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Toward an Integrated Interface for Archaeology and Archaeometry

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Archaeologists have a long history of embracing methods and techniques from other disciplines. Their efforts to find culturally interpretable patterning among the objects of the past, to understand the processes of culture change, and to reconstruct, explain, or predict diversity within the material record are built on insights gained by scientists' data-gathering and interpretive techniques (Gumerman and Phillips 1978). Understanding human interaction within the natural and social environment, for example, is augmented by specialists whose expertise in the areas of botanical, faunal, dietary, and compositional analyses depends upon technical developments occurring outside the archaeological discipline. Although some of these borrowings have become a common part of the archaeological curriculum and practice, other techniques from the physical, engineering, and materials sciences have been adopted less frequently. In general, however, the demand for data produced by the applications of scientific techniques to archaeological materials has increased over the years.

The number of scientists interested in archaeological applications has also grown. In fact, the commitment of these scientists to the study of archaeological materials and problems has given rise to a separate field called archaeometry. Although a definition of archaeometry is subject to debate, in practice it most commonly involves chronometric dating and materials identification, characterization, and attribution to source by physical and natural science techniques (see Butzer 1982:157). The

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practitioners obviously vary in background. They come primarily from the natural and physical sciences, but they have been joined recently by individuals from the materials sciences. The latter have training in engineering as well as in the physical sciences, and they emphasize an interest in the properties and history of materials such as glass, ceramics, and metals.

In an effort to derive a shared focus and direction for archaeometry, Jacqueline Olin (1982:19) defined the general field of endeavor as the "application and interpretation of natural science data in archaeological and art historical studies." In this definition, "interpretation" is left vague, but it can be construed to relate to a variety of things: (1) achieving successively higher levels of data accuracy and precision, (2) delivering technical descriptions of data patterns in a particular archaeological or art historical context, and (3) elucidating the cultural implications of the data. Presumably, it is the first two aspects of interpretation that set archaeometry apart from archaeology in general.

Whether loosely or narrowly defined, however, archaeometric research usually has one of three foci. This fact has been formally recognized in the National Science Foundation's guideline for applying for archaeometry funding in the anthropology program. The major approaches to research are: (1) the straightforward application of archaeometric techniques to answer archaeological research questions posed by archaeologists; (2) the application of archaeometric techniques to answer archaeological questions posed by archaeometrists and (3) research to develop techniques to answer archaeological questions.

In spite of a proliferation of analytically based reports over the past 10 years or so (Earle and Ericson, eds. 1977; Hughes, ed. 1981; Ericson and Earle, eds. 1982; Freestone, Johns, and Potter, eds. 1982) and in spite of the potential for positive and innovative archaeological and archaeometric cooperation through the NSF, discord and separatism between archaeologists and archaeometrists have surfaced with increasing frequency in the literature, at conferences, and in the evaluation of one another's contributions to the field. In fact, instead of promoting harmonious cooperation, the formalization of the archaeometry focus intensified some of the friction between archaeologists and scientists. Communication across disciplines is limited, and even publications that encourage dialogue and integrative reports have had little impact on resolving the issues that underlie this problem. Why? In reaction to the continual scarcity of archaeologists at archaeometry symposia, Francois

Widemann (1982:29) raised the question "Why is archaeometry so boring for archaeologists?" (see also J. Perrot 1982:59). A cursory review of the offerings suggests that the low level of interest reflects the absence of anything of the human condition in the reports at such symposia, but the problem is more subtle than that. Indeed, archaeometrists wish to contribute to such questions, or they would not spend their time or resources on analyses for which they receive little acknowledgment and even less financial reward. At the core of the problem is the fact that archaeometry has been predominantly a multidisciplinary, rather than an interdisciplinary, undertaking in archaeological investigation.

This situation is not restricted to projects pursued independently by archaeologists or archaeometrists of various persuasions; it is common in most collaborative work. As Karl Butzer lamented over a decade ago (Butzer 1975:106), "few archaeological teams have achieved interdisciplinary — as opposed to multidisciplinary — collaboration." The frequency of technical appendices or separate technical articles in archaeological reports testifies to the continuation of this pattern. This inclusive yet functionally separated presentation of data does not overcome the difficulties found in the independent research efforts; it simply creates an illusion of "scientific rigor."

Although well intentioned, Philip Betancourt's (ed. 1984) project on East Cretan White-on-dark ware is a prime example of what Deetz (1968:48) labeled "sterile methodological virtuosity" (see also Matson 1951:114) — an example of "scientific rigor" proceeding without purpose. Manufactured during the Early Minoan III period, this White-on-dark ceramic became the principal fine ware of eastern Crete, as well as a period marker. Citing as rationale for the project "a commitment to a coordinated examination of archaeological artifacts from different points of view," Betancourt (ed. 1984:XVIII) enlisted the support of a number of scientists who submitted varying numbers of samples to extensive analytical scrutiny. Among the separate techniques were petrographic examination, Mossbauer spectroscopy, neutron activation, proton microprobe analysis, as well as photoacoustic and xeroradiographic examination. Each author presented a report consisting of descriptive data. No specific problem was advanced, nor was there an attempt to integrate the data from this distinctly multidisciplinary analytical program. But why were the resources expended, and what was gained?

