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Theory and Experiment in the Study of Technological Change[1]

by Michael B. Schiffer and James M. Skibo

This paper sets forth a theoretical framework for investigating technological change. The presentation begins by positing three fundamental kinds of knowledge that inhere in all technologies: recipes for action, teaching frameworks, and techno-science. It is proposed that changes in technology require growth in techno-science, which results from the trial-and-error efforts of artisans striving to solve practical problems. Each technological solution embodies the new techno-science and leads to artifact designs that compromise various performance characteristics. The priorities that ancient technologies placed on particular performance characteristics can be studied by archaeologists using principles of modern science (from archaeology and other disciplines) augmented by new experiments. The utility of this framework is illustrated by a case study from the prehistory of the eastern United States involving the shift from Archaic to Woodland ceramic technologies. This example rests on a series of experiments that investigated the effects of temper type on ease of manufacture, cooling effectiveness, heating effectiveness, portability, impact resistance, thermal shock resistance, and abrasion resistance. In terms of these performance characteristics, Archaic and Woodland ceramic technologies appear to exhibit contrasts. Archaic ceramic technology placed a high priority on ease of manufacture and portability, whereas Late Woodland technology stressed heating effectiveness and performance characteristics that promote longer uselives. The priorities of these technologies provided workable solutions to the problems of pottery design in each society.

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This paper presents a provisional theoretical framework, built upon the efforts of Braun (1983) and McGuire and Schiffer (1983), for investigating—and ultimately explaining—changes in the processes and products of technologies. The utility of this framework is illustrated by a case study that focuses on the shift from Archaic to Woodland ceramic technologies in the eastern United States. The theoretical framework and case study both underscore the need for archaeological experiments to fill gaps in the modern scientific understanding of extinct technologies.

A technology is a corpus of artifacts, behaviors, and knowledge for creating and using products that is transmitted intergenerationally (adapted from Merrill 1965:576; see also Richter 1982:8). Traditionally, emphasis has been placed on inferring the specific sequence of activities employed by ancient artisans to produce a given form. Replicative experiments, formal and physicochemical analyses, studies of manufacturing tools and by-products, and other lines of evidence have gradually revealed how particular artifacts were made. At the

1. The experimental studies undertaken by the Laboratory of Traditional Technology on the effects of fiber temper on various performance characteristics were stimulated by Kenneth C. Reid's (1984*a*, *c*) hypotheses. We appreciate his collaboration and constant encouragement throughout this project. The research was supported in part by grants from the National Science Foundation (BNS-83-10609 and BNS-84-19935) to M. B. Schiffer and by gifts from Harcourt Brace Jovanovich and the Stephen Tyler Fund (of the University of Arizona Foundation) to the Laboratory of Traditional Technology. We thank Mettler Instruments, Setra Systems, Lab-Line Incorporated, Tekmar Company, GCA/Precision Scientific, Tenney Engineering, Discount Agate House, IBM, and Burr-Brown Research for donations of equipment used in the experiments. Jeremy and Adam Schiffer helped carry out the experiments on heating effectiveness. David P. Braun provided us with a stimulating discussion of an early draft of this paper; however, we did not always arrive at a satisfactory resolution of the issues he raised. John Douglas also supplied useful queries, few of which we were able to answer definitively. Hugh Aitken, Gordon Bronitsky, Richard Krause, William Longacre, Ben Nelson, John Olsen, Stephen Plog, Arleyn Simon, Vincas Steponaitis, and Alan P. Sullivan commented on various drafts. Russell Wiseman prodded the senior author into carrying out more experiments on workability than were originally envisioned, and these were very fruitful. David J. Hally kindly sent us copies of several references unavailable in Tucson.

same time, interest has grown in explaining variability and change in artifacts and in the technologies that produced them (e.g., Braun 1983; McGuire and Schiffer 1983; Hayden 1977*a, b;* Goodyear 1979; Rice 1984).

Archaeologists have proposed a number of high-level theories regarding the abstract determinants of artifact variability (e.g., Binford 1962, 1965; Dunnell 1978; Jelinek 1976; McGuire 1981; McGuire and Schiffer 1983; Plog 1980; Rathje and Schiffer 1982; Sackett 1977; Sullivan 1978; Wobst 1977). In practice, aspects of variability are partitioned according to the style-function dichotomy or in terms of utilitarian function (techno-function), social function (socio-function), and ideological function (ideo-function). Thus, the blade of a knife has a sharp edge because of its intended techno-function, cutting, whereas decoration on the handle is in accord with stylistic conventions and serves a socio- or ideo-function. In addition, it is recognized that some variability must be explained with reference to material properties (Jelinek 1976), for example, the difference between knives of stone and steel. And, of course, still other formal properties of artifacts owe their origin to formation processes such as recycling and deterioration (Schiffer 1983, 1987).

Although attractive and useful, this framework of causality has operational and theoretical problems. Operationally, it is difficult to partition variability into causal domains. Some type of residual model (McGuire 1981), whereby variability not attributed to materials, techno-function, or formation processes is assigned to socio- or ideo-function, is most frequently employed. Such operations must, however, be predicated upon reliable procedures and principles for identifying techno-functions, and these have not been adequately developed, nor are the available principles in widespread use. For example, temper is treated in many ceramic analyses as if it had only socio-functions. However, a number of investigations have begun to identify possible influences of temper on techno-function (e.g., Braun 1983; Bronitsky and Hamer 1986; Rye 1981; Steponaitis 1983, 1984), and it is now apparent that temper "choice" can no longer be considered a priori as entirely stylistic. Clearly, to put artifact analysis on a rigorous operational footing, the corpus of principles for understanding variability—especially those needed to partition variability into various causal domains (cf. Sullivan 1978)—must be expanded and applied more widely.

There are two main theoretical problems. The first is the gap between abstract determinants of variability and the specific forms taken by artifacts (Rice 1984). How do factors pertaining to social organization and basic lifeway—implicated in modern explanations of artifact variability—activate the hands of artisans? Resolution of this theoretical disjunction might provide an approach to artifact variability that admits of more definitive and testable explanations than those currently available (McGuire and Schiffer 1983). The second theoretical problem is that the present framework is essentially static. Although study of change is not precluded, attention is usually directed at accounting for variation within a given society or between contemporaneous ones. Ironically, we have so far largely failed to take advantage of the archaeological record as a unique source of information on long-term behavioral change (Plog 1974). To exploit its untapped potential will require modifications of existing theory.

In the remainder of this paper, provisional formulations are offered that perhaps can contribute in the long run to remedying these operational and theoretical deficiencies. The operational problem highlights the need to develop principles for identifying that portion of artifact variability attributable to techno-function. Theoretical concerns call forth effort to understand how abstract determinants of artifact function actually influence—and change—the behavior of artisans.

Knowledge and Technology

A useful place to begin is with the knowledge that inheres in technology. Although archaeologists have been reluctant to deal with this subject explicitly (for an exception, see Young and Bonnichsen 1984), assumptions about the knowledge in technology underlie all explanations of technological change. Indeed, archaeologists commonly make judgments—usually without justification—about what ancient artisans are likely to have known. An example is provided by the interpretation of corrugated pottery from the American Southwest. During the later centuries of prehistory, Anasazi and Mogollon potters created textured wares that were used for cooking and storage. Some archaeologists suggested that vessel exteriors were corrugated in order to enhance the transfer of heat from a cooking fire to the pot's contents. In opposing this hypothesis, McGregor (1965:282) commented that "this credits the makers with more reasoning intelligence than they probably possessed in such a matter." McGregor's statement is based on the implicit assumption that the scientific basis of nonindustrial technologies is not very sophisticated.

Additional assumptions are found in ethnoarchaeology, where investigators can observe and interview people participating in living technological traditions (e.g., Arnold 1971). The most common assumption, one that this paper takes some pains to refute (see also Young and Bonnichsen 1984), is that all technological knowledge is explicit and can be elicited from any practitioner of the technology. A second—equally dubious—assumption is that technological knowledge is composed entirely of science-like understanding. This latter assumption leads archaeologists to seek out ethnographic and ethnoarchaeological statements about *why* specific technical procedures are employed. In this way, anonymous informants are elevated in archaeology to the status of authorities on the scientific underpinnings of technologies. Similarly, experimental archaeologists learn a technology and use themselves as informants, offering seemingly definitive conclusions about the hows and whys of a technology. Unfortunately, these implicit assumptions have filled the literature with untested assertions about technological knowledge. Because these conceptions influence explanations and uses of informant statements, they should be scrutinized closely. Moreover, an appreciation for the complex and differentiated character of technological knowledge can help archaeologists build a more satisfactory theoretical framework for studying technological change. At the very least, it will facilitate a more critical handling of informant statements.

The Nature of Technological Knowledge

Technological knowledge has three essential components: recipes for action, teaching frameworks, and techno-science.

Recipes for action are the rules that underlie the processing of raw materials into finished products (Krause 1985:29–31). A recipe for action consists of (1) a list of raw materials, (2) a list of tools and facilities employed, (3) a description of the sequence of specific actions undertaken in the technological process, and (4) the contingent rules used to solve problems that may arise (cf. Merrill 1965:585). A recipe for action, then, attempts to summarize the knowledge which, if possessed by the artisan (or artisans), would account for the technological behavior. It must be stressed that *recipes for action are models built by the investigator* on the basis of visible behavior or its archaeological traces. Although informants are a valuable resource for constructing recipes in living communities, it should not be presumed that the practitioners of a technology can provide a complete or accurate verbal account of the rules that underlie their behaviors (cf. Laudan 1984*a, b*). The archaeological, ethnographic, and ethnoarchaeological literatures contain examples of recipes for action, and quite formal models have sometimes been constructed (e.g., Krause 1984, 1985; Young and Bonnichsen 1984).

Anyone who has attempted to learn a technology—be it glassblowing or haute cuisine—by studying recipes can readily appreciate why most technologies are passed down from generation to generation by means other than explicit rules. Thus, the second type of knowledge in a technology is embodied in its teaching framework, which fosters intergenerational transmission. A teaching framework consists of a series of practices that can include imitation, verbal instruction, hands-on demonstration, and even self-teaching by trial and error. Because the sine qua non of learning recipes for action is practicing the manipulation of materials, most teaching frameworks make extensive use of practical experience. Verbal instruction is also required, especially in more complex technologies, to provide aspiring artisans with essential cues for executing an action successfully. Thus, the transmission of technologies usually demands ceaseless practice and masters who, following tradition, can efficiently channel learning. By this process, teaching frameworks transmit that most intangible of all knowledge, know-how (cf. Hummon 1984). In addition to the knowledge that facilitates verbal and nonverbal instruction, teaching frameworks can involve toys and models as well as mnemonic devices, magic, parables, myths, and legends. The latter provide vivid narrative contexts for dry technical detail, thereby increasing the likelihood that recipes for action will be learned and put into practice correctly. A final element of teaching frameworks is *rationales*, the explanations that might be offered to a novice (or an inquisitive anthropologist) for particular aspects of a technological process. Responses can range from a detailed technical exegesis that resembles a scientific explanation to statements that reduce to the ultimate truth "that's the way we've always done it." As flexibly employed ideological statements, rationales promote the learning process by providing authoritative answers, thereby reinforcing the higher status of the master. In short, successful technologies include well-developed teaching frameworks that are transmitted, along with recipes for action, from generation to generation.

The third knowledge component of technology is techno-science, the principles that underlie a technology's operation. Techno-science accounts for why recipes for action lead to the intended product (cf. Bunge 1974:30) and why that product, once made, can perform its function(s). Because every technology rests upon a suite of scientific principles, it is tempting to regard technology simply as applied science. Recent scholarship in the history of technology has shown, however, that many principles of modern science were an outgrowth of technology, not the reverse (e.g., Layton 1971, Hughes 1976, Rapp 1974, Aitken 1976, Staudenmaier 1985, deSolla Price 1984). These studies stress that the technologist, striving to solve immediate practical problems, often stumbles into domains not previously explored scientifically (Skolimowski 1974). By using trial-and-error and more structured methods of experimentation the artisan forges new basic science in a technological context. DeSolla Price (1984) also points out that technologies bring into human experience (and sometimes into nature) entirely novel phenomena, ranging from molten metals to fired clay, the explanation of which often requires new technology-specific principles. In the technologies of nonindustrial societies, most techno-science is implicit and likely to surface only during times of experimentation (if at all). Thus, the death of a technology often means the death of its techno-science as well, since the latter is nowhere recorded. In the technologies of industrial societies much techno-science is documented and has been incorporated explicitly into teaching frameworks. Nevertheless, a great many artisans practice their craft in ignorance of the underlying techno-science. For example, it is doubtful that even today many makers of bread understand the fundamental principles of leavening and baking; nor do they need to, as long as they have learned well the appropriate recipes for action. The principles that describe the operation of all technologies are lower-level laws and theories (cf. Bunge 1974); for the technologies of prehistory (and often of history), these principles necessarily are *constructs of the observer, derived from modern science.*

The preceding discussion brings us to a number of assumptions about technological knowledge somewhat different from those usually found in archaeological and ethnoarchaeological studies:

1. The techno-science that underpins the operation of a technology is frequently not explicit.

2. Even when large parts of a technology's techno-science are explicit, individual artisans may be unable to articulate it.

