropriate technical choices on performance because the results are so salient. Pots that explode during firing or that cannot hold water, for example, cue not the next interaction on the pot's behavioral chain but additional experiments. Thus, the earliest stages of experimentation should be driven by the need to reach threshold values of primary performance characteristics so that downstream interactions can proceed.

Artifacts participating in different activities, especially of use, have different sets of primary performance characteristics. Cooking pots used in stone boiling, for example, might have as primary performance characteristics only paste workability, vessel dryability, vessel firability, resistance to disintegration, and possibly heat retention (see Reid 1989).

Visual performance characteristics may also be primary. For example, the primary performance characteristics of a slipped-and-painted vessel employed prominently in a religious ritual most likely would include paste workability, vessel dryability, a surface capable of receiving a slip, a slip that could serve as the ground for painting the design, vessel firability, and certain slip- and paint-based visual performance characteristics that permit people to distinguish that vessel from all others. Clearly, a pot that does not perform appropriately could present an insuperable obstacle to interaction during use (for examples, see Miller 1985). Visual performance characteristics can also become primary in manufacturing and distribution activities. For example, as vessels are being made, potters pass judgments on their own pots and, when working in groups, on each other's; vessels that fail to reach threshold values of visual performance characteristics might not be dried or fired. And, of course, pots that fall short of threshold values of visual performance characteristics in marketing activities can fail to cue purchase.

Secondary Performance Characteristics and Secondary Technology

Usually after roughing out the technical choices of the primary technology, the artisan addresses the remaining weighted performance characteristics; these are termed secondary performance characteristics. The technical choices that produce acceptable values of secondary performance characteristics comprise secondary technology. In contrast to a primary performance characteristic, failure to achieve a high-enough value of a secondary performance characteristic is unlikely to truncate an artifact's behavioral chain. Thus, the development of secondary technology is a process of fine-tuning an artifact's design so that it can facilitate countless interactions.

In view of the centrality and coherence of the primary technology, we suggest that artisans, when fashioning secondary technology, tend to favor technical choices having largely benign effects on primary performance characteristics. A common result is that the artisan adopts increasingly "costly" technical choices. For example, in seeking to raise a vessel's heating effectiveness, the potter can turn to technical choices that decrease the permeability of the interior surface, such as an organic coating, polishing, or smudging (Schiffer 1990). Although creation of a low-permeability interior surface need not appreciably impair primary performance characteristics or modify the primary technology, new material-acquisition and manufacture activities might be required. A case in point comes from the Kalinga village of Dangtalan in the Philippines, where potters coat their cooking vessels with a pine resin. Not only must the resin be collected in a forest many miles away, but the material goes through laborious processing before it is applied (Longacre 1981). Moreover, application of the resin involves another tool, takes time, and requires skill. If this example is typical—and we believe that it is—then secondary technology often complicates procurement and manufacture processes by adding technical choices that are labor-, skill-, or material-intensive.

When viewed individually, the "costly" activities of secondary technology may appear to make little sense. These activities, however, cannot be understood in isolation, but must be situated in relation to an artisan striving to discover a suite of technical choices for attaining appropriate values of secondary performance characteristics without sacrificing primary performance characteristics or drastically affecting the primary technology's integrity.

We do not claim that the primary technology is never changed during artifact design or redesign. After all, depending on the correlate matrix (and serendipity), the artisan can discover a technical choice that improves secondary performance characteristics without degrading any primary performance characteristics. In addition, minor—especially quantitative—modifications of primary technology would seem to offer room for reduced-risk experimentation. In the case of cooking vessels, for example, the potter would have relatively wide latitude in experimenting with the amount of temper, wall curvature and thickness, and use of more or less fuel during firing. However, if situational factors alter dramatically, then both primary and secondary technologies can be expected to undergo substantial change.

Compromise in Artifact Design

With knowledge of situational factors and correlates, the investigator can build a set of expectations about which of an artifact's performance characteristics should be weighted. However, study of actual artifact designs, on the basis of estimated performance characteristics, will doubtless turn up many instances of ideally weighted performance characteristics that had little or no influence on technical choices. Compromised performance characteristics—ones that on the basis of situational factors should have been weighted in a design but were not—reveal the operation of additional processes that require attention.