We believe that the first step in remedying the separation of scientific data from cultural interpretation is understanding that the objectives of specialists differ in more than just methodology. In this chapter, we examine sources of cross-disciplinary friction as it impacts Americanist archaeology in the hope that such examination will encourage changes in the way archaeologists and archaeometrists pursue their collaborative research.

Many of the observations that we make are not new to the archaeological literature. They have appeared in different guises in methodological discussions by scholars seeking an interface between academic and "salvage" archaeologists (Schiffer and Gumerman, eds. 1977), and among archaeologists of various theoretical persuasions who have tried to integrate divergent archaeological research objectives (Moore and Keene, eds. 1983).

Beyond discussing what we perceive as causes for potential tensions that limit the collaboration of archaeologists and archaeometrists, we suggest that the nature of interdisciplinary research demands a more structured form of participation, one that starts with the development of a research design that is better articulated with archaeological theory. We will focus our discussion on issues pertaining to ceramic materials. It is likely that there are some aspects peculiar to each type of material or scientific subdiscipline, but, by limiting the scope of the present chapter, we can address the issues more directly.

A Difference in Perspective

It is reasonable to expect that archaeologists and archaeometrists will differ in their specific interests: Each has an approach that is relevant for certain problems and not for others. The approach, described by C. S. Pierce (Goudge 1969) as the "cognitive burden," reflects the manner in which the researcher was trained, and it influences the ways that data are collected, applied, and interpreted. Even the formulation of basic questions is likely to differ. This is the source of the three archaeometric research loci recognized by NSF:

1. When archaeologists formulate problems, they pose research objectives in the context of their archaeological discipline. They often treat the techniques and data as secondary to the cultural interpretation.
2. Archaeometrists also may ask cultural questions, but their theoretical or methodological perspective comes from the natural and

physical sciences. This perspective, coupled with less familiarity with specific archaeological contexts, results in greater emphasis on the techniques and the derived data. Analysts may choose research problems to fit their available equipment and techniques.

3. Technique development is a natural outgrowth of the archaeometrists' theoretical and applied knowledge of physicochemical processes structuring variation in the natural or physical environment. Although their ultimate goal is to benefit archaeological interpretation, archaeometrists give primary attention to scientific theory, analytical requirements, experimental design, and mechanical and procedural means of measurement. They undertake analysis of data patterning and interpretation to evaluate the efficiency of the scientific technique. Correspondence with archaeological interpretation is used primarily as a check on the technique or procedure.

With these different objectives, communication can easily break down among investigators; multidisciplinary, functionally separate endeavor becomes the norm. Problems arising from the inability to move between the constructs and data of different disciplines are now surfacing in the form of fragmentation in research effort, competition for funding resources, generation of insufficient data of questionable utility, noncommunication, and poor integration of collaborative research efforts.

Recognizing that disciplinary boundaries are inhibiting creative research and that government funding tends to be too discipline specific, Sigma Xi, the Scientific Research Society, conducted a survey regarding the characteristics, problems, and opportunities of cross-disciplinary research (Sigma Xi 1988). One finding was that no consensus existed among its members regarding the distinction between multidisciplinary and interdisciplinary research. In fact, many of the responding scientists and engineers used the terms interchangeably. Among those who did perceive a distinction, multidisciplinary work entailed a specified role for each participant in a project, one that did not necessitate shared ideas or theories. Interdisciplinary research, on the other hand, was marked by "members of two or more fields, working together on a project, achieving genuine theoretical and intellectual integration" (Sigma Xi 1988:23).

We think that it is useful to emphasize the concept of *interdisciplinary* research because it highlights the different goals, attitudes, and backgrounds that the practitioners bring to the research process, as well as the need for *integration* of those different theoretical perspectives and different data sets when pursuing (presumably) shared objectives. Although "true" integration is more likely to be a goal rather than a common expectation in archaeology, it is nonetheless a goal worthy of pursuit.

The Nature of the Archaeological Record

Material remains are essential components of the archaeological record. How was the record produced? What cultural or noncultural processes were responsible for the fragmentary traces of the past that have been recovered (Schiffer 1987)? Part of the record is associational; another part is physical and, as such, is subject to measurement according to physical parameters. This physical part can be linked to a culture's technology, the study of which provides a natural bridge between the scientific and humanistic disciplines (Cross 1982; Kingery 1987a). The study of technology and reliance on the measurable parameters of the physical record is not simply "applied science" but is "the application of scientific and *other organized knowledge* to practical tasks" (Cross 1982:222, emphasis in original).

This "other organized knowledge" is important, for it provides the "contextual" framework for interpretation and integration of new data within systematized knowledge. In its absence, description of the physical parameters of artifactual remains may be given and even limited inferences offered as interpretation, but the inferences provide for little more than what H. A. Simon (1969) refers to as a "satisficing" rather than an "optimizing" interpretation.