3. When asked why a particular technological practice is carried out, the artisan usually draws upon the teaching framework for a response.

4. Without sufficiently well-developed modern science, the observer has no way of knowing whether such a response is techno-science, rationale, or mythology.

5. Observers must be aware of their own assumptions about a technology's techno-science when describing and explaining a technology "in action."

These theoretical assumptions lead us to formulate the following methodological principles:

1. All informant statements about the hows and whys of a technology, including those offered by archaeologist-practitioners, should be treated simply as hypotheses that do not necessarily have high prior probabilities (*sensu* Salmon 1982).

2. The techno-science content of a technology is revealed by applying the principles of modern science to its processes and products; these principles must be frequently augmented, especially in the case of dead technologies, by new experiments carried out by archaeologists under controlled conditions.

Before considering the sources of technological change, we want to stress that an understanding of the techno-science content of a technology is a prerequisite for explaining technological variability and change. In order to illuminate the techno-science embedded in any technology, archaeologists must develop their general understandings—modern science—to a high level of sophistication. The possibility that a technology can operate on principles unappreciated by the archaeologist is readily illustrated by the case of heat treatment in lithic technology. Ethnographic descriptions of stone heat treatment were once dismissed as fanciful by some archaeologists, because of their limited understanding of the principles of stone working. After experiments by Crabtree (e.g., Crabtree and Butler 1964) and others showed that heat treatment does improve the flaking properties of certain lithic materials, archaeologists accepted it as part of the flintknappers' repertoire of techniques. By seeking the traces of heat treatment in tools and debitage, archaeologists have found that this practice was common in prehistory. In addition, countless experiments in heat treatment have deepened our understanding of the process. Indeed, enough modern science is now at hand to permit the archaeologist to frame and test anthropological hypotheses to explain why heat treatment was used by some societies and not by others. Without a substantial foundation of modern science for identifying techno-science, archaeologists can scarcely hope to explain technological variability and change.

Technological Change: Sources and Processes

The principal source of technological change resides in the "functional field," the set of techno-functions, socio-functions, and ideo-functions that the artifacts in a society have to perform (cf. Rice 1984). The functional field, in turn, responds to changes in basic lifeway and social organization. For example, subsistence stress may lead to the adoption of a new crop. The behaviors involved in planting, tending, harvesting, transporting, storing, and processing that crop establish new techno-functions, thereby expanding the functional field. Some of these new functions may be carried out by existing artifacts, such as digging sticks, requiring no technological change. At the same time, changes in the functional field may cause practitioners of existing technologies (e.g., stone workers, bakers, potters) to undertake experiments aimed at creating a new product to perform the new functions. Processing a new crop could call forth innovations by stone technologists (for grinding), architectural technologists (for storage), and ceramic technologists (for cooking). If this crop eventually comes to have a central place in the diet, other activities will change, leading to additional perturbations in the functional field. As the plant is incorporated into social and ritual activities, new socio-functions and ideo-functions will be created, generating a demand for still more innovation. Sometimes it will be discovered that a society's technologies cannot supply the requisite items to cover the altered functional field, and so new technologies may be developed or adopted. In short, the ultimate source of most artifact innovations (and deletions) is changes in the functional field, which stem from factors of lifeway, social organization, and prior changes in the functional field (cf. Schiffer 1979).

The second source of change is feedback from the context of use when function is more or less constant. A technologist creates a form to carry out particular functions, but that form may not work well initially. In some cases the technologist will continue experimenting until a more satisfactory design is achieved. Even when an entire technology and a family of successful forms is adopted wholesale from elsewhere, one can expect feedback from use (and manufacture) to lead to more changes.

A third source of change, which becomes especially important where artisans are part- or full-time specialists who can profit (in any sense) from expanding the markets for their goods, is "producer pressure." This drive to innovate constantly—even when functions are unchanged—is most likely to develop when there is marketplace competition among artisans. For example, competitive conditions, perhaps as overall demand increased, probably stimulated the development of mass production techniques in those technologies in which it is feasible, such as pottery making (cf. Arnold 1985). Where production is small-scale and organized for local consumption, producer pressure of a sort can still arise. Some artisans might carry out experiments in order to find ways to minimize manufacturing effort or to improve performance characteristics. For example, where fuel for cooking and heating is scarce, artisans would have a constant incentive to make fuel-saving innovations in a variety of technologies.

This brief discussion of sources of technological change is obviously not exhaustive, but it does provide a starting point for identifying the situations in which artisans are apt to carry out experiments. (For a more detailed discussion of change with reference to pottery technology, see Rice 1984.) The artisan striving to innovate is faced with the necessity of conducting experiments in order to increase the techno-science content of a technology.

Every technological process involves a sequence of behaviors that results from specific technical choices. For example, a potter chooses one clay rather than another, adds much temper instead of little, and makes large coils in preference to small ones. In periods of technological stability, artisans are probably unaware of these choices; they simply follow the recipes. During periods of experimentation, however, the artisan becomes sensitive to alternative actions that might be taken and their consequences.

Technical choices determine the formal properties—attributes—of artifacts. Formal properties, in turn, affect performance characteristics, the behavioral capabilities that an artifact must possess in order to fulfill its functions in a specific activity (cf. Hally 1986; Klemptner and Johnson 1985:102). For example, performance characteristics of pottery relevant to the activity of "cooking over an open fire" include heating effectiveness, impact resistance, and thermal shock resistance (Braun 1983). Performance characteristics usually have optimal levels or states. For example, in the activity of butchering game, a knife should have the ability to cut cleanly, should be easy to grasp, and should not wear out quickly. Ideally, then, the tinkering artisan tries out different technical choices, attempting to optimize an artifact's activity-relevant performance characteristics. In practice, however, many performance characteristics fall short of optimal levels because of their complex causal relationships with technical choices and formal properties. (In the present framework, "optimal" must be defined with reference to local societal factors. For example, the optimal heating effectiveness of a cooking pot in a residentially mobile society with unlimited fuel supplies would differ greatly from that of a cooking pot used in a town with chronically scarce fuel.)

In general, each technical choice affects more than one formal property and performance characteristic. Not uncommonly, technical choices have polar effects: some performance characteristics are enhanced while others are degraded. For example, the decision to add large amounts of mineral temper to cooking pots affects a host of formal properties ranging from porosity to specific gravity. These formal properties, in turn, give vessels (1) improved thermal shock resistance and (2) greater heating effectiveness but (3) decreased impact resistance (Skibo, Schiffer, and Reid n.d.). In addition, each performance characteristic can be affected by many technical choices and formal properties. For example, the heating effectiveness of a ceramic cooking vessel is influenced by wall thickness and the pore structure of the paste, among others. These formal properties are affected by the potter's technical choices, such as the employment of particular forming techniques and the addition of specific kinds and quantities of temper. It is the discovery of these complex causal processes that contributes to growth of a technology's techno-science.

The absence of one-to-one relationships between technical choices and performance characteristics and the prevalence of polar effects make it difficult to design an artifact that optimizes the values of all activity-related performance characteristics. For example, if one attempts to optimize the heating effectiveness of cooking pots by making very thin walls, great losses in impact strength are incurred. Similarly, impact resistance can be improved by thickening the walls, but heating effectiveness will be degraded. These polar effects promote compromises in the design process wherein some—perhaps most—performance characteristics are realized at suboptimal but acceptable levels. Sometimes, of course, experimentation (or borrowing) leads to major breakthroughs by which it becomes possible to optimize several previously compromised performance characteristics (cf. Aitken 1976:129–30). For example, metal cooking pots have excellent heating effectiveness, superb thermal shock resistance, and great resistance to impact.

In the absence of breakthroughs, however, other technical choices may compensate for performance characteristics having unacceptably low values. Although some details remain to be confirmed experimentally and archaeologically, the Mississippian pottery of the eastern United States provides a case in point. The use of burned, crushed shell as a tempering material, the hallmark of Mississippian ceramics, improved the workability of excessively plastic montmorillonite clays (Million 1975) and may have increased thermal shock resistance (Bronitsky and Hamer 1986), especially in cooking wares (Steponaitis 1983, 1984). However, when shell-tempered wares are fired at 600–1,000° C (the usual range for open firings), calcium oxide is formed that later hydrates to calcium hydroxide. The resultant threefold expansion in crystal volume causes spalling ("lime-blowing") in the finished product (Rye 1981). This loss of surface integrity degrades several performance characteristics, including impact and abrasion resistance as well as visual impact. The Mississippians overcame these deleterious effects of shell temper by adding salt, which acts chemically to inhibit spalling and thus permits firing temperatures in the range of 800–900° C (Stimmell, Heimann, and Hancock 1982; Klemptner and Johnson 1985, 1986). (Curiously, the millennia-old technique of using chlorides to eliminate lime-blowing was rediscovered in this century and patented [see Butterworth 1953:860].) This example indicates that it might be useful at times to distinguish between *fundamental* and *derivative* technical choices, the latter being adopted primarily to compensate for the adverse effects of the former (for a parallel discussion regarding settlement choices, see Trigger 1978:190–91).

One can make a number of assumptions about how diligently artisans strived to create items that embodied favorable trade-offs in important performance characteristics. For example, it is tempting to assume that artisans would necessarily discover a combination of technical choices that provided the best overall compromise of performance characteristics. In the present framework, however, it is assumed only that experimentation was likely to continue until it led to a satisfactory—not necessarily the best—product. In particular, artisans could have made some dreadful fundamental choices, perhaps because of insufficient experimentation at the outset, and then experimented at greater length to solve the remaining problems with derivative technical choices. Early Woodland (Tchefuncte) pottery from the Lower Mississippi Valley provides an example. Gertjejansen, Shenkel, and Snowden (1983) carried out an extensive series of replicative experiments that have illuminated the problems faced by Tchefuncte potters. The substrate in that region consists mostly of montmorillonite clays that are extremely plastic; shrinkage is so great that drying and firing pots without severe warping and cracking is a formidable challenge, even for a modern potter. Tchefuncte potters chose this awful clay, despite the availability of somewhat less abundant, naturally tempered clays that would have performed better. Moreover, they did not add temper. Nevertheless, they discovered, probably by trial and error, that pots could be produced with their poor clays by lengthy drying, a long preheating period, and a very slow firing. In short, one need not assume that artisans found the *best* overall design that was possible under the circumstances.

In seeking to enhance use-related performance characteristics, the artisan learns that technological changes do not come without costs. For example, improving the performance of one or more use-related performance characteristics often leads to an intensification of manufacturing effort. As the example of Mississippian pottery intimates, new materials may have to be procured, sometimes at greater distances, perhaps through trade; raw materials may require processing for longer periods or in different ways; and manufacturing may necessitate new tools, facilities, or even social arrangements (Schiffer 1979). Thus, in any analysis of technological change, one must look closely at manufacturing processes themselves. In effect, one can consider "ease of manufacture" to be a family of performance characteristics specific to the activities of raw-material procurement and processing and item manufacture. Similarly, artifacts could perform well in use and be easy to manufacture but require high levels of maintenance or need replacement often. For analytical purposes, then, it is also useful to recognize "ease of maintenance" as another important family of performance characteristics related to the activities of keeping artifacts operational (cf. Bleed 1986).

McGuire and Schiffer (1983) have called attention to the necessity of compromising, in the design process of domestic structures, performance characteristics pertaining to manufacture, use, and maintenance. They argue that factors of social organization and basic lifeway determine the pattern of compromises in specific cases. For example, high residential mobility favors the use of houses that are easy to build but often difficult to maintain. In contrast, greater settlement longevity shifts the balance in favor of more manufacturing effort, which is repaid by houses that are easier to maintain and last longer. Thus, seemingly remote factors of lifeway and social organization *condition the acceptability of particular design compromises.* The artisan experiments and creates, but the success of the process or product—whether or not it is adopted—is determined by extratechnological factors. Eventually, the tinkering artisan, building on an expanded basic science, arrives at a series of technical choices that produce performance characteristics acceptable under prevailing societal conditions. These new behavior patterns, which probably represent a novel mix of design compromises, become stereotyped as recipes for action. Finally, teaching frameworks are altered to become congruent with the new recipes for action.

It is these static technological systems that ethnographers and ethnoarchaeologists describe. Yet, for the archaeologist, change processes are the most interesting. The archaeologist can observe the formal properties of artifacts and record their changes through time. Because these attributes are the consequences of technical choices and the basis of performance characteristics, the archaeologist has strong evidence for studying processes of technological change (Braun 1983). Moreover, the mix of performance characteristics for any given artifact will exhibit a pattern of compromises determined by that artifact's place in the functional field and by a society's social organization and lifeway.

Although formal properties are the archaeologist's window into processes of technological change, one must operate analytically at the level of performance characteristics. Fortunately, principles of material culture dynamics (i.e., correlates [Schiffer 1975, 1976]), in and out of archaeology, make it possible to link formal properties to performance characteristics. Even so, modern science has many gaps, especially in regard to extinct technologies, and these must be filled with new principles based on experiments if the behavioral aspects of technologies are to be understood and technological changes explained (cf. Steponaitis 1984, Klemptner and Johnson 1986).