In seeking to pinpoint the factor(s) at work, the investigator assesses, on the basis of reconstructed behavioral chains, the effects of social heterogeneity on feedback to the artisan. Where social heterogeneity is very high, inadequate feedback likely played a role in compromised performance characteristics, particularly in post-distribution activities. However, even where social heterogeneity is low, the investigator is apt to find that the artisan has forged some unhappy compromises. Let us turn to factors that can cause such compromises.

Technological Constraints

The correlate matrix often creates technological constraints that no amount of trial-and-error tinkering can surmount. For example, situational factors of use and maintenance in many societies would lead the investigator to identify impact resistance as a secondary performance characteristic that ought to be influential in cooking pot design (e.g., Braun 1983; Schiffer and Skibo 1987). Achieving high values of impact resistance poses a problem, however, because vessels must also reach the threshold value of thermal shock resistance during use—a primary performance characteristic. Almost inevitably, sufficient use-related thermal shock resistance comes at the expense of impact resistance. The reason is that most technical choices that increase resistance to thermal shock—e.g., more temper, lower firing temperature, thinner walls—also lower impact resistance. Moreover, as cooking pots age, they lose impact resistance because of accumulated damage from thermal cycling (Rice 1987:230; Tani 1994). As a result, clay cooking pots used on an open fire have excellent thermal shock resistance but, compared to other wares made by the same potter, may have poor resistance to impacts (this is reflected in the relatively short use lives of cooking pots—e.g., B. Nelson 1991). These kinds of compromises, which often arise in response to technical choices having polar effects (Schiffer and Skibo 1987), develop in the course of navigating the correlate matrix and can be expected in most artifact designs. Needless to say, identifying technological constraints requires the investigator to have an intimate knowledge of correlates.

A number of very general recurrent patterns in compromises disclose higher-order technological constraints in correlate matrices. One of the most common patterns is the sacrifice of ease of procurement and manufacture in favor of post-manufacture performance characteristics. These kinds of compromises are likely when post-manufacture activities have many weighted primary and secondary performance characteristics. The explanation for such patterns is simple: a suite of technical choices yielding high values of many post-manufacture performance characteristics is unlikely to have, as well, low requirements for labor, materials, and skill. Not surprising, then, as situational factors change, often leading to new performance characteristics with high ideal values, procurement and manufacture processes can become much more complex and costly (McGuire and Schiffer 1983; Schiffer and Skibo 1987; cf. Hayden 1981).

Conflict and Negotiation among Social Units of Behavioral Chain Activities

In cases of appreciable social heterogeneity, the actual weights of performance characteristics also reflect compromises produced by additional social processes. Building on ideas in McGuire and Schiffer (1983), we propose that, in the activities of different social units participating in an artifact's behavioral chain, dramatically different ideal weights may be assigned to performance characteristics. These "conflicts" lead to compromises in performance, often at the expense of one social unit's activities. In constructing explanations, it is helpful to model such compromises as stemming from conflict and negotiation processes between social units—conceived as groups or categories of people—over performance priorities (Conkey 1991; McGuire and Schiffer 1983; Schiffer 1995b). Clearly, this formulation puts into behavioral terms the seemingly vacuous claim that artifacts have politics (Winner 1986:19–39).

Compromises may be effected by a variety of specific social processes, and often reflect asymmetries of social power (Nielsen 1995). A good rule of thumb, no more than a convenient starting point, is that *social units with greater power are often able to convert ideally into actually weighted performance characteristics*. An example comes from the "institutional" ceramics purchased by prisons and dormitories for food consumption (see De Cunzo 1995). Two social units are relevant here, each with different performance priorities and, consequently, different ideally weighted performance characteristics: (1) the owners and managers of the institutions who purchase and maintain the pottery and (2) the people who actually use the ceramics on a daily basis. Relative to the former group, performance characteristics such as durability, ease of replacement, and cleanability ought to be weighted; relative to the latter group, weight should be placed on ease of carrying, food-holding capacity, and perhaps some visual performance characteristics. Because of the power asymmetry between these groups, however, institutional wares embody the design priorities of owners and managers, not those of the actual users. We would expect an identical outcome for negotiations between masters and slaves over factory-made pottery (see Otto 1977). Similarly, it can be hypothesized that recipients of second-hand pottery form powerless user groups whose activities and performance priorities have no effect on artifact design.