Among other things, satisficing explanations—the quick interpretation — will result from a lack of sufficient knowledge about the relationship of a given class of artifacts to the greater cultural context. In the absence of an adequately developed research design, research is likely to be carried out at a superficial level — no matter how detailed the individual analyses. The conclusions derived will suffer in diminished specificity. Interpretation of the past requires more than just an indefinite number of measurements that can be made on artifacts; interpretation is made possible by the intersection of objects and theory (Moore and Keene, eds. 1983:135).

SOURCES OF DIFFERENCE IN PERSPECTIVES

Intradisciplinary Distinctions

The phenomenon of archaeologists and archaeometrists talking past one another is caused partly by the fact that archaeologists, as consumers of archaeometric services, are no more unified in their disciplinary approach than are archaeometrists. We will consider two major archaeological factions, which have distinctive research goals and disciplinary viewpoints that determine their needs and interests regarding the use of scientific data generated by the archaeometrists.

One group of archaeologists can be characterized as having ties to fields such as classics and art history. For the scholars trained in these traditions, the single object can stand as a reification of early societies' values and, by extension, their norms. This value accorded individual objects (so-called exemplars) is taken to an extreme position by some analysts who, though acknowledging that "there is no single meaning held within an object of importance to art, technology or archaeology" (Kingery 1987b:684), nonetheless emphasize the "deeper meanings contained within" objects (Kingery 1987b:679).

The interest in the individual object has a strong institutional base. Predominately serving art history and the classics, museum research laboratories, such as the Museum of Fine Arts in Boston and the British Museum, and laboratories, such as Oxford's Research Laboratory of Archaeology and the History of Art, have provided fertile ground for the development of scientific techniques and their application to archaeological materials. In these contexts, analytical scientists and Old World archaeologists give technical examination of mosaics, pottery, metal, figurines, coins, sculpture, and architecture special attention (Sterud 1979:693; Carpenter 1963:5–7).

An object's presumed inherent value and meaning come from a historical particularist view of the significance of art and crafts. Thus, technology construed as the set of techniques of manufacture for an object, is an important concern. Laboratory analysis is expected to reveal the artist's technique, nuances of control and style inferred from detailed description of technique, and, by extension, historical sequences and high periods in art and technique. Conservation of objects must be based on a thorough knowledge of the techniques employed in their manufacture to prevent obscuring or altering these important characteristics. Furthermore, the value of these objects as examples of fine art and as representatives of the antecedents of Western technical progress and aesthetics often depends on authentication techniques. For museum collections where provenance and archaeological context are limited and where objects have been collected as singular representative examples of a culture, technical examination of objects is used routinely to verify their antiquity and point of origin. We must note that, although the majority of these studies concern single objects within a normative perspective, changes are taking place in this field, too; for example, studies of trade and exchange are increasing (Koehler 1978; Reedy 1986).

A different group of researchers consists of archaeologists who have been trained as Americanists in a natural history and anthropological tradition (Willey and Sabloff 1980:79–81). Although different emphases such as cultural reconstruction, processual, behavioral, and contextual archaeology all contribute to a rich mosaic of theoretical and methodological orientations that make Americanist archaeology difficult to define (Dunnell 1983:521), the practitioners typically utilize artifacts from a different perspective than their classically trained colleagues. The Americanists share a broad research framework engendered by academic training, lodged principally in anthropology departments where a primary goal of studying other cultures, past or present, is not only to document the descriptive "who, when, and where" of each but to examine problems of *how* the archaeological record was formed and *why* the factors or changes that occurred in past living systems produced the materials recorded in the present (Binford 1964). During the last two decades, *how* and *why* have become central concerns as U.S. archaeology has moved toward an explicit attempt to link the behavioral past with the full range of archaeological material recoverable in the present (Schiffer 1976).

With an increasing interest in attempting a more behaviorally oriented understanding of past communities, the interest in social organization similarly increased, as did a concern for variation. People adjust to each other and their environment, and these adjustments result in changes in the goods that they produce. Accordingly, no single object can be taken as representative unless its representativeness is expressed in terms of variation in similar products. To ignore variability in the archaeological record in favor of a normative viewpoint treats culture as a "uniform, learned entity" (Kelley and Hanen 1988:21).

Anthropologically trained archaeologists who are interested in explaining human behavior and, thus, in explaining the material record within the context of the society that produced it will likely be frustrated by the lack of shared perspective with archaeometrists. Those archaeologists may find the studies do not address their questions, or they may find the archaeometrists' conclusions to be overdrawn. Americanists are very likely to react negatively when the archaeometrists' interpretations fail to consider the complexities of the cultural record (Schiffer 1976, 1983, 1987; Reid 1985). Though we are not suggesting that only the archaeologist possesses knowledge that will contribute to a better understanding of the past, it is a truism that the more one knows about the specifics of an archaeological context, the more complex the situation becomes. "In a practical sense, the degree of perceptual distortion [of the archaeological record] is inversely related to experience, to one's knowledge, implicit or explicit, of the record's formation" (Reid 1985:16). Broad generalities or inferences based on limited sampling in the case of single object examination, or conclusions about one aspect of the culture that fail to note its relatedness to other causes of the phenomena being observed, contribute minimally to our understanding of the past.