Explaining Technological Change

The difficulties that attend the explanation of technological change should not be underestimated. It is obvious, for example, that a simplistic hypothesis-testing framework, concentrating on only one or two technical choices or performance characteristics, is not apt to illuminate a change process. Inevitably one must consider many performance characteristics if the *pattern* of design compromises is to be appreciated. In the final analysis, however, it matters not whether the search for explanation begins with hypotheses about change processes or with studies of particular performance characteristics, so long as the investigator appreciates the necessity of compromise in the design process. We now propose a simplified framework that can help to orient inquiry in specific cases.

It is assumed that the investigator desires to explain an instance of technological change, such as the replacement of one form by another. (Although many other kinds of technological change take place, we focus here on the simplest case.) The process begins with the construction of a *performance matrix* for each artifact. A performance matrix is a list of the performance characteristics thought to be relevant to all activities of each artifact's life history, from procurement through use and maintenance. For each characteristic, one estimates its performance value. When it is impossible to estimate this value precisely—even after experiments—one assesses the likelihood that the characteristic was heavily weighted in the design process. By comparing these weightings, one can identify patterns of compromise in performance characteristics that can be related, through correlates, to extratechnological factors. (This approach is used in the example below.)

In the next stage, one builds models that treat the performance matrix—and the compromises it embodies—as a set of outcomes resulting from specific technological choices influenced by the functional field and more remote variables of lifeway and social organization. This part of the process cannot yet be described in more specific terms. There is a dearth of principles for linking factors of lifeway and social organization, through the functional field, to design compromises. Indeed, by comparing performance matrices and testing hypotheses to account for their differences, archaeologists will be able to contribute to the establishment of an entirely new family of principles (for a beginning, see McGuire and Schiffer 1983).

Changes in the functional field, then, are the immediate causes of artifact change. Factors pertaining to basic adaptation and social organization impinge upon the functional field, requiring new functions and making old ones obsolete. By appreciating the patterned differences between the performance characteristics of artifact types, one has a basis for hypothesizing those factors of lifeway and social organization that might be responsible for the changes. Countless other lines of evidence can be used to evaluate these hypotheses. One can also begin the explanatory effort with specific hypotheses, perhaps seeking to use artifact changes to evaluate ideas about transformations in basic lifeway. The starting point makes no difference as long as one establishes appropriate linkages—with correlates—from adaptive and social factors through the functional field to compromises in the performance characteristics of artifacts.

As noted above, producer pressure also leads to technological—and artifact—change. This is most likely to occur in settings where household and village production of an item is superseded by remote, specialized manufacture linked to consumers by regionwide distribution networks. These systems are governed by different principles because the interests—and design priorities—of artifact users and makers do not coincide (McGuire and Schiffer 1983). Indeed, when there is a lack of intimate contact between artifact users and makers, design priorities and compromises can shift drastically in favor of the producer. For example, ease of manufacture, portability, and visual impact may come to dominate the design process at the expense of performance characteristics relating to techno-function. (Ironically, it is precisely in these more complexly organized systems that techno-science pertaining to techno-function may be lost.) Thus, organizational factors make it possible for producer pressure to create technological changes.

The Archaic-to-Woodland Ceramic Transition

The earliest known pottery-making tradition in the United States appeared during the Late Archaic period, around 2500 B.C. in the Southeast (Steponaitis 1986, Shannon 1986, Stoltman 1966). Some authors (e.g., Jenkins and Krause 1986:30–47) refer to the pottery-making pre-Woodland societies of the Southeast as the "Gulf Formational stage." However, we will adhere to the traditional Archaic and Woodland constructs. In any event, the manufacture of fiber-tempered pottery continued, in some areas, to about 500 B.C. (Jenkins and Krause 1986:31).

The recent discovery in the Kansas City area of fiber-tempered sherds in Late Archaic contexts (Reid 1984*a*, *b*) has raised the possibility that such wares originally were more widespread in eastern North America. Indeed, Reid (1984*a*) has suggested that the Southeast is a preservational enclave in which fiber-tempered wares were not destroyed by freeze-thaw processes. Our experimental studies provide some support for this claim (Skibo, Schiffer, and Reid n.d.). For purposes of the following discussion, we accept the possibility of a fiber-tempered ceramic technology over much of eastern North America in Late Archaic times. That even in many parts of the Southeast fiber-tempered pottery is not particularly abundant (e.g., Griffin 1972, Stoltman 1972) suggests that it was susceptible to a variety of destructive environmental processes, including breakdown from long-term water saturation (cf. Skibo and Schiffer 1987), perhaps as a result of low firing temperatures.

The product of this early ceramic technology is a distinctive ware tempered with various organic materials, including Spanish moss (Simpkins and Allard 1986), palmetto palm (Brain and Peterson 1971, Crusoe 1971), and prairie tallgrasses and sedges (Reid 1984*a*). Although a dearth of restored vessels (and quantitative sherd analyses) hampers accurate description of vessel morphology, fiber-tempered pots appear to have been made in a limited number of forms, mainly small flaring bowls and jars (e.g., Jenkins and Krause 1986:34; Walthall 1980:88). Bowls may have predominated, especially in the earliest times (e.g., Griffin 1945, Sears and Griffin 1950). Bases are typically flattened, and the wall-base join is often quite angular (e.g., Caldwell 1952:313; DeJarnette 1954:275; Milanich and Fairbanks 1980:156; Walthall 1980:88). Vessel walls tend to be highly variable both in thickness and in degree of surface smoothing (Sears and Griffin 1950; Shannon 1986), and little control was exercised over firing conditions (cf. Crusoe 1972:96). Although plastic surface decoration such as incising and punctating is widespread (Sears and Griffin 1950, Jenkins 1975), fiber-tempered pottery is, overall, the quintessential crudware.

The beginning of the succeeding Woodland period is marked by the appearance of ceramics that often contain large amounts of mineral temper. The earliest Woodland vessels resemble fiber-tempered wares, however, in that they are usually thick-walled bowls or short jars with a flat or conical base (e.g., Ozker 1982:71; Griffin 1983:254; Smith 1986:35). Later in the period vessels acquire hemispherical bases and a more typical jar shape. By the end of the Woodland period, vessel forms have proliferated in some areas, and it is likely that these ceramics were also performing social functions. It appears that great care and skill went into the manufacture of many Woodland vessels.

Culture-historical units such as Late Archaic and Early Woodland are stages marked by particular trait constellations, and these stages are not contemporaneous throughout eastern North America. Thus, our efforts are devoted to explaining a shift in ceramic technologies that occurred at different times in different places. Moreover, if Reid's freeze-thaw hypothesis turns out to be limited in applicability, the shift may not have occurred at all in certain regions. Despite our global view of these change processes, it is in the context of local adaptations that rigorous testing of our scenario needs to be carried out.

Although we repeatedly refer to the transition between Archaic and Woodland pottery, our focus is on explaining the technological change from fiber- to mineral-tempered pottery. An explanatory sketch is offered to account for salient aspects of this technological transition. By identifying differences in the performance characteristics of the pottery produced by each technology on the basis of experiments and principles in the literature, we can pinpoint the factors that apparently had the greatest influence on vessel design. A comparison of these design priorities for Archaic and Woodland pottery furnishes a basis for exploring changes in the societal contexts of these ceramics that might have promoted the technological change. In this way, we show how changes in the large-scale aspects of past adaptations can be linked to changes in technology. Heretofore, there has been little interest in the techno-functional analysis of fiber-tempered pottery. An important study of Woodland ceramics based on principles of ceramic engineering has, however, recently been performed by Braun (1983), and the present discussion draws heavily upon his thoughtful work (see also Steponaitis 1984).

Braun (1983) tracked trends in a number of ceramic attributes throughout the Woodland period in western Illinois and eastern Missouri. He concluded that technological changes such as the acquisition of hemispherical bases and the decrease in wall thickness indicate that heating effectiveness was becoming more important, and he linked this emphasis with the increasing dependence for food on starchy grains that had to be boiled for long periods to improve their digestibility. Presumably, as greater reliance was placed on this food preparation technology, potters would have discovered by trial and error, for example, that a decrease in wall thickness markedly improves heating effectiveness. However, an immediate effect of thinner walls is to reduce impact strength. This adverse effect was offset, according to Braun, by changes in vessel shape (more rounded) and temper size (reduction of large particles). Braun's provocative analysis provides a baseline for investigating the design factors and performance characteristics of fiber-tempered pottery. In particular, one might expect that heating effectiveness was not assigned a high priority by Archaic potters. Similarly, it can be anticipated that impact strength was equally unimportant. Because Early Woodland vessel forms are similar to those of fiber-tempered wares, we believe that the temper change itself is the key to identifying the performance characteristics that were important in Late Archaic pottery technology. After all, much of the clay used for fiber-tempered wares already contained sand (Crusoe 1972); the organic matter was usually added deliberately.

To obtain some understanding of Archaic ceramic technology, we undertook an experimental program aimed at quantifying potentially important performance characteristics of fiber-tempered pottery. Unlike Braun, we could not rely solely on available principles of ceramic engineering, because the effects of temper on ceramic performance in low-fired wares are not well understood (cf. Bronitsky 1986). Moreover, even when extant principles permit one to predict the direction of an effect, experimentation is still needed to determine if the magnitude of that effect is sufficient to have been *behaviorally significant.* For example, a change in impact strength occurring at the third decimal place could not have been detected by ancient peoples—i.e., was not behaviorally significant—and so could not have influenced ceramic technology. Obviously, making judgments about what might have been behaviorally significant is difficult; we are aware that our judgments are fallible. (Perhaps specific claims about behavioral significance can be grounded eventually in cross-cultural laws of human perception.) In any event, by conducting experiments, we have gained a better appreciation for the techno-science that underlies fiber-tempered pottery technology, thus furnishing a basis for explaining the transition to Woodland ceramics.

Our selection of performance characteristics to test was influenced by extant hypotheses about the possible beneficial effects of organic temper. For example, a number of investigators (e.g., London 1981, Matson 1965*a*) have suggested that fiber temper, by creating large pores in the fired pots, would permit stored water to permeate to the exterior surface, where it would evaporate, thereby cooling the vessel contents. Reid (1984*a*) has proposed that the pores created by the burned-out fiber would also promote good thermal shock resistance. In addition, on the basis of a preliminary cross-cultural survey, Reid (1984*c*) has shown that residentially mobile groups that add temper often make use of organic material (see also Skibo, Schiffer, and Reid n.d.). These findings have led Reid to suggest that fiber temper might have been chosen to improve impact resistance and portability. Additional hypotheses regarding the benefits of organic temper, in the literature of the Southeast and elsewhere, treat properties such as paste workability and drying rate (for summaries, see Skibo, Schiffer, and Reid n.d.). Drawing upon these ideas, we identified a set of performance characteristics that *might* have been affected by temper choice: ease of manufacture, cooling effectiveness, heating effectiveness, portability, impact resistance, thermal shock resistance, and abrasion resistance. Experiments were undertaken on briquettes or replicated vessels to quantify these performance characteristics in relation to untempered, fiber-tempered, and mineral-tempered wares. We now turn to a discussion of the experimental findings (for a complete account of experimental materials, procedures, and results, see Skibo, Schiffer, and Reid n.d.).

EASE OF MANUFACTURE

Ease of manufacture is really a family of performance characteristics, none of which is particularly easy to quantify (Bronitsky 1986).

Plasticity is an important performance characteristic that facilitates forming. That organic matter can improve plasticity is widely recognized (e.g., Shepard 1965:52–53; London 1981). However, in the eastern United States, where natural clays abound with adequate—often excessive—plasticity (Million 1975; cf. Norton 1952:22–26), it is doubtful that organic matter would have been needed to increase plasticity. Thus, our experiments investigated other possible effects of organic temper on the workability of already plastic clays.

To examine the effect of temper on the rate at which workable paste loses water and stiffens (the paste-drying rate), a simple drying test was carried out on a sample of briquettes of three paste compositions: untempered, fine-sand (less than 1.0 mm) tempered (38.5% by dry clay volume), and horse-manure-tempered (38.5% by dry clay volume). (In this and all subsequent experiments, horse manure, which was chosen to represent many organic tempers, was used untreated.) The rate of water loss was monitored by weight reduction, and the time required for the clay to become leather-hard was noted. The results (expressed as mean time to reach the leather-hard stage) indicate that manure temper causes slightly more rapid drying (3.75 hours) than untempered paste (4.25 hours), but sand temper yields a much more rapid drying rate (2.50 hours). The lackluster performance of manure temper should not be surprising; after all, plant fiber is mostly cellulose, a material well known for its water retention.

In order to discern the practical import of these rather clear-cut variations in paste-drying rate and to detect any other differences in workability, we made small coiled bowls from the same pastes and recorded our subjective impressions of their working properties. Although the sand-tempered paste did dry more quickly than that tempered with manure, the latter had a surprisingly good ability to support even out-curved walls. This wet strength probably results from the lightness and fibrous texture of the paste. In all other respects, the organic-tempered paste was no better in workability than the sand-tempered paste.

Although unsophisticated, these tests did disclose differences in workability that may have been behaviorally significant: (1) sand-tempered pastes have the highest paste-drying rate, and (2) organic-tempered pastes have the greatest wet strength in small vessels. The advantage in wet strength of organic-tempered pastes could have compensated, at least in part, for a slower drying rate, thereby permitting rapid vessel construction.