In the consumer products made by monopolistic or oligopolistic manufacturers in modern industrial societies, which have behavioral chains of extreme social heterogeneity, performance characteristics actually weighted in designs often pertain to activities of manufacture, distribution, and purchasing, whereas many use- and maintenance-related performance characteristics are badly compromised (Norman 1988). For example, visual performance characteristics of consumer electronic products in trade show, advertising, and retailing activities commonly have high values, whereas performance characteristics facilitating ease of use—e.g., controls that can be readily identified, easily grasped, and precisely manipulated—do not. In these cases it appears that, despite the existence of feedback (as when designers and engineers use the very same products themselves), consumers have little power to affect the designs relative to other social groups on the artifacts' behavioral chains. Sometimes, however, consumers can become empowered—through political action and governmental regulations—and influence design, as in the incorporation of passenger-safety devices into automobiles over the strenuous objections of the automakers themselves.

In other cases, structural asymmetries in social power do not lead to the expected outcome of a negotiation process. For example, the designs of many toys in the United States today appear strongly to reflect performance characteristics ideally weighted in the play activities of children rather than those ideally weighted in parents' purchasing activities. Apparently, the parents' structural social power in the family does not predetermine the result of every negotiation. This example allows us to stress that *conflict and negotiation should always be modeled as artifact-specific social processes*, because seemingly powerless people can influence a negotiation's outcome (for useful discussions of social power and negotiation, see McGuire and Paynter 1991; Orser 1996:Chapter 7).

Conflicts over the actual weights of performance characteristics between the social units of an artifact's behavioral chain activities can be resolved in many ways, including an explicit negotiation process, an implicit negotiation process, and the simple exercise of power (in the sense of "power over"—Giddens 1993:118). Regardless of how conflicts were resolved in a given case, these social processes are patently reflected in the compromise patterns exhibited by an artifact's performance characteristics.

Discussion and Conclusion

The theoretical framework presented here establishes a basis for formulating researchable questions on the causes of design variability in artifacts. Investigators, we suggest, are now compelled to ask new questions and to ask old questions in new ways.

Above all, we must abandon many cherished theoretical and analytic categories. No longer does it make sense to ask if technical choices were stylistic or functional, for these categories lack unambiguous behavioral referents among the myriad determinants of design variability. Even the categories of techno-function, socio-function, and ideo-function employed by behavioralists (e.g., Rathje and Schiffer 1982:65–67) now seem unwieldy for explanatory research (see Nielsen 1995). And, of course, asking if variability is technological or cultural simply is not meaningful. Apparently, the blunderbuss categories with which we have grown so comfortable are useless for setting forth precise and productive explanatory questions about design variability.

By identifying and integrating the many factors that influence artifact design, the present framework establishes a new standard for explanation. In constructing an explanation, the investigator must argue not merely that specific factors affected a design, but also demonstrate that others did not. Apparently, one cannot resolve problems of equifinality without controlling for the influences of all *potentially relevant* causal factors. Needless to say, this high standard of explanation entails a laborious and complex research process.

The investigator begins by placing the artifact's sequence of resource procurement and manufacture activities—technical choices—into its entire behavioral chain. Situational factors are then linked to the components of behavioral chain activities. Employing correlates that operate on activity components, the investigator enumerates sets of primary and secondary performance characteristics that ought to have been weighted along with their expected values. This requires, for each activity, a consideration of all people-people, people-artifact, and artifact-artifact interactions. Drawing on the artifact's properties (formal and otherwise), experiments, ethnoarchaeology, theory, the historic record, and other lines of evidence, the investigator estimates the actual values of an artifact's performance characteristics (e.g., Gould 1990:160–223). From these estimated values one ascertains which situational factors, in which interactions and activities, actually influenced the artifact's design. Employing performance matrices (Schiffer 1995b; Schiffer and Skibo 1987), one can readily discern compromises among performance characteristics. Compromised performance characteristics can, after appropriate investigations, be apportioned to other causal factors, including social heterogeneity affecting feedback to the artisan, insurmountable constraints of the correlate matrix, and conflict and negotiation processes. Remaining variability can be attributed to the effects of the artisan's knowledge and experience. Only through this systematic research process can one explain artifact designs rigorously and achieve an understanding of technology as a social process—a goal shared by many anthropologists (e.g., Appadurai 1986; Dobres 1995; Dobres and Hoffman 1994; Fournier 1995; Gould 1990; Lechtman and Steinberg 1979; Lemonnier 1992; McGuire and Schiffer 1983; Miller 1985; Nielsen 1995; Pfaffenberger 1992; Sassaman 1993; Schiffer 1991, 1992, 1993; Schiffer, Butts, and Grimm 1994; Wiessner 1983, 1984).