Application and Acceptance

From the archaeometrist's perspective, interaction with archaeologists is further complicated by the fact that not all archaeometric techniques are equally supported or rejected. Certain techniques are widely sought after by archaeologists, and certain technical developments are followed with great attention. Others remain obscure despite the ease with which they might be applied. A vast range of analytical data can result.

The incorporation of data by the archaeological community, however, is not a random or automatic event; it depends upon the ability to fit the data obtained into a relevant theoretical framework or problem orientation. In Americanist archaeology, for example, despite early demonstrations of the utility of analyzing ceramic constituents to demonstrate trade among prehistoric communities (see A. Shepard 1936b), such studies were rare until the 1960s (Cordell, this volume). Not until broad historical outlines were more firmly placed and interest focused more on reconstructing the patterns of settlement and social organization does it seem that Americanists were prepared to address questions of exchange in prehistory. As archaeological research interests changed, new techniques such as chemical analyses and old techniques such as petrography fired the archaeological imagination (Earle and Ericson, eds. 1977).

The identification of local versus nonlocal wares, for example, was not simply a logical progression in the sequence in which questions can be asked of the archaeological record. These new research directions were part of a shift from site-specific descriptions of archaeological remains and sequences to a broader regional approach, one that led to data interpretation within a more cultural anthropological or an ecological, adaptive framework.

In the meantime, however, techniques suited to describing aspects of prehistoric ceramic technology were infrequently sought out. With a few notable exceptions (A. Shepard 1936b; Matson 1965a), archaeologists chiefly viewed aspects of ceramic technology as a means to characterize and identify culture groups (for example, through the use of temper types). Their viewpoint was strongly normative, and they saw no reason to consider variability within traditions, particularly in light of the relatively primitive nature of New World ceramic practices and the presumed continuity of technique between prehistoric and ethnohistoric populations. Ethnographic accounts appeared to obviate the need for detailed investigation of technique in such seemingly conservative crafts.

In recent years, however, Americanist archaeology has begun to alter its view of ceramic technology. Drawing on concepts from cultural ecology, the systems approach, and results from the plethora of trade studies, archaeologists have moved from the use of technology to identify cultural groups toward research focused on identifying or reconstructing the activities of ancient ceramic production centers and, in a related aspect, understanding the evolution of craft specialization. Accordingly, technology is increasingly viewed as a system whose components respond to other social parameters: craft organization; relation of producers to consumers' uses of the products; access to and restriction of key resources by environmental, economic, and political means; ideological conventions; and other factors that restrict or encourage experimentation and innovation. In this context, variation in aspects of technique is potentially important, even within simple technologies, and appropriate materials analysis techniques used to investigate these dimensions in ceramic artifacts attract attention. As noted above, although early practitioners sought to address these very problems, it is the readiness of the field to tackle the problems that determines how widely certain archaeometric techniques will be employed.

It should be clear by now that for archaeological utility, a single framework for applying archaeometric techniques and interpreting the resulting data can seldom serve all factions adequately. For most Americanists, the significance of the data is best evaluated when the object is viewed as part of a sample whose characteristic parameters have been established and whose relevance to understanding cultural history or processes influencing behavior has been specified at the outset of the analysis. It is the contribution that the sample makes to understanding process that is most important. If there has been a tendency to criticize an object-oriented approach as having limited value, we wish to be clear in stating that the contribution and success of the studies and approaches must be evaluated in terms of the goals of the research framework involved and the nature of the interpretations offered.

Problems Inherent in a Multidisciplinary Approach

Advances have been made through the application of archaeometric techniques to ceramic objects, both in anthropological and art historical archaeology. Nevertheless, the historical trends in the adoption of analytical techniques and the separate research goals among archaeologists and between archaeologists and archaeometrists have led to a breakdown in the efficacy of the application of the analytical tools. This contributes to the generation of expensive data sets for archaeologists who may not be prepared to understand and utilize them or even consider the data beneficial (Figure 14.1). We no longer have the resources to support this type of research.

Regardless of its research focus, virtually every interdisciplinary research endeavor comprises interrelated stages where lack of coordination and planning can result in reduced effectiveness of the final product: (1) problem definition; (2) methodology; and (3) interpretation. For each type of archaeometric research, whether it is the application of archaeometric techniques by either archaeologists or archaeometrists or the development of a technique, certain aspects are more problematic than others. By recognizing how and where breakdown in interdisciplinary research is most likely to occur, we can move toward making archaeometric research more truly interdisciplinary. We will examine aspects of each of these research stages in turn.

Problem Definition

A common cause of fragmentation in cross-disciplinary research design is a lack of theory leading to a problem definition that is shared

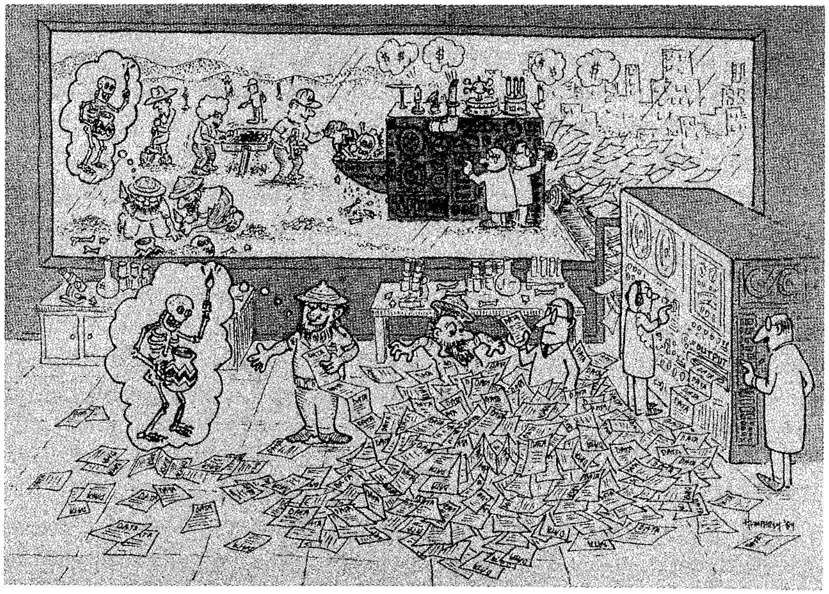

Figure 14.1. Cartoon prepared for this chapter by Bob Humphrey (1989).

by the archaeologists and analysts. Theory is of central concern, for it imposes constraints upon what is most useful to ask and what should be observed. Further, it provides the means whereby the resulting empirical observations and their relations may be integrated into a systematic body of knowledge (Dunnell 1982:6).

When archaeometric techniques are applied to answer archaeological questions, the context of the research is a cultural problem, regardless of whether those questions are posed by archaeologists or archaeometrists. The theoretical basis, therefore, must be derived from cultural theory if the data are to be interpreted with reference to cultural significance.

Even when working in an area in which little previous archaeological or archaeometric research has occurred, a theoretical framework applied in conjunction with whatever is known enables one to design research to address at least general kinds of problems (Canouts 1977). As the major temporal and spatial relationships of the world cultures have been roughed out, so have analytical and geological parameters been determined for using particular kinds of physicochemical analyses; unfortunately, this is occasionally neglected, as exemplified in an application of proton-induced X-ray emission analysis of pottery from Motupore Island, Papua, New Guinea (Allen and Duerden 1982:52). Although the technique had been in use for a number of years, the researchers felt that they needed to see what patterns could be found in the ceramic paste before they could define an archaeological research project.

Attention to existing theory and to the context within which an investigation is to be conducted will greatly reduce the need to reinvent the wheel in each application of an analytical technique, although there are always idiosyncrasies in a particular situation. Innumerable questions can be formulated concerning archaeological materials, but problem definition within a theoretical framework nevertheless enables the researchers to isolate those problems most worthy of investigation from all possible problems.

Methodology

One of the ways to help formulate the problem and move it closer to methodology is to develop a research design. Relative to the writings on hypothesis formulation and testing, discussion of research design has received little attention, with notable exceptions exemplified by the writings of Lewis Binford (1964), Thomas King (1971), Alfred Goodyear, Mark Raab, and Timothy Klinger (1978), and George Gumerman (1977). A central purpose of a research design is to give direction to the work being undertaken. It improves research efficiency by providing criteria for determining the relevance of data and by establishing criteria for assessing the adequacy of inference to be drawn from the data (Goodyear, Raab, and Klinger 1978:161). The construction of a research design, therefore, is heavily dependent on the interrelationship between archaeological theory and method, familiarity with the current state of knowledge about a subject, and acquired information about availability of resources necessary to investigate the problem.

If data from fields with different sets of theories, assumptions, or operating principles are to be integrated within a single study, a clearly formulated research design is especially demanded. Because the design must incorporate data derived from the natural and physical sciences, it is essential to address the logic behind the choice of data to be gathered; that is, anthropological or other cultural terms must be defined in ways that allow them to be measured by physical and/or chemical attributes in the artifact. This step also brings into focus the kind and amount of cultural variation that might be expected from the results of some measurement (in other words, what range of variation is likely to be important in defining patterns and in discriminating between groups of results or deciding on levels of significance).

Interdisciplinary collaboration at the level of research design is of fundamental importance for another reason. It insures that the sampling design is appropriate, both in terms of assemblages (that is, the numbers and kinds of objects and the spatial, temporal, and functional context required to answer the archaeological questions posed) and in terms of the analysis to be performed (that is, how to sample the objects to provide the material for measurement of the specific variables identified in the research design). Frederick Matson (1982:20) noted that, all too often, convenience dictates sample selection, illustrated by a recent characterization of manufacturing technologies for pottery from the Near East and nonprovenienced pottery from China (Vandiver 1988:154).

Eventually, the investigator comes face-to-face with specific decisions about analysis. Frequently, the single criterion for analytical technique is availability of instrumentation and the analyst's avocational interest in art and archaeology. As new archaeological issues come into vogue, scholars often indiscriminately adopt analytical techniques used successfully by their colleagues in other situations. No archaeometric technique, however, has built-in interpretive value for archaeological investigations; the links between physical properties of objects and human behavior producing the variations in physical states of artifacts must always be evaluated. Both the archaeologist and archaeometrist, therefore, must be involved at the outset of the project to create an analytical framework that is meaningful.

Technique Development

There is a design context in archaeometric research that departs from some of the constraints discussed above. This is the development of techniques by archaeometrists. Although technique development is intended to solve particular archaeological problems, problem definition for the research arises largely in terms relevant to the field of science involved (chemistry, physics, and so forth). Nevertheless, the quality and precision demands are dictated by the cultural context, that is, what sort of data will actually answer the questions that can be addressed at any point in time. Knowledge of archaeological problem orientation and research priorities allows the scientist to evaluate the impact technique development will have. A new or modified technique may permit the archaeologist to refine his or her understanding of an area, or there may be aspects of analysis where greater precision will allow significant new questions to be asked, rather than saying more of the same thing in finer detail. Here, the clarity of archaeological problems can contribute to technique development. For example, we can see whether precise knowledge of firing temperatures in ceramics is likely to be of much utility, given the archaeological questions being asked, or where archaeologists have reached an impasse in their interpretations because they are unable to obtain a particular type of data about sets of objects. Obviously, priorities will change as the field develops and as shifts in the foci of investigation take place.

Interpretation

Interpretation of archaeometric data does not begin when the archaeologist attempts to make cultural sense of elemental concentrations or descriptions of microstructures. It first takes place at the technical level. For example, interpretation of chemical data in characterization studies involves a number of steps that convert a series of raw counts of X-ray or other emissions into an "absolute" figure, representing the elemental concentration that will be stored in the data base. Sometimes, these data are further reduced or modified by applying calibrations or other corrections. Analysts must make decisions about the applicability of such measures, and these decisions affect the way results are reported. It is not always feasible for archaeologists to be directly involved in carrying out or assisting in the analytical work, but they should take the time to become acquainted with data interpretation at the analytical level. They will then be able to understand how the processes involved potentially affect data precision and patterning that will be sought at the next level of abstraction. If we are to continue to commit resources and time to these analyses, we must also commit intellectually to striving for high-quality data and responsible interpretation.

In other cases, data interpretation involves a slightly different problem. For example, petrographic techniques were developed to describe rocks and minerals and to provide data that would be interpreted in a theoretical framework designed to illuminate processes of petrogenesis. Data compilation and data reduction procedures common to petrography assume such a purpose. Although archaeologists certainly can use the techniques profitably, they must be aware of how these purposes affect the data they will ultimately use for cultural interpretation. To the extent that ceramic materials are minimally modified and the archaeologist proposes to compare them to geological materials and their formation processes, petrographic interpretation is relatively straightforward. However, as ceramic technological complexity increases, the natural characteristics and relationships of the original materials are altered, and interpretive techniques must be modified to elucidate the cultural patterning observable in prehistoric pottery.

Some archaeologists have recently championed techniques from ceramic engineering as an untapped resource for advancing archaeological progress (for example, Bronitsky 1986a, 1986b). Apart from the fact that convincing arguments have not yet been made for the widespread utility of much of the potential data, most of the analyses were developed for high-tech ceramics and conditions peculiar to the production and use of such materials. Consequently, the conditions of the tests were designed around formal and physical properties that are not matched by most archaeological ceramics. Direct application of these techniques to materials that do not meet the test specifications provides results that are ambiguous, at best. In Vincas Steponaitis's (1983, 1984) attempt to understand the effect of temper type and coarseness on thermal shock resistance, he acknowledged that test results were only suggestive due to problems in adapting the tests to the archaeological ceramics. Despite his disclaimer, other researchers have accepted the relationship as conclusive, and when they find shell in their pottery, they infer that the intent of the potters was to minimize thermal shock (Hally 1986:278). But a caveat is in order here. The demonstration that prehistoric ceramics have certain performance characteristics is not, in itself, a demonstration that potters were consciously operating to achieve those properties. They may have been natural outcomes of choices made for other reasons.

In 1978, Ruth Tringham pointed out the failure of inferential "leapfrogs" and proposed a set of guidelines for experimental work and technique development that explicitly addressed the characteristics and limitations of archaeological materials. Her guidelines could be applied to situations where models pertaining to properties of modern, homogeneous, high-tech ceramic systems have been expanded to include the behavior and characteristics of impure, heterogeneous materials that are characteristic of archaeological ceramics. This point is very important, but such technique refinement is seldom undertaken without archaeological impetus because impure materials lack commercial value. Some work has been done along these lines, but often it is without the rigorous experimental structure that produces results with utility beyond a particular situation. For example, in Gordon Bronitsky and R. Hamer's (1986) attempt to evaluate the effects of different tempering materials on impact and thermal shock resistance, they tried to overcome the limitations imposed by archaeological sherd materials by making a series of test briquettes. Because they chose to use a modern refined ceramic clay whose firing properties and resultant interaction with the tempers was not comparable to most archaeological ceramics, the applicability of the results to prehistoric materials is questionable.

As archaeologists emphasize investigations of ceramic technology and its place in prehistoric societies, we will increasingly need to explore technological choices and practices that lie outside our immediate models of ceramic manufacture and to determine whether those actions produce physical properties and characteristics in ceramic materials that uniquely identify them. Currently, archaeologists are the principal investigators in replicative and experimental studies (Schiffer and Skibo 1987, 1989; Skibo and Schiffer 1987; Skibo, Schiffer, and Reid 1989; Vitelli et al. 1987). They are attempting to forge a link between the performance characteristics of ceramic materials and the culturally patterned decisions by the ancient potters — a link between a materials approach and behavior that cannot be accommodated by present models. It is too early to judge their success, but there is no doubt that this research can only succeed if it is interdisciplinary. To be useful, this line of investigation must meet demanding standards of both the archaeological and materials sciences disciplines.

Toward an Integrated Interface

The problems raised above stem from a number of factors, none of which are really new. The lack of communication between members of different disciplines (for example, archaeologists and materials scientists) extends well back to Anna Shepard and Wesley Bradfield's early work in the 1920s at Cameron Creek (Bishop, this volume). The review of Shepard's work in this volume illustrates that as methods have improved, there has been pitifully little progress made beyond the level of the descriptive report. Indeed, since the start of Shepard's career, there has been a proliferation in new methods, leading to a seemingly infinite number of measurements of a vast range of archaeological remains.

Archaeology is more and more a borrowing discipline — whether from cultural anthropology, ecology, or the physical sciences. In many cases, analysts with specialized training, well outside the bounds of traditional archaeological studies, have been brought in to provide so-called contextual studies of a prehistoric environment. Unfortunately, in some cases, the models from these outside disciplines are used without modification for archaeological data. A difficulty with this practice for studies of ceramics lies in the fact that these materials represent an intersection of the cultural and natural worlds. Understanding the patterning this intersection evinces requires an integrated perspective, one that is not accommodated by existing models from either archaeology or the natural sciences.

There is also a problem with the way in which archaeological research is organized. Although used to describe modern archaeology in general, Michael Schiffer and George Gumerman's statement characterizes the current interface between archaeology and archaeometry:

> An appraisal . . . to which we come reluctantly is that precious little is known about how to design the kinds of projects that address timely research questions in a realistic manner. Far too often, research is characterized by a poor fit between questions and resources, the use of techniques of recovery and analysis without adequate justification, and a failure to achieve sufficiently credible results to serve as a foundation for future research or as a basis for management recommendations (Schiffer and Gumerman, eds. 1977:129).

If it is accepted that scientific analyses will continue to make an important contribution to archaeological investigation by augmenting other types of data, then we must find a way to increase the effectiveness of archaeometric research within the archaeological context. We have discussed a number of areas where pitfalls are common, areas that would benefit the most from active interaction and decision making by both archaeologist and analyst. We possess the ability to change and improve the interaction if we can build a theoretically oriented design framework that meets the needs of interdisciplinary research and develop a new interdisciplinary approach to research management.

Developing a Generic Research Design

Whether recognized by the researcher or not, the aspects of theoretical framework, problem definition, methodology, application, and interpretation are all inextricably linked in the conduct of research. Although often ignored, it is theory that frames the problem, limits the methodology, defines the suitability and extent of the sampling design, sets the analytical procedures and requirements, and permits the incorporation of derived data into a systemic body of knowledge. It is the methods, however, removed from theory, that now abound. Undeniably, new techniques of analysis have vastly increased our data-gathering capabilities; yet, as noted by Arthur Moore and James Keene, "In our rush to demonstrate that the past is knowable, little effort was directed toward demonstrating that the past is understandable" (Moore and Keene, eds. 1983:4). This has resulted in what they have termed "The tyranny of methodology" (Moore and Keene, eds. 1983:5). One manifestation of this "tyranny" is found in the application of methods without an adequate theoretical framework, problem formulation, or cultural context that tends, therefore, to trivialize the very phenomena for which understanding is sought (Keene 1983:142).

Anna Shepard's inability to find strong acceptance for her data was less the result of different methods than of the lack of a common theoretical umbrella under which her observations could be understood by the archaeological community. As a consequence, her data could not be integrated with the other kinds of data that archaeologists were using. Even with all the attention given to theory development of the post-1960s, some type of theoretical structure that can accommodate data from archaeometric and archaeological analyses still remains to be developed. A few attempts are being made (Schiffer and Skibo 1987), but many more such studies are necessary in order to determine relevant relationships. There is too great a tendency to extrapolate and apply the findings of one study to another without appreciating the range of variation occurring under different conditions.

Major disciplines, like the earth sciences, physical sciences, and social sciences, represent fairly discrete units of highly integrated knowledge: "The factors that serve to build [these disciplines] along disciplinary lines are insufficient to integrate knowledge across disciplines" (Warfield 1986a:H–46). As specialization in a discipline increases, a force exists to further that specialization (Mills 1959:59). One way to begin to bridge these boundaries of convention is through definition. We must begin to define anthropological or cultural terms in a way that can be measured, using the physical and chemical properties of the artifacts. There is no reason to believe, however, that someone will develop an integrating theory that will serve to accommodate the diverse interests and data of archaeologists and archaeometrists. It is more likely that progress in theory construction will be characterized by gradual accretion from the rough formulation of relationships among observed entities found to covary in certain contexts and under certain conditions, by hypotheses about primitive relationships, by evaluation of these relationships under different conditions, and by evaluation of the significance of the suggested relationships. This evolution will probably be punctuated by far more failures than successes, but the failures will contribute to the growth of the knowledge base that will permit new formulations.

We do not offer a "supradisciplinary" theory here, capable of subsuming archaeological and archaeometric concerns. Rather, we point to the need for such development and suggest that the lack of adequate theory accounts for the inability of archaeologists and archaeometrists to successfully integrate their respective data sets in a manner that will increase our understanding of the past. This lack of theory can be seen as having limited Shepard's success in the past, as well as ours today.

Developing a Social Context for Conducting Research

For more than 30 years, Anna Shepard emphasized the need for *cooperation* between technologists and archaeologists. This need was recognized at the 1938 ceramic conference (Shepard and Horton 1939) and has been echoed by others (Matson 1951; R. Jones 1982; Widemann 1982, among others). Cooperation is a word, however, that can stand for a vast range of interaction — from the submission of ceramic fragments upon request to coparticipation in all stages of a research project.

Improvement in the design process starts with the recognition that the integration of diverse types of knowledge becomes increasingly difficult for a single investigator to assimilate and synthesize. Belief and assertion or recourse to authority can be substituted for knowledge, but the effectiveness of the research endeavor will diminish. It is preferable to follow the contention of logician C. S. Pierce (Goudge 1969), who suggested that any application of scientific method becomes a cooperative, social venture — not an individual affair. It is a group activity, as noted by George Gumerman (1977:100) in reference to the management needs of contract archaeology. In this view, individuals, analysts and archaeologists alike, must become dependent upon each other for their complementary strengths with a lessening of their individual biases.

The archaeologist and the archaeometrist should each be but *one of several* active participants in the design and conduct of the research. This "research matrix" offers several advantages: (1) it promotes a sharing of ideas and objectives that are not common to everyone in the group; (2) it reduces the effect of dominant personalities; and (3) it assigns a priority to the objectives set by the group (Warfield 1980, 1986a, 1986b). To meet these objectives, it is obvious that the group must *be managed;* this can be achieved by the use of one or a combination of what John Warfield has called "consensus methodologies" (Warfield 1982). These are group problem-solving techniques that provide for an efficient generation and structuring of ideas, as well as a complete process for designing and choosing among alternatives. Notable in the methodologies is the "nominal group technique," which provides a method for the generation, refinement, and ranking of ideas, and "interpretive structural modeling," wherein the group's ideas are structured with the help of a trained facilitator. In essence, participants must give up individualistic "control" to insure that a requisite amount of informational variety has been built into the design system. By "requisite" we mean that the research situation is not over- or underdesigned and that the appropriate materials and approaches are brought to bear on the specified problem.

We should recognize, too, that during the course of executing the research program, certain factors will tend to dominate the design. To insure the appropriateness of continued sampling and analysis, as well as to prevent the dominance of a single aspect, group interaction should be designed to take place iteratively, with meetings at specified intervals to review progress, maximize communication, and plot future direction. If samples have been analyzed according to preplanned stages of review, emerging problems and unforseen conditions can be addressed at an early stage, permitting the researchers to contribute to the resolution of difficulties and insuring the best possible return on the archaeometric endeavor. In this way, research efficiency will be increased, redundancy limited, the funding base broadened, and — as work continues — the information obtained from the archaeometric effort will be available, even if in preliminary form, to a wider number of scholars who are interested in the findings but are not directly participating in the project.

Even when the relationship between the analyst and archaeologist is formally one of producer-consumer (when, for example, the archaeologist contracts for analytical services), some level of small group interaction should be expected as part of the contract. Responsible individuals and companies will want to provide their customers with high-quality data and expertise, but members of the archaeological community must take responsibility for initiating the dialogue.

FINAL CONSIDERATIONS

Unfortunately, regardless of the advances in the design management of research or the sufficiency of the theoretical structure leading to an understanding of the past, the present structure of academia itself does not support truly collaborative research and publication. Promotion and tenure decisions