The effort required to procure and process different tempers also influences ease of manufacture, but such effects are not readily quantified. For example, the tempers had to be gathered—but we do not know from what distance. Nonetheless, that organic materials were at times cut to size (Reid 1984*a*) suggests an added manufacturing cost that could easily have been avoided by the use of sand temper.

On the basis of an extensive series of petrographic sections, Crusoe (1972:13–14, 22) reports that the paste of fiber-tempered wares often exhibits a laminated structure. According to Gertjejansen, Shenkel, and Snowden (1983:46), a laminated structure derives from inadequate clay preparation, in this case, a failure to mix clay and temper thoroughly. Very poor mixing is unlikely to result from adding temper to dry, powdered clay; it would appear that the fiber temper was added to wet unprocessed clay. The likelihood that fiber was mixed into wet clay suggests another possible effect of organic temper: the rapid drying of excessively wet or plastic clays. One can expect that in areas of high rainfall and humidity such as the eastern United States, clays were sometimes—perhaps often—procured too wet for forming into vessels. The addition of any dry temper would have reduced excess water and lowered plasticity, perhaps to the point of making the clay immediately workable. The magnitude of the effect of temper on clay drying will depend on (1) the volume amount of temper, (2) the surface area of particles, and (3) the water-absorption capacity of particles. Holding constant the volume of temper, we expect fine sand and, especially, dry organic matter to be the most effective clay-drying agents.

We carried out a simple test to determine if the predicted differences in temper type on clay drying are behaviorally significant. Water was added to a dry clay until it formed a sticky mixture having the consistency of fresh pudding. Temper was then added gradually until the paste reached acceptable workability. The required amounts of temper, expressed as the volume ratio of temper to original dry clay, varied markedly: horse manure (1.04), fine sand (1.93), and coarse sand (2.47). Both horse manure and fine sand produced pastes that, although highly tempered, could be readily formed into coils. At optimum workability, however, the coarse-sand paste had the consistency of wet concrete and was scarcely workable. We judge these differences to be behaviorally significant.

During the Late Archaic period, when potters apparently did not devote much time to clay preparation, excessively wet or plastic clays could have been quickly turned into workable pastes by the addition of dry organic matter. If clay drying was the main function of organic temper, then the amount of fiber should vary greatly from vessel to vessel, depending on the original moisture content of the clay (J. Jefferson Reid, personal communication, 1986).

Ease of manufacture is also affected by the techniques used for vessel forming. Sears and Griffin (1950) state that fiber-tempered vessels were formed by working a single mass of clay; this is known as pinch-pot technique (Nelson 1966). However, the height of some fiber-tempered pots (e.g., 28 cm [Jenkins 1972]) and the rectangular shape of others (e.g., Milanich and Fairbanks 1980:156) suggest that additional forming techniques were used. One possibility is the rudimentary technique of slab construction. This technique simply involves creating and joining slabs of clay (see Nelson 1966:145; Rye 1981:71) and is taught today to aspiring potters in our own society—usually before coiling or throwing—because almost anyone can learn quickly to make a slab pot. Using a slab technique or perhaps a small number of flattened coils (cf. Gertjejansen, Shenkel, and Snowden 1983), Archaic potters could have made their pots *at one sitting,* without the need for thinning or intermediate drying stages, because the near-vertical thick walls can support themselves. Finally, it should be noted that slab technology requires no tools except, perhaps, a scraper.

To examine these propositions, several typical fiber-tempered vessels were built using slab techniques. Slabs were made entirely by hand pressure applied to fist-size balls of clay. A round slab was used for the base, and a few roughly rectangular slabs were added to make the walls; slabs were joined by slight overlapping. Joining the slabs and smoothing the walls (with a wooden scraper) almost inevitably resulted in a flaring form. Construction (including slab making) required about 15–25 minutes. In one case, when the experimenter began with very wet clay, the entire process—from pudding-like clay to completed vessel with decoration—took about 35 minutes. Although suggestive, this replicative experiment cannot show how the Archaic pots were made, for that inference requires technological study of the prehistoric sherds. Nonetheless, it helps support the suggestion that the fiber-tempered wares of the Southeast, employing ubiquitous raw materials and simple forming techniques, were very easy to make (relative to later wares).

Drying of the fiber-tempered vessels in the laboratory took 3–4 days. In more humid Louisiana, replicated Tchefuncte vessels—essentially untempered—required 4–14 days to become bone-dry (Gertjejansen, Shenkel, and Snowden 1983:55). Although long drying times do not translate directly into more manufacturing effort, there is a greater opportunity for accidental vessel breakage. (Long drying times also suggest that Archaic vessels were made at settlements having occupation spans in excess of several weeks.)

After forming and drying but before firing, pots are rather susceptible to breakage. It is well known that organic materials—often called binders—strengthen greenware bodies, whereas mineral temper (including grog) weakens them (e.g., Onoda 1978, Williamson 1978). The beneficial effects of organic temper on greenware strength are attenuated on already plastic clays, such as those preferred by preindustrial potters. Although we did not devise a test for this performance characteristic, it should be kept in mind that Archaic greenware bodies were probably less likely to break during handling than the mineral-tempered vessels of the Early Woodland period.

A final factor we considered that affects ease of manufacture is the probability of failure during firing. As noted elsewhere (see "Thermal Shock Resistance"), fiber-tempered pottery had an adequate degree of thermal shock resistance to survive firing. However, in our experience these wares are susceptible to failure during *rapid* firing because of moisture retention. When the temperature rises too rapidly, the water turns to steam in the vessel walls, shattering the pot. Thus, somewhat more care is required in firing than with sand-tempered wares (cf. Gertjejansen, Shenkel, and Snowden 1983). This impediment could have been overcome by derivative technical choices such as very slow firing or water smoking—the preheating of vessels (Shepard 1965:83).

Taken together, these various aspects of ease of manufacture suggest to us an expedient ceramic technology, one that was easily taught and just as easily practiced. In the Late Archaic, a high priority was placed on keeping pottery technology simple.

COOLING EFFECTIVENESS

In order to test the evaporative cooling hypothesis, we compared the cooling effectiveness of three paste compositions (untempered, 28.4% large sand [1.0–2.0 mm], and 28.4% horse manure) using replicated whole vessels—in this case bowls—fired at 650° C. (Temper concentrations were calculated on the basis of volume ratio to wet clay.) By cooling effectiveness we mean the amount of temperature drop provided by evaporative cooling. The weight of water lost (as an index to permeability) and water temperature (as a measure of cooling effectiveness) were monitored, usually over 19.5- and

TABLE 1
Effects of Temper on Cooling Effectiveness during Typical 19.5-Hour Periods

Temper Type	650° C Firing: Water Loss (g)	650° C Firing: Water Temp. (°C)[a]	919° C Firing: Water Loss (g)	919° C Firing: Water Temp. (°C)[b]
Sand	47.5	19.6	66.5	19.0
Manure	42.3	19.6	48.6	19.0
Untempered	35.9	19.6	37.8	18.9

[a]Air temperature 22.7° C.
[b]Air temperature 23.0° C.

24.0-hour periods. Then the pots were refired at 919° C and the experiment was repeated. The findings for both firing temperatures were clear-cut and surprising (table 1): although vessels differed greatly in permeability (with sand-tempered the highest and untempered the lowest), there were no differences in water temperature. Apparently all vessels—regardless of paste composition—possessed sufficient excess permeability to cause the maximum temperature drop (between 3.0° and 4.5° C, depending on temperature and humidity in the laboratory). Further experiments carried out with heat guns aimed at the vessels did produce differences in cooling effectiveness that were correlated with permeability. The latter findings suggest that under extreme conditions of use (e.g., in very arid environments when used as containers for hard water, which would eventually clog vessel pores), sand- and organic-tempered vessels would retain their cooling effectiveness longer. Thus, the likely high permeability of Archaic fiber-tempered wares could have made them suitable as long-lasting evaporative coolers.

However, several factors suggest that paste composition would not have had behaviorally significant effects on the cooling effectiveness of Archaic pots. First of all, in the high humidity of the eastern United States, evaporation rates tend to be low. Thus, any low-fired vessel having sufficient temper to survive firing would probably possess more than enough permeability for maximum evaporative cooling, even if vessel pores began to clog. Second, in view of the probable fragility of the Archaic vessels, it is doubtful that they would have lasted long enough to undergo much clogging. It should also be noted that sand temper would have been as effective as organic material at providing excess permeability.

On the basis of these findings we conclude that cooling effectiveness was not a performance characteristic that greatly influenced the design of Archaic fiber-tempered wares.

HEATING EFFECTIVENESS

Most investigators believe that fiber-tempered wares were cooking pots. In a cross-cultural study, Mills (1985) found that mobile peoples often employ flat-bottomed pots to cook meat, providing some support for the inference that Late Archaic pots were used for cooking (but see Smith 1983:273–74).

Principles of ceramic engineering allow us to formulate general expectations about the effects of temper on heating effectiveness (e.g., Kingery 1960:499–508). The sand, having a higher thermal conductivity than the porous paste it replaces, should improve a vessel's ability to transfer heat. Although organic temper increases porosity, the pores are large; according to Grimshaw (1971:936–40), large pores conduct heat better than small ones (holding constant the total volume of pores). Thus, sand-tempered vessels should have the greatest heating effectiveness, followed by those with organic temper and no temper. To determine if these predicted effects of temper on heating effectiveness are behaviorally significant, we carried out a series of experiments in which water was boiled in the pots used previously to assess cooling effectiveness. We placed 200 ml of water in each bowl and then heated it over a gas burner. The time required to boil water (table 2) and the curve of temperature rise were recorded. As predicted, the water in the sand-tempered vessels, despite their slightly greater thickness, heated up most rapidly and boiled first. Water in the organic-tempered bowls came within 1–2° C of boiling but did not boil. We attribute this problem to the greater absorption of water by the vessel walls, which appreciably reduces heating effectiveness (cf. Tankersley and Meinhart 1982:230). Nevertheless, water in the organic-tempered vessels initially heated up more quickly than that in the untempered bowls, suggesting that with the use of effective coatings fiber-tempered vessels would have had greater heating effectiveness than untempered wares.

It should be recalled that fiber-tempered wares often contained sand. Thus, the addition of organic temper to such clays probably would not have had a behaviorally significant impact on heating effectiveness. In any event, the combination of sand and organic tempers yielded a paste that certainly had greater heating effectiveness than untempered equivalents but less than Woodland wares with more mineral temper.

As noted previously, thickness and vessel shape also influence heating effectiveness. The often thick walls of fiber-tempered vessels obviously do not promote rapid

TABLE 2
Effects of Temper on Heating Effectiveness

Temper Type	Mean Water Temperature (°C): 3 min.	5 min.	7 min.	Minutes to Boiling or Peak Temperature
Sand	46.4	71.4	92.4	7.8
Manure	43.8	66.0	86.1	10.0
Untempered	41.6	64.5	84.8	8.7

heat transfer. Moreover, the openness of these bowls is not highly conducive to good heat containment (Hally 1986:280). On the other hand, a vessel with low walls and a flat base can have most of its exterior surface in contact with the fire, a configuration that could have compensated, at least in part, for thick walls and great openness.

All this suggests that heating effectiveness was not given a high priority in Late Archaic pottery technology. This fits well with Braun's (1983) conclusion that heating effectiveness became progressively more important during the Woodland period. Nevertheless, the fiber-tempered pots would have been serviceable cooking vessels, especially if fuel was not scarce or if cooking with pottery was a minor component of food preparation technology.

It has been assumed above that Archaic pots were used for cooking over an open fire. If, alternatively, they were employed for stone boiling, heating effectiveness becomes irrelevant. In stone boiling good heat transfer by the container is undesirable. In addition, the open shape would facilitate introduction and removal of water, hot rocks, and whatever was being cooked. Thus, for stone boiling, thick walls and openness are not liabilities. Indeed, with a resinous coating or skin lining, an Archaic vessel could have been used very effectively for stone boiling. Clearly, effort must be devoted to determining Late Archaic and Early Woodland cooking practices, perhaps through ceramic use-wear analysis (e.g., Hally 1983).

PORTABILITY

Portability of ceramic vessels is complexly determined by several factors, the most important of which are shape, size, wall thickness, and density of the fired clay. Shape influences how easily something can be carried, for example, whether it nests readily with other loaded items. An open vessel allows nesting and so promotes portability. Obviously, smaller vessels are more portable (cf. Smith 1983:270–71), and most fiber-tempered pots are relatively small (for cooking pots). However, walls are frequently thick. The final component of portability, density, was calculated directly from the volume and weight of briquettes containing various kinds and amounts of temper. It was found that briquettes with 25–40% organic temper (by volume ratio of temper to wet clay) are 20–30% less dense than equivalent briquettes with sand temper. This large difference would have had a palpable effect on vessel weight and is certainly behaviorally significant. Fiber-tempered pots would have been more portable than mineral-tempered wares (holding the other factors constant). We conclude that portability could have been a performance characteristic important in the design of Archaic fiber-tempered wares.

IMPACT RESISTANCE

Impact resistance was assessed by means of a falling-weight impact tester (Mabry et al. n.d.). In this test, steel balls are dropped on 8-cm-square specimens from increasing heights until breakage. The height at breakage is used as a relative measure of impact strength. Test briquettes of five paste compositions (untempered, grass-tempered, manure-tempered, fine-sand-tempered, and coarse-sand-tempered) were fired at 550° C, 650° C, 750° C, and 850° C. The general results were in accord with theory: tempered briquettes were less resistant to impact than untempered ones (Shepard 1965:25–27). Sand-tempered briquettes turned out to be slightly stronger than organic-tempered ones overall (table 3). Differences in strength between paste compositions increased at higher firing temperatures—again, in accord with theory (Grimshaw 1971:879–80). In our view, it is doubtful that differences in impact strength between tempered wares at the low firing temperatures that were probably typical for fiber-tempered wares (see "Abrasion Resistance") are behaviorally significant.

TABLE 3
Effects of Temper on Impact Strength at Various Firing Temperatures

Temper Type	Mean Height at Failure (cm)[a] 550° C	650° C	750° C	850° C
Organic	40.37	42.13	43.69	48.06
Sand	41.43	44.13	47.69	54.93
Untempered	42.71	45.88	50.86	60.50

[a]Ball height above the base of the impact tester; actual heights above specimens are somewhat less (see Mabry et al. n.d.).

The falling-weight impact test simulates only one failure mode, that of a moving object striking a stationary pot. Ignored are differences in strength that would affect failure when pots are dropped. In this dynamic failure mode, vessel weight plays an important role, since the force of impact is a function of object mass (Miller 1977:61). Thus, in this failure mode, the lower-density (hence lighter) fiber-tempered wares would most likely have greater impact strength than otherwise equivalent sand-tempered wares. Other factors that influence failure in both modes include the presence of resinous coatings, vessel shape, and wall thickness. Coatings could have been applied to reduce permeability, and Reid (1984*c*) has suggested that the sandwich structure formed by coatings might increase impact strength. To test this proposal, additional impact tests were carried out on briquettes coated with a thin layer of shellac (to simulate a variety of organic resins applied to vessel surfaces). The coatings, it turned out, did not significantly affect impact strength. In any event, coatings could have been applied to any paste. Regarding vessel shape, it should be noted that the open shape of fiber-tempered vessels, with angular joins at the base, is the antithesis of the globular form that is most resistant to impact (Braun 1983). Thicker walls and joins would increase resistance to impact, but only in the stationary failure mode. Thicker (and thus heavier) pots would be more likely to break when dropped.

High firing temperatures dramatically increase many ceramic strength properties, including impact strength. The low firing temperatures that may perhaps be assumed for fiber-tempered wares would have rendered them rather vulnerable to breakage.

The above discussion suggests that impact strength had little influence on the design of fiber-tempered wares.

THERMAL SHOCK RESISTANCE

All ceramics must possess some degree of thermal shock resistance to survive firing, and cooking vessels must be capable of withstanding repeated thermal shocks. This performance characteristic was tested using briquettes of the five paste compositions, fired at 650° C, using the procedures of Bronitsky and Hamer (1986). Briquettes were alternated between boiling water and ice water. After 20 cycles, the residual strength was measured with the falling-weight impact tester. The findings indicate, again in accord with theory (cf. Kingery, Bowen, and Uhlmann 1976:541, 829–30), that untempered wares have the least resistance to thermal shock. Relative to unshocked briquettes, the untempered briquettes lost much strength. However, the tempered specimens—whether organic- or sand-tempered—did not undergo any significant strength reductions after thermal shock. These results suggest that the addition of fiber—or any temper—probably would have conferred an adequate degree of thermal shock resistance on the Archaic wares. In the Woodland and Mississippian periods, when thermal-related performance characteristics seem to have been accorded a much higher priority (Braun 1983; Steponaitis 1983, 1984), further refinements in technology may have been made to improve thermal shock resistance. It is doubtful that thermal shock resistance was an influential factor in the specific choice of organic temper by Archaic potters.

ABRASION RESISTANCE

Abrasion resistance, the ability to withstand abuse from scratching and scraping, is required of cooking vessels if they are to survive repeated cleanings. Briquettes of the five familiar paste compositions and four firing temperatures were employed in a barrel-tumbler test of abrasion resistance (Skibo and Schiffer 1987, Vaz Pinto et al. 1987). Weight loss of briquettes was calculated for each type of briquette after two hours of tumbling in pea gravel. As in our previous studies of abrasion resistance, organic-tempered wares proved the most readily damaged by abrasion. Depending on other factors, such as temper size and shape, mineral-tempered wares can be either more or less resistant to abrasion than untempered wares. Two additional findings help to place these results in perspective. First, the differences in abrasion resistance of various paste compositions decrease at higher firing temperatures. Second, firing temperature has a far greater influence on abrasion resistance than paste composition. Although the firing temperature of Archaic fiber-tempered wares is not yet known, we may suppose, on the basis of the rudimentary techniques of manufacture and the intact fibers sometimes found (Crusoe 1972:13), that it was not very high. In further support of this contention we note that Crusoe (1972:114), who examined a great many fiber-tempered sherds from all over the Southeast, indicates that "most of the fiber-tempered potsherds are extremely friable." Scratch tests of fiber-tempered sherds (Shannon 1986) disclosed a range of Mohs hardness from 2.0 to 3.0—which is quite low. Thus, it can be tentatively concluded that fiber-tempered pots had low abrasion resistance.

Clearly, the choice of organic temper and probable low firing temperatures together demonstrate that abrasion resistance was not a performance characteristic that affected the design of Archaic fiber-tempered pottery.

DISCUSSION

Having investigated a number of performance characteristics of Late Archaic pottery, we can draw upon Braun's (1983) techno-functional analysis of Woodland ceramics to compare the products of the two technologies.

Rather than listing specific values for performance characteristics, we have simply indicated whether or not each characteristic seems to have been assigned a *high* priority by the technology (table 4). (In view of the likelihood that vessels in both technologies were used mainly for cooking, cooling effectiveness is not treated further.) The patterns are rather clear-cut. Archaic technology placed a high priority on ease of manufacture and portability, whereas Woodland—especially Late Woodland—technology stressed heating effectiveness and characteristics that promote longer uselives (e.g., impact resistance, thermal shock resistance, and abrasion resistance).

The priorities of these technologies make a great deal of sense when each is viewed in relation to the society in which it functioned. Late Archaic pottery was made expediently by a society that was mainly hunter-gatherer

TABLE 4
Comparison of Performance Characteristics for Late Archaic and Woodland Pottery Technologies

Performance Characteristic	Late Archaic	Woodland
Ease of manufacture	+	−
Heating effectiveness	−	+
Portability	+	−
Impact resistance	−	+
Thermal shock resistance	−	+
Abrasion resistance	−	+

in subsistence base. Although domesticated plants were present (Ford 1979), the available evidence suggests only slight reliance on horticultural resources. The resource base is thought to have been broad-spectrum, including seeds, shellfish, and small terrestrial animals, the exploitation of which required a variety of "gadget technologies" (Hayden 1981). While cooking in pots was part of the repertoire of food preparation techniques, we doubt that it was in any way central. Most likely, ceramics were adopted because cooking in a pot—even if it took the form of stone boiling—would require less attention than cooking in skins or with hot rocks in baskets. In a society increasingly dependent on a wider range of foodstuffs, some possibly needing more preparation than before, the cooking pot may have represented a technological simplification. Easy to make (and perhaps to carry from camp to camp), the Late Archaic cooking pot could have freed busy hands for more demanding tasks.

On the basis of the association of Late Archaic fiber-tempered wares and shell middens in the Southeast, Stoltman (1974:233) suggests that ceramic containers were developed in order to facilitate the live transport and boiling of shellfish. This idea merits careful consideration in view of the common occurrence of early pottery in maritime settings. However, better understandings of pottery survival and of the regional archaeological record of Late Archaic manifestations might weaken the pottery–shell-midden association. Stoltman also believes that Late Archaic peoples were central-based wanderers (Stoltman 1972:52) or sedentary (1974:233), but his main evidence for the latter possibility is the practice of pottery making itself. As already noted (Reid 1984*c*; Skibo, Schiffer, and Reid n.d.), residentially mobile groups can and do make pottery. Another view, perhaps more widely held, is that Late Archaic populations in the Southeast shifted their residences seasonally, returning during the dry season to the same riverine camps for many years (Smith 1986:31–32). Conceivably there was variation in Late Archaic settlement systems, especially between coastal and interior riverine societies (cf. Steponaitis 1986:375–77).

The ways in which Late Archaic and Early Woodland lifeways differed cannot be specified definitively. Moreover, one can expect regional variability in adaptive patterns and, consequently, in ceramics (cf. Braun 1985: 527). It is clear, however, that agricultural resources remained a minor component of the diet in Early Woodland times. Ozker (1982:78–79), who believes that residential mobility was still important during this period, offered a provocative discussion of the functions of Early Woodland pottery: "Schultz Thick and other early thick wares were introduced not for culinary improvement but were initially an innovation that made possible significant additions to the subsistence system. . . . pottery vessels made possible the reduction of a nutritionally valuable but awkward snack food into a rich, compact, easily transportable food: nut oil." She further suggests that these vessels were easy to make and could have been discarded at the abandonment of the seasonal camps where nut processing took place. The possibility that Early Woodland vessels were treated as "disposables" or abandoned as site furniture (*sensu* Binford 1979:264) is intriguing and merits further study. Certainly, with large amounts of mineral temper, those vessels were less portable than the earlier fiber-tempered wares, but they would have had greater heating effectiveness.

In the following centuries, dependence on agricultural resources increased, as did residential stability (cf. Smith 1986:50–53). By Late Woodland times, use of ceramic vessels to cook starchy agricultural grains had apparently become important. As Braun (1983) has pointed out, these changes in diet and cooking procedures had profound repercussions on ceramic technology. When ceramic vessels play a pivotal role in food preparation, performance characteristics that relate directly to cooking will be given a higher priority. Late Archaic and Early Woodland pots would have heated their contents slowly and wasted fuel. Moreover, they would have been relatively fragile and prone to excessive wear. As these liabilities became more obvious, potters would have begun to experiment in order to improve those performance characteristics that, in a new functional field, were deemed crucial. This shifting of design priorities led to a vastly expanded techno-science that is clearly reflected in the products of Late Woodland ceramic technology.

These technological changes were not without costs. In particular, gains in use-related performance characteristics were made at the expense of ease of manufacture. For example, the manufacture of Late Woodland pots would have required various tools for thinning vessel walls and much more time. Moreover, the skill level needed for making these vessels was undoubtedly high, and so teaching this technology probably involved considerable effort. One can anticipate, then, that the teaching framework for passing on Late Woodland pottery technology had become fairly complex.In short, the compromises evident in this ceramic technology reflect a common pattern in which manufacturing processes become more elaborate and costly in order to produce a product that performs better in use. In traditions in which the socio-functions of ceramics become paramount, one finds enormous expenditures of manufacturing effort to enhance visual impact (for extreme examples, see Kingery and Vandiver 1986).

Ceramic manufacture in Late Woodland times was a sophisticated technology resting on an impressive foundation of basic science hard-won over the millennia by the experiments of creative artisans. It is doubtful, however, that Woodland potters had formed explicit concepts of heating effectiveness or could articulate the relationship between temper size and thermal shock resistance. Thus our lack of informants from the past does not hinder our ability to explain technological change; the priorities of each technology are strongly reflected in the performance characteristics of the resultant artifacts. Clearly, the compromises that influenced technical choices in Archaic and Woodland ceramic technologies indicate that factors of basic lifeway that impinged upon the functional field eventually activated the hands of potters.

The explanatory sketch presented here is, of course, highly provisional; many of its assumptions could be undermined by future research. Moreover, much variability has been homogenized to permit a focus on the main features of these technological changes. Nevertheless, this scenario will be useful if it leads to productive research and, ultimately, to better explanations.

Conclusion

The grand sweep of archaeological time furnishes us with a unique laboratory for studying technological change. The archaeological record contains evidence relevant for reconstructing technologies and the societies in which they functioned. Following Braun's (1983) lead, we have suggested that the most fruitful way to approach the explanation of technological change is to make comparisons on the basis of performance characteristics relevant to each society's functional field. These comparisons reveal how much priority was placed on achieving optimal values of each performance characteristic. Explanations, then, seek to show technological change as a response to an altered functional field in a larger societal context. This approach to the explanation of technological change has been illustrated with a case drawn from eastern North America, the transition from Archaic to Woodland pottery. The earlier work of Braun had identified the performance characteristics stressed in Late Woodland times and their likely cause; our study has extended Braun's analysis into the Late Archaic period. We anticipate that experimental archaeology, dedicated to exposing the basic-science underpinnings of dead technologies, will come to occupy an important role in the explanation of technological change.

Comments

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Petrie (1904:15–16) described pottery as "the greatest resource of the archaeologist." Although archaeological interest in this medium has not changed, many of the procedures for investigating pottery have. Shepard (1965) recognized a trend toward more physical and experimental techniques when she summarized ten years of ceramic analysis in her foreword to the fifth printing of *Ceramics for the Archaeologist.* A sequential examination of recent anthologies of pottery studies (e.g., Matson 1965*b*, Fry 1980, van der Leeuw and Pritchard 1984) confirms that this research focus has been intensified during the last two decades. Schiffer and Skibo's experimental analysis of the different technological characteristics of Archaic fiber-tempered and Woodland mineral-tempered pottery is part of this growing research emphasis.

Although the tremendous potential of experimental and technical ceramic studies has proven seductive, to date these analyses have achieved varying substantive results. Generally, the most convincing and significant of them (e.g., Braun 1983, Steponaitis 1984) do not necessarily employ the most sophisticated or "scientific" technologies but rather (1) endeavor to understand long-term processes of cultural change (e.g., technological, exchange, production), (2) incorporate, whenever appropriate, additional, independent lines of contextual evidence (experimental or archaeological) to support the interpretive positions derived from the technical analyses, and (3) use analytical materials and methods that conform to or closely approximate the artifacts and activities being modeled. Schiffer and Skibo have focused on an interesting case of technological change, and their experimental analyses have achieved several potentially useful (though preliminary) results. However, some aspects of their experimental design (and hence certain interpretations) are not supported convincingly, and the study as a whole might have been enhanced by fuller context-specific (Archaic-Woodland transition) and comparative (other cases of fiber temper) analyses.

Although ceramic engineers are finding that clay is extremely complex, different clays having distinctive properties, Schiffer and Skibo tell us little about the specific clays used experimentally in their study. How do they compare with those employed by the different Archaic and Woodland potters? Furthermore, while the experimental results may be relevant for horse manure, how do we know that manure is an appropriate proxy for fibers? For example, Rye (1981:33–34) has observed that organic tempers may not all have the same effect on clay plasticity.

I also question whether Archaic vessels actually were more portable than their Woodland counterparts. Density is only one relevant consideration. Vessel-wall thickness, rather marked for many Archaic containers, is another, as is size. In addition, how truly portable are vessels that are neither abrasion- nor impact-resistant? A look at a few other archaeological instances of fiber-tempered ceramics (Kidder 1968; Hole, Flannery, and Neely 1969: 115; Yen 1982) suggests that, as with the Eastern Archaic, fibrous inclusions were often used during early stages of pottery making but are not *necessarily* associated with residential mobility.

While I am unconvinced by the relevance of "portability," I agree with the authors that "ease of manufacturing" may be a relevant attribute for understanding Archaic fiber-tempering. Expediency considerations extend beyond the specific process of vessel manufacturing, however, to include the ease of procuring the various materials that could have served as temper (see also Rye 1976:112). Having recognized the various costs of working without temper, Archaic potters may simply have opted for lightweight, readily available, easy-to-process vegetal fibers as inclusions. Finally, rather than viewing the later Early Woodland shift to mineral tempers as related to a switch to more "disposable" vessels, I suggest that this change was the result of a selection for more durable vessels (more impact-, abrasion-, and thermal-shock-resistant), perhaps a response to a more consistent or intensive use of ceramic containers during the Woodland.

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Schiffer and Skibo's analytical framework is systematically sound, well argued, and theoretically promising. The authors' emphasis on middle-range-theory building, i.e., attempts to specify precise relationships between the concepts we use and the classes of empirically observable phenomena we encounter, is certainly welcome. Welcome, too, are their attempts to overcome the static bias that inheres, if sometimes subtly, in much of the work we do. Their division of the essential components of a technology into (1) recipes for action, (2) teaching frameworks, and (3) techno-science is eminently reasonable. Nevertheless, for sufficiency's sake, recipes for action should be divided into recipes for fabrication and recipes for use. Customary modes of artifact manufacture may and sometimes do respond to a different range of external pressures and respond to them in a different way from customary modes of artifact use. I am not suggesting that modes of manufacture and modes of use are unrelated, merely that they respond to some external stimuli in slightly different and theoretically significant ways. More important, there seem to be mutual-causal feedback relationships between the two. Thus modifications in modes of use may fix some of the variability expressed by modes of manufacture or vice versa whatever the source of this variability. In any case, once fixed the variability in question has, by definition, entered the teaching framework, where it may be either explicated or rationalized. Then, and I presume only then, may the process of variability fixation be *productively* explored (during archaeological inquiry) by the construction of a performance matrix or explained by referencing the techno-science component of the technology in question.

The authors' performance-matrix approach is both interesting and useful. Insofar as it requires tradition-free measures of performance, however, it must be used as they have used it, with caution. Performance characteristics, insofar as they are "behaviorally significant," may be as tradition-bound as they are context-sensitive. Understanding persistence may indeed be as important in attempts to explain culture change as exploring transformations. Then too, caution must be exercised in linking change to performance-driven experimentation. In some cases experimentation itself may modify performance expectations. Differently put, experimentation may not be as frequently the handmaiden of necessity as we might think. At least the prospect deserves our attention.

The authors' use of "functional field" as the ultimate explanatory framework is also interesting and potentially productive. Nevertheless, to characterize it as "the set of techno-functions, socio-functions, and ideo-functions that the artifacts in a society have to perform" has its difficulties. In short, a functional field is a community's technology. It is, however, virtually impossible to analyze a community's technology without first subdividing it into smaller units or subfields to which the ideas of recipes for action, etc., can be systematically applied. This much at least is implied by the authors' choice of ceramics to exemplify their ideas. Yet if we systematically partition a functional field, as for accessibility we must, vexing problems face us. A description of the recipes for action, teaching frameworks, and techno-science components of even a small community's technology would be time-consuming, costly, and difficult to achieve. It would, for example, require an experienced and highly trained research team dedicated to multiple hypothesis-test-specific programs of field and laboratory research focused upon single sites or components, an unlikely, if not impossible, prospect given the current state of funding and level of acrimony in our discipline.

I presume, nonetheless, that the ideal research program and subsequent site report might just be so organized and presented. Delineating a community's technology, defining in essence a single "functional field" or, better yet, a series of them, might just provide the data base we need to make meaningful claims about a specific time-ordered set of transformations in a given region or locale. In all likelihood, however, achieving this ideal would, given the practical limits we now face, divert resources and attention from the broader study of dynamism in artifact manufacture and use, an issue the authors quite rightly see as an essential one in archaeological inquiry. Thus it seems to me that we face several immediate problems with the concept, problems that, for now, can only be overcome by either reworking our understanding of "functional field" or laying it aside to seek instead a general body of theory that pinpoints cases crucial to the study of dynamism in artifact manufacture or use. This latter work, as the authors indicate, still lies before us.

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Schiffer and Skibo outline a framework for investigating the products of past technologies that is useful for describing the technological attributes of artifact classes but has serious shortcomings with regard to the explanation of technological change. It focuses on laboratory testing of artifact classes and is largely divorced from other aspects of archaeological research. Moreover, it does not fully delineate the broader archaeological context of the materials under study. I feel that this is a serious flaw.

The archaeological context is critical for understanding the technological parameters of artifacts. It is difficult to define "performance characteristics" when one does not really comprehend the range of activities associated with an artifact class. To identify such activity sets, one must examine the relationships of the artifact class with other artifact classes, faunal specimens, floral remains, and architectural features defined in the archaeological record. Artifact classes must be viewed not as isolated entities but as part of a constellation of archaeological remains and the behaviors they may represent.

A case in point is Schiffer and Skibo's investigation of the change from fiber- to mineral-tempered pottery. Here they assume that the pottery was used to cook over an open fire. The results of their analysis suggest that the Archaic people who produced fiber-tempered pottery "placed a high priority on ease of manufacture and portability," whereas the Woodland people who produced mineral-tempered pottery "stressed heating effectiveness and characteristics that promote longer uselives (e.g., impact resistance, thermal shock resistance, and abrasion resistance)." They imply that the technological changes reflect a transformation from the expedient production of pottery by relatively nomadic hunter-gatherers to ceramic manufacture by more residentially stable horticultural groups. Without examining the contexts of fiber- and mineral-tempered pottery, however, it is difficult to determine which performance characteristics are suitable. For example, the different characteristics of fiber- and mineral-tempered pottery may relate more directly to different cooking technologies than to changes in residential patterns. The shape, paste, and temper of the fiber-tempered wares may be related to stone boiling (a point the authors consider briefly), whereas mineral-tempered pottery may represent a technology developed for cooking over fires. Some of the performance characteristics that Schiffer and Skibo examine for fiber-tempered pottery (e.g., heating effectiveness, thermal shock resistance) may not be entirely appropriate if these vessels were never placed over an open flame.

A study of archaeological contexts yielding fiber-tempered ceramics would certainly produce a better understanding of the cooking technology being employed. For example, are these ceramics found on sites containing fire-cracked rock concentrations? Do they exhibit burn marks on their bases? What kinds of foods were potentially cooked in these vessels? In addition, a more thorough study of documented fiber-tempered-pottery sites could contribute to an assessment of their occupants' residential stability. Are they necessarily less stable than the occupants of sites yielding mineral-tempered ceramics? Recent studies of Archaic sites (e.g., Phillips and Brown 1983) suggest that there is considerable variation in residential duration patterns.

Schiffer and Skibo's approach is a good beginning, but it needs to be incorporated in a broader one that includes the archaeological context of the artifacts under study. (This may seem ironic given the senior author's past contributions on "behavioral-chain" analysis and formation processes.) Laboratory work cannot be divorced from findings in the field or expectations generated by well-thought-out research designs. While fiber-tempered ceramics may seem crude and relatively inefficient for cooking over a fire, their performance characteristics may have been more than adequate for stone boiling.

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Schiffer and Skibo have provided a well-defined theoretical and methodological framework for applying modern experimental data to the explanation of cultural processes. They stress identifying "that portion of artifact variability attributable to techno-function" because these characteristics are more conducive to replicative experimentation. I believe that they are justified in stressing the techno-functional aspects of artifacts, but the social and ideological functions of artifacts, particularly pottery, cannot be ignored.

Elaborately decorated pots (e.g., Hopewellian jars with raptor motifs) are sometimes placed in Early and Middle Woodland tombs as grave goods. These vessels are easily recognized from their contexts as having important social and ideological meaning and are usually identified as ceremonial even when found in habitation debris. Conversely, the social and ideological aspects of "utilitarian" pots are not as readily apparent and are not well suited to discovery by experimentation. Braun and Plog (1982) have provided one possible method for examining the influence of social and ideological aspects of "utilitarian" pottery. Thus, it cannot always be assumed that the main source for changes in pottery resides in the techno-functional realm.

Schiffer and Skibo have cautioned against oversimplifying the technical choices and/or performance characteristics examined when conducting replication experiments. The rest of my comments are directed toward features not considered by them that might have influenced the Archaic-Woodland pottery transition.

Schiffer and Skibo's experiments are based in part on Braun's (1983) hypothesis that pottery in the Midwest changed shape and became thinner during the Woodland period because potters adopted vessel forms that more effectively heated and cooked food. It is likely that increased cooking effectiveness of pottery is *one* reason for the changes noted, but it may not be the only reason. Weaver ware recovered from the early Late Woodland Rench site in Illinois includes a conoidal-based jar form (Jackson and McConaughy 1983) in at least two sizes that are probably related to different functions. The smaller jars (under 4-liter capacity) usually display heavily burned exterior surfaces and often have charred organic remains adhering to their exteriors and/or interiors. These are interpreted as cooking pots. The larger jars (approximately 5–16-liter capacity) do not display heavily burned exteriors or have charred organic remains adhering to them. They are interpreted as probably not cooking pots but water or food storage jars. If the larger jars were used for storage, a techno-functional approach would suggest that manufacturers would want stronger (i.e., thicker-walled) storage vessels to hold the heavier contents. Thermal conductivity would not be a factor influencing their production. Storage jars are, however, as thin as the cooking pots from Rench, and both are thinner than preceding Middle Woodland forms. This suggests that reduction in vessel-wall thickness during the Woodland period is not solely a response to a need for increased thermal conductivity.

Holstein (1973*a*, *b*) replicated shell-tempered Monongahela pottery and noted that "thicker walled vessels had a greater tendency to spall than did thin walled vessels. Thinness may help reduce spalling as thin sherds and vessels would have a higher probability of being completely dry at firing and thinness would also eliminate the problem of uneven heat distribution" (1973*b*:85). This observation needs to be supported by additional experimental work. However, it might provide another techno-functional explanation for the reduction in wall thickness displayed by Woodland ceramic assemblages, one that could be applied to both cooking- and storage-jar production: the attempt to reduce the number of failures during firing.

Braun (1983) has also described a general trend toward reduction in temper size during the Woodland period in the Midwest. Temper size influences vessel-wall thickness because walls are minimally as thick as the temper particles. Thus, experiments should be performed to determine how changes in temper size and production techniques might have influenced vessel shape and wall thickness.

The long unaided-drying times noted for experimental pots prior to firing need not imply lengthened occupation spans at Archaic sites as is suggested by Schiffer and Skibo. Preheating pots to drive off excess moisture can reduce the drying time needed prior to firing.

Schiffer and Skibo have provided an important framework for relating experimental technological studies to the archaeological record. Experimentation can provide information about techno-functional aspects of material culture, but any hypotheses about culture change must also consider the sociological and ideological impact of the items studied.

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Schiffer and Skibo provide some fresh theoretical premises and terms with which to model prehistoric technological change. They also make one of the few existing synthetic statements about North American fiber-tempered ware. These new arguments should spark discussion among archaeologists of the southeastern United States and others interested in global and continental patterns of material-culture change.

Most enlightening is their tracing of theoretical links between artifactual and systemic change. By broadening and extrapolating from Braun's (1983) conception of pots as tools, they illuminate the inferential path between formal properties of artifacts and the systemic conditions in which artifacts are used. Some of this discussion simply describes archaeologists' standard procedures for evaluating artifact function, but the concept of functional field is a new and truly valuable contribution. It gives us crisper language with which to unravel a multivariate and dynamic causal structure.

Several difficulties remain in modeling this complex linkage between artifact and system. The greatest difficulty lies in the statement that "changes in the functional field . . . are the immediate causes of artifact change." This statement and other parts of the discussion imply too simple a relationship between functional field and performance characteristics. To characterize this relationship adequately we need theory that deals with what Binford (1979) calls the organization of technology.

We cannot ignore the fact that most activities are embedded in other activities (Binford 1977). The creation or selection of an artifact depends as much on the relationships among the activities as on the performance characteristics required by the activities themselves. Among the conditions that weigh on such choices are how often the artifact is used, whether its use is anticipated, and whether raw materials for making the artifact are at hand when the need arises. In other words, the same function may be performed with different implements according to the specific way in which an activity fits into an overall strategy of procuring and processing resources. For example, hunters may not wish to make a bifacial tool to process game encountered occasionally near their stone quarry; adequate cutting edges are easily obtainable there on expediently manufactured flakes. But if one of their seasonal hunting stands is far from the quarry, they may make a biface for game processing before going there because the biface is an efficient way of storing future cutting edges (M. Nelson 1987). Again, while corn is a staple in both southern and northern Mexico and is usually consumed in the same form (cornmeal cakes or tortillas), in the south a distinctive type of pot is made for rinsing boiled corn and in the north this function is performed by a basket (B. Nelson 1985). This difference may relate to a difference in frequency of wet vs. dry grinding. In the south, where wet grinding is prevalent, rinsing is an everyday activity and the special pot is made to accommodate that need. In the north, where corn is often ground dry, the basket is used for rinsing on those occasions when wet grinding is elected.

Also in regard to ceramics, I am persuaded by Miller (1985) that in some settings much formal variability has little or nothing to do with performance characteristics. Perhaps such cases are most common in intricately organized societies like those of India. The proliferation of categories may be the result of potters' expounding, as it were, upon the multitude of social contexts in which pots are used. In other cases, variety may be the result of purely artistic permutation of design possibilities.

Experimentation is a good way to begin overcoming some of these difficulties, as Schiffer and Skibo's treatment of the Archaic-to-Woodland ceramic transition attests. I must take issue, however, with what seems a static view of ethnoarchaeology. While experiments will refine our understanding of how formal properties are related to performance characteristics and therefore acquaint us with unfamiliar technology, they will not help us to understand the organization of technology. That understanding comes most easily from seeing technology in action, especially different technological solutions to the same problem as context varies (Binford 1978). Ethnoarchaeologists can make valuable comparative observations about variability both within and between living cultural systems.

Despite these reservations, I feel that Schiffer and Skibo have performed a service for archaeology by clarifying the logic of our reasoning about ancient technologies. Equally useful are their substantive conclusions, which to my mind are quite compelling.

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The model for understanding technological change suggested by Schiffer and Skibo can be characterized as a kind of multivariate optimization of selected attributes whose solution may lie in the achievement of threshold values of acceptability rather than true optimization. The recognition that optimization of one attribute may negatively affect others is important (for an example beyond ceramics, using mudbricks, see Rosen 1986:84–85), since it implies that "degeneration" of what we assume to be significant technologies and/or attributes of technologies may sometimes be explained as a by-product of selection for other attributes. The same holds true for "positive" attributes—in some cases these need not have been deliberately chosen but may be the consequences of other technological choices.

Another important point reiterated by the authors is that artisans need not understand the properties or the science of the objects they manipulate or produce but may operate according to "recipe for action" alone. This has significance for understanding technological change, since it suggests that experimentation may be based not on "techno-science," to use the authors' terminology, but on the specific cultural perceptions of the experimenter.

The authors indicate two main theoretical problems in understanding technological variability and change. The first is "the theoretical disjunction" between "social organization and basic lifeway" and "the hands of the artisans." The second is the long-term processes of behavioral change. In other words, these can be interpreted as processes for generating short-term change and processes for the transformation of some of the short-term changes into long-term changes. Implicit in Schiffer and Skibo's case study is a utilitarian-functional assumption that technologies adopted over the long term are functionally adaptive to the culture with which they are associated (cf. Dunnell 1978). Combined with the points noted above, this suggests two distinct stages or processes in technological change, the first consisting of a series of almost random changes dictated by individual and cultural perceptions of the worth and importance of specific technologies and features (which need not be at all adaptive in the long term) and the second consisting of the selection or fixing of specific features on the basis of long-term adaptive value. It is easy to imagine how such a system would operate. Features whose value related to specific social contexts would be abandoned or significantly modified with those specific contexts, whereas those of more general value, such as utilitarian aspects, would tend to be preserved. Thus, utilitarian technological change becomes generally cumulative.

Such an evolutionary model allows comprehension of technological progress without necessarily attributing post hoc directionality to the changes observed in the archaeological record. The experiments and conclusions described provide an important baseline from which to begin evaluation of such models.

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Scholarly investigation of the causes and effects of prehistoric technological change is critical for archaeologists. Schiffer and Skibo have bravely opened themselves to crossfire by presenting an explicit theoretical framework, methodology, and archaeological example of the merits of their approach. This commendable effort to initiate a new round of debate is an important first step on the road to greater understanding of the processes of prehistoric change.

First, a comment on studies of technological change in general: One of the most fruitful areas for this kind of research is thorough ethnographic study. Unfortunately (for archaeologists, at least), all too often ethnographers are not much interested in material cultural items or describe the completed objects rather than the techniques of manufacture. How and why specific techniques are modified or radically altered from one generation to the next are rarely addressed. Studies of this nature could provide a baseline for the kind of archaeological analysis advocated here.

Schiffer and Skibo mercifully provide us with a reasonable definition of technology, something that is relatively difficult to find in the general anthropological literature. However, they have not been very clear when it comes to differentiating between "technical" and "technological"; "technical" appears to be used in reference to mechanical procedures while "technological" appears to be a more inclusive category. Some clarification on this point would be helpful.

Schiffer and Skibo rightly caution archaeologists who learn a technology and then use themselves as informants "offering seemingly definitive conclusions about the hows and whys of a technology." This caution, while justified, overlooks the fact that these experimental approaches may be extremely useful in separating practical and technical (mechanical) procedures from aesthetic or other seemingly arbitrary procedures. Additionally, limitations placed on the technologist by the raw materials and techniques employed can be isolated, thus saving endless hours of useless analysis of attributes that are technologically insignificant. Perhaps we could say that the work of the experimental archaeologist in studying technological change is most pertinent in deriving "recipes for action" and the "teaching framework." In this connection, while it is evident that most of Schiffer and Skibo's observations are derived from experiments, their experimental methods are inadequately described.

I agree that the application of the principles of modern science to prehistoric technology is critical, as Schiffer and Skibo's heat-treatment example illustrates. I think, however, that another caution is necessary: that our experiments point to particular beneficial qualities is not sufficient reason for assuming that these qualities had the same significance for their manufacturer/users. This caution also applies to Schiffer and Skibo's discussion of the intent of artisans attempting to optimize their choices during periods of experimentation. Given our incomplete understanding of prehistoric human behavior, it seems unrealistic to assume that ideas of optimization derived from our current standards of what is optimal are directly related to what was optimal for prehistoric technologists. In doing this Schiffer and Skibo fall into the very trap they point to with reference to the work of others assuming special knowledge of why people do what they do.

I applaud the effort of Schiffer and Skibo to examine an aspect of prehistoric technological change and, in so doing, to devise a model useful to other archaeologists with similar interests. I think that they could go farther with their own analyses by carefully defining their terms and outlining the specific aspects of prehistoric "lifeways" that are best illuminated by using this model.

Reply

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We are pleased that our paper has provoked a number of thoughtful comments. This reply strives to clarify important issues and correct misunderstandings.

Theoretical issues. Lightfoot makes the most sweeping—and least accurate—claim about the theoretical framework, that it "is largely divorced from other aspects of archaeological research." In this statement and ancillary points, he conflates two issues that must be kept distinct: (1) the adequacy of the theoretical framework and (2) how well its application is illustrated by the case study. He concludes, incorrectly, that deficiencies in the case study (which are real) stem from a flawed theoretical framework. The "serious shortcomings" he attributes to the framework include a failure to make sufficient provision for contextual data and an excessive emphasis on laboratory experiments.

The paper states unambiguously that explanations for technological change are society-specific and that testing must be carried out on the archaeological record of local adaptations. Moreover, a recognition of the influence of lifeway-society factors on the process of technological change is central to the theoretical framework; inferring those factors inevitably requires recourse to myriad lines of evidence beyond the formal properties of the artifacts themselves.

It is true that the case study does not include original analyses of *primary* archaeological evidence. For inferences about lifeway and society we relied upon statements in the literature. Obviously, tests of the explanatory sketch—and it is no more than that—will require new analyses of diverse evidence, probably by investigators more knowledgeable than we about the archaeological record of the eastern United States (and its formation processes). Even so, provision of this sketch has focused attention on issues of lifeway and society that now need investigation. For example, uncertainty about Late Archaic cooking practices—what was cooked and how—should lead to use-wear and residue analyses of fiber-tempered pottery as well as to the examination of other lines of evidence. Similarly, questions about residential mobility and seasonality should be addressed through appropriate analyses. In short, we agree with Lightfoot that studies on primary archaeological materials are required; indeed, the theoretical framework deems them essential.

An effort to place our contribution in its research context might have led Lightfoot to appreciate why the case study so heavily stressed laboratory experiments. For decades, prehistorians offered hypotheses to account for the use of fiber temper in ceramics of the eastern United States (and elsewhere) that were built upon assumptions—some implicit, others explicit—about the effects of fiber on sundry performance characteristics. After Kenneth Reid drew our attention to the fiber-temper problem, it became evident that these assumptions had to be tested, for they introduced an unacceptable degree of uncertainty into explanations for Archaic ceramic technology (and its eventual replacement). We believed that the facilities and expertise in the Laboratory of Traditional Technology could help reduce that knowledge bottleneck. Indeed, the experimental program, although limited in many respects, did illuminate some important effects of fiber temper and paved the way for our explanatory sketch.

The theoretical framework, too, emphasizes the integral role of controlled experimentation in the study of technology and technological change precisely because so many archaeological explanations are founded on dubious assumptions about how performance characteristics are affected by technical choices. As the case study amply illustrates, progress cannot be made in explanation until those assumptions are tested.

Nelson properly calls attention to theoretical issues that remain in modeling the "complex linkage between artifact and system." After noting that all activities are embedded in other activities, Nelson suggests that "the creation or selection of an artifact depends as much on the relationships among activities as on the performance characteristics required by the activities themselves." We agree, but we would point out that other activities can only influence artifact selection if they impinge upon specific performance characteristics of artifacts in the reference activity. For example, in the case of lithic cutting tools, the crucial performance characteristics for some activities seem to be good durability or maintainability. Expedient flake tools are adequate for cutting if stone is abundant, whereas hunters who lack immediate access to stone should favor cutting tools that are quite durable or readily resharpened, such as bifaces. (For an extended treatment of interconnected activities and technological change, see Schiffer 1979.)

We dispute Nelson's contention that "the same function may be performed with different implements according to the specific way in which an activity fits into an overall strategy of procuring and processing resources." This statement is predicated on the assumption that the activity itself remains constant (e.g., butchering game or processing maize) while the artifacts employed vary with the situation. This may be a useful way of framing some problems in activity analysis, but it is at odds with assumptions of the present theoretical framework. According to the senior author (e.g., Schiffer 1976:45–52), activities performed with different implements in different ways in different places are *not* the same activity. We see no way of reconciling this fundamental difference in definition, but it is important to recognize that the two perspectives are not so divergent as to preclude common understandings. Indeed, we are all focusing on similar classes of activity-specific variables to explain technical choices.

Both Nelson and McConaughy stress the need to consider the influence of social and ideological functions on the design of artifacts. Although the paper almost exclusively treats techno-functions, this emphasis is not an inherent limitation of the theoretical framework. We do recognize that social and ideological functions are among the determinants of artifact form (cf. Rathje and Schiffer 1982, McGuire and Schiffer 1983) and merit consideration in theories of technological change. Indeed, it should be possible to generalize the concept of performance characteristic to include factors that demonstrably affect the suitability of artifacts to perform social and ideological functions. For example, artifacts differ in the degree to which they stand out from their surroundings, can be distinguished at a distance, cause the eye to linger, contrast visually with other artifacts having similar techno-functions, suggest analogies to other forms having well-established meanings, etc. Ethnoarchaeologists are ideally situated to isolate and define the recurrent kinds of performance characteristics that facilitate symbolic artifact functions. Experimental archaeology complements ethnoarchaeology by delineating those performance characteristics that relate to techno-function (as our case study shows).

Krause states that "a functional field is a community's technology." In contrast, we repeat that a functional field is the set of *functions* carried out by a community's artifacts. The emphasis on *functions*, abstracted from the artifacts that perform them, facilitates the formulation of certain general questions that might not otherwise arise. For example, What explains the highly variable ways in which particular societies map artifacts onto seemingly similar functional fields? Or, How do the artifacts of different societies respond to identical changes in the functional field? To pose such questions requires that functions be conceptualized separately from the artifacts that carry them out.

The senior author has often acknowledged that ethnoarchaeology plays an important role in providing general principles (as well as specific information) for archaeology (e.g., Schiffer 1976:6; 1978). Thus, it comes as a surprise that Nelson should accuse us of having a "static view of ethnoarchaeology." It is not clear what he means; perhaps his concern stems from our reference to the "static" systems that ethnoarchaeologists study. Ethnoarchaeologists to date have not studied change, perhaps having concluded that short-term observations would not be relevant for testing hypotheses about long-term processes. We would like to see investigations of technology—even technological change—in systemic context, because ethnoarchaeologists can uniquely observe artifact-behavior relations under "natural" conditions. What we object to in ethnoarchaeology is the uncritical use of informant responses about the effects of technical choices on performance characteristics. Such relationships can only be established, we maintain, by employing rigorous experimental designs (often in the laboratory). If Nelson is simply suggesting that ethnoarchaeology can contribute to the study of technology (including its "organization"), then we agree. The lack of interest in technology on the part of ethnographers noted by Warburton makes the need for its investigation by ethnoarchaeologists all the more pressing.

Krause calls attention to the enormous effort that would be needed to study exhaustively the technology of even one small-scale society—presumably in an ethnoarchaeological context. We are not convinced that such complete descriptions are currently infeasible. After all, one could divide up the labor by organizing a team of ethnoarchaeologists. If our theory-building efforts should demand exhaustive descriptions of technology, then we could probably design—and perhaps secure funding for—appropriate research projects.

Although comparative data (e.g., from ethnography and ethnoarchaeology) can contribute importantly to the study of technology, one should not expect to find many low-level cross-cultural principles of widespread applicability. One can detect such an expectation in Feinman's remark that "fibrous inclusions were often used during early stages of pottery making but are not *necessarily* associated with residential mobility." The idea that fiber temper was chosen everywhere to affect the same performance characteristic—and so must be highly correlated with a particular lifeway factor such as residential mobility—is unrealistic and contradicts our theoretical premises. Although we did not address this issue explicitly, the theoretical framework does imply that invariant cross-cultural associations between specific technical choices and specific lifeway-society factors will be rare; the usual pattern ought to be more limited associations. It is easy to see why this must be so. Because technical choices affect more than one performance characteristic, the same technical choice (e.g., fiber temper) can play quite different roles in different technologies. Fiber temper could have been added to increase clay plasticity in some societies, to reduce it in others, and to promote portability in a third group. As we note, the specific role of fiber temper in a given ceramic technology would be conditioned by lifeway-society factors (and by other technical choices). Because some technologies as well as some conditioning factors are reasonably common, we anticipate that the specific conditions favoring specific technical choices would recur in a number of societies. For example, there is a tendency for pottery-making groups that exclusively add organic temper to be residentially mobile (Skibo, Schiffer, and Reid n.d.). On the other hand, as Feinman observes, sedentary societies also employ fiber temper (but seldom exclusively). Once we learn, through experiment, the major effects of particular technical choices on performance characteristics, we will be in a better position to seek out—and explain—any limited cross-cultural regularities that do occur.

In accusing us of assuming "that ideas of optimization derived from our current standards of what is optimal are directly related to what was optimal for prehistoric technologists," Warburton reveals a misunderstanding of relevant parts of the paper. We state unambiguously that "in the present framework, 'optimal' must be defined with reference to local societal factors." Nonetheless, given the many connotations of the term "optimal," its inclusion in the theoretical discussion was probably a mistake. Rosen has understood what was intended by "optimal," but he nevertheless rephrases a major theoretical premise to eliminate it. In his terms, artisans would strive to achieve "threshold values of acceptability" in important performance characteristics. We hasten to add that these thresholds would be activity-specific in the context of a particular society. We like Rosen's modification and consider it closer to our meaning than the original phrasing. Rosen also attempts to establish a linkage between the theoretical framework and evolutionary models. We prefer, however, that our framework not be unnecessarily encumbered with biological baggage. For example, there is no compelling need to divide the process of technological change into stages suggested by evolutionary processes. If stages do need to be defined at some point, they should be behaviorally relevant and designed to solve a given theoretical or empirical problem.

Warburton asks us to clarify our use of "technical" and "technological." Her impression that the former refers to "mechanical procedures" whereas the latter is "a more inclusive category" is essentially correct. We doubt that more precise definitions could be easily formulated (or are needed) at present. Regarding definitions, we must point out that Krause confuses "technological knowledge" with "technology" in stating that recipes for action, teaching frameworks, and technoscience are the "components of a technology." In the theoretical framework, technology consists of knowledge, behavior, and artifacts, and the three components listed by Krause refer only to kinds of technological *knowledge.*

In closing this discussion of theoretical issues, we wish to make another point, insufficiently stressed in the paper itself. Because the theoretical framework is very general and abstract, it accounts for *no* specific instances of technological change. Rather, its purpose is to guide inquiry by shaping the formulation of appropriate questions and the research strategies to answer them. We hope that application of this framework to specific cases will permit archaeologists eventually to establish the middle- and low-level principles needed for rigorously explaining particular technical changes.

Experimental issues. Because previous archaeological treatments of technology tend to frame explanations in terms of one or just a few performance characteristics, it is tempting to focus on these when experiments are carried out. However, our theoretical framework specifies that explanations must account for changes in the pattern of compromises among performance characteristics. Thus, as in our case study, testing should involve a host of performance characteristics that can be considered relevant to particular activity-society contexts. We reiterate that exclusive attention to a single performance characteristic will seldom lead to sound explanations of technological change.

Warburton states that our "experimental methods are inadequately described." Because we regard the present paper as mainly a contribution to higher-level theory, few details are furnished on experimental methods. The reader has, however, been advised that "a complete account of experimental materials, procedures, and results" can be found in Skibo, Schiffer, and Reid (n.d.). Until that work is published, we will cheerfully provide a preprint to anyone who requests it.

Warburton contends that we minimize the potential contributions of archaeological experimenters "who learn a technology and then use themselves as informants." Although this avenue of experimental research is clearly valuable, we called attention to its limitations in ascertaining "the hows and whys" of a technology. Artisans and archaeologists who acquire such skills can contribute, as Warburton notes, to formulating recipes for action. In some cases, information can also be provided on teaching frameworks. However, only if these craft skills are harnessed within real experimental designs can contributions be made to techno-science.

Feinman poses several interrelated questions about the choice of clays and temper. In effect, he is asking if our results can be generalized beyond the specific clays and tempers used in the experiments to those employed by Archaic and Woodland potters. Because every natural clay has a unique combination of chemical and mineral constituents, our clays must differ in some respects from those used by most—if not all—Archaic and Woodland potters, in the same way that clays in Florida differ from those in Alabama. The tough job for the investigator is to choose a clay (or any material) for a particular experiment that is comparable in *relevant* properties to that used in the past. Short of sampling all clays in the eastern United States to ascertain their properties, experimenters must make reasonably informed judgments. For example, when the effects of fiber temper on ease of manufacture were examined, a clay with good plasticity was chosen because surface clays in the eastern United States are quite plastic. For this particular experiment, we judged that most other clay properties, including curing temperature, color, and chemical composition, would not adversely affect the reliability of our conclusions. Regrettably, clay choice was not as well thought-out in other experiments. For example, the clay used for testing thermal shock resistance has excellent thermal shock resistance without added temper, and so the test is not very sensitive. Although still learning how to make good clay choices, we are confident—but by no means certain—that the basic findings can be extrapolated to the clays used by Archaic and Woodland potters.

Feinman incorrectly implies that only one type of fiber temper was used in the experiments; in fact, both horse manure (a fine material) and dry grass (a coarse material) were used in tests in which size and shape of the temper particle (and the void remaining after firing) were thought to influence the performance characteristics. We believe that horse manure and dry grass adequately represent the varied comminuted plant fibers used by Archaic potters and so should serve to disclose the *common* effects of such tempers on performance characteristics. Because the voids left behind by firing affect use-related performance characteristics, temper size, shape, and quantity should be more important than the particular fibrous material per se. These temper attributes seem to vary greatly in Archaic ceramics; thus, no single choice could represent all combinations. Fortunately, the major effects documented in the experiments should be relatively insensitive to minor differences in temper. We acknowledge, however, that our findings cannot be uncritically generalized to termite eggs, animal fat, hair, blood, and other quite different organic substances sometimes used as temper.

Issues relating to the explanatory sketch. Feinman questions the conclusion that Archaic pots "were more portable than their Woodland counterparts," pointing out that both vessel size and wall thickness (in addition to density) influence portability. He has apparently overlooked our discussion of these factors; an appraisal of size, shape, wall thickness, and density led us to conclude that portability could have been important in the design of fiber-tempered wares. Feinman asks if "vessels that are neither abrasion- nor impact-resistant" could be "truly portable." This question bespeaks a misunderstanding of performance characteristics: they are continuous variables, not binary categories. Pots are abrasion- or impact-resistant *to some degree* on a given scale; no pot simply "has" or "lacks" abrasion or impact resistance. We do not believe that differences in these performance characteristics for Archaic and Woodland vessels would have been of sufficient magnitude to be behaviorally significant insofar as their influence on portability is concerned.

McConaughy challenges the assertion that long drying times for fiber-tempered vessels indicate occupation spans in excess of several weeks for late Archaic settlements. He points out that preheating before firing could have substantially reduced drying time (and thus minimum occupation span), and he is right.

In an interesting case from the Rench site in Illinois, McConaughy calls attention to the decrease from Middle to Late Woodland times in wall thickness of both storage and cooking jars. Since storage jars do not require good heating effectiveness, why do their walls also become thinner? This is a provocative question, and we wish David Braun could help us answer it! McConaughy's suggestion, based on Holstein's (1973*a*) experiments, that thinner walls could reduce firing failures for both vessel forms merits very careful consideration. Although Holstein's findings seem sound, more experiments would be needed (1) to establish precisely the effects of wall thickness on firing success and (2) to determine if such differences are behaviorally significant. In any event, McConaughy's hypothesis is attractive and does not necessarily conflict with our explanatory sketch (or Braun's).

However, McConaughy's claim that a techno-functional approach would suggest that storage jars need to be very strong and so should have been thicker cannot be accepted. In the first place, if storage jars normally were stationary in use, then great strength might not have been necessary. Clearly, we need to learn more about how these vessels were used. Second, even if strength had been important, there are many ways to achieve it in addition to making thicker walls, among them higher firing temperatures, more globular shape, and a reduction in the amount or size of temper. (The trend toward smaller temper particles documented by Braun [1983] may relate to improving impact strength.) Thus, thin walls can be compatible with good impact resistance if other technical choices—perhaps derivative—are made.

In attempting to account for changes in specific technical choices (e.g., decreasing wall thickness), it must be recalled that each choice can affect many performance characteristics and that any given performance characteristic can be influenced by myriad technical choices. The explanation of technological change requires consideration of the interactive effects of many technical choices on the various performance characteristics that might be relevant in a particular activity-society context. In view of these complex causal relationships, the simultaneous decrease in wall thickness observed by McConaughy in storage and cooking pots may or may not be related to the same performance characteristic. A more thorough analysis is evidently in order.

Lightfoot offers the superficially appealing hypothesis that a change in cooking technology—from stone boiling to heating over fires—was responsible for the change from fiber to mineral temper. In order to make his hypothesis testable, he needs to argue in somewhat greater detail how differences in vessels produced by the two technologies relate to the posited differences in cooking practices. In particular, he should specify which performance characteristics are important for stone boiling in the context of Late Archaic society. We are skeptical at this point that fiber temper can be shown to enhance any such cooking-related performance characteristics. We did, of course, discuss stone boiling in Archaic pots, and we believe that effort should be devoted to ascertaining cooking practices. Nonetheless, we expect our explanatory sketch to survive with little modification even if it is shown that stone boiling was employed by Late Archaic cooks, because ease of manufacture and portability—enhanced by fiber temper—were, we maintain, the most important influences on this pottery technology.

Feinman, too, finds fault with aspects of our explanatory sketch. He suggests that Archaic potters, "having recognized the various costs of working without temper . . . may simply have opted for lightweight, readily available, easy-to-process vegetal fibers as inclusions." This is a weak hypothesis because sand is also abundant and can be employed without processing. It should also be noted that the use of fiber temper was widespread in the eastern United States, almost certainly crosscut social boundaries, and persisted for one to two millennia. Thus, an explanation for this *recurrent* technical choice based on low cost of raw materials, when less costly alternatives were available, is unconvincing.

Concluding remarks. We thank our colleagues for their constructive comments, and we hope that this exchange will contribute to ongoing efforts to put archaeometry and experimental methods in the service of the anthropological goal of explaining behavioral variability and change.

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Serials

■ A new journal of Bantu studies entitled *Nsi* (meaning "The Earth") was inaugurated by the Archaeology Department of the Centre International des Civilisations Bantu in April. The main aim of the journal is to form a link among Bantu researchers, many of whom work in isolation with very little in the way of support facilities. For this reason, the editors particularly welcome short reports on work in progress as well as longer articles about completed research. Bibliography of recent publications in Bantu studies will also be included. Articles and reports may be submitted in French or English. Write: B. Clist and R. Lanfranchi, B.P. 770, Libreville, Gabon.