By the same token, it must be granted that explaining design variability is only one of many social issues surrounding technology. For example, in examining the role of artifacts in creating, maintaining, and disrupting social classes, the investigator is necessarily concerned with patterns of artifact "adoption" (Schiffer 1991, 1996; Schiffer, Butts, and Grimm 1994) or "consumption" (McCracken 1988; Miller 1987; Spencer-Wood 1987), which deal mainly with the quantitative, relational, and spatial dimensions of variability. Explanations of the latter kinds of artifact variability clearly require other bodies of theory (e.g., Miller 1987; Neff 1992a; O'Brien et al. 1994; Schiffer 1995b). Thus, the present theoretical framework is not relevant for investigating all questions about the social context of technology, only those dealing with variability in design.

It should be apparent that our theoretical framework has no place for the kinds of facile explanations of design variability that permeate the archaeological and anthropological literatures. On the one hand, postprocessualist explanations for the most part privilege mentalist definitions of symbol and meaning over behavioral ones, ignore situational factors despite giving lip service to "context," and fail to assess performance characteristics—of any kind—in behavioral chain activities. On the other hand, many processual (and some behavioral) explanations invoke societal complexity, agricultural intensification, or residential mobility without indicating, for example, how any of these factors impinged upon the components of behavioral chain activities, changed the mix of ideally weighted performance characteristics, affected feedback to the artisan, or influenced negotiation processes. Postprocessualists and processualists have contributed greatly to the present framework by identifying a host of potentially relevant causal factors, but their specific explanations are unsatisfactory.

Regardless of an investigator's theoretical orientation, rigorous explanations of design variability must be built on a behavioral foundation. And this demands a thorough grounding in correlates, behavioral chains reconstructed in great detail, estimated values of interaction-specific primary and secondary performance characteristics, inferences about the knowledge and experience of artisans, reconstructions of other pertinent behavioral, social, and environmental variables, and so on. Although presently we are quite some distance from meeting these requirements in any specific case, at last we know what it takes to achieve success at the explanatory level.

The example of the humble cooking pot has permitted us to showcase a theoretical framework that makes behavioral variation something to be expected. The immense design variability in artifacts is not caused by inscrutable "cultural" factors, much less by style and function, but results from people trying to solve the problems of everyday existence—conceptualized in terms of activity-specific interaction and performance—in different behavioral, social, and natural environments (see also Conkey 1991; Dobres and Hoffman 1994; Miller 1985). Explaining such variability rigorously will not be easy, but in principle it is possible.

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Notes

1 Participants in activities can sometimes solve performance problems by making changes in other (nonformal) dimensions of artifact variability (Schiffer, Skibo, Boelke, Neupert, and Aronson 1994). For example, poor thermal shock resistance of a cooking pot can be ameliorated by reducing the effective heat of the fire (through changes in fuel or in the spatial relationship between fuel and pot). Clearly, an even more general theoretical framework, focused on all behavioral choices, remains to be built.

2. Because a given kind of interaction can occur in several activities on an artifact's behavioral chain, some performance characteristics are less activity-specific—and thus are more generalized—than others. Impact resistance, for example, is a pot's ability to retain its strength and integrity after being repeatedly dropped or struck (Bronitsky 1986; Mabry et al. 1988). Because the latter interactions are possible in myriad post-firing activities, impact resistance is a fairly generalized performance characteristic. Another somewhat generalized performance characteristic is abrasion resistance (Schiffer and Skibo 1989).

3. In addition to knowledge and experience, other properties of the artisan, dependent at least partly on his or her biological substrate—e.g., size, motor patterns, perceptual acuities, and creativity—can also influence performance.

4. Technical choices, because they affect the components of behavioral chain activities, can also be included among the situational factors influencing the ideal weights of performance characteristics. A case in point is the discussion later on forming techniques and paste workability (see Manufacture).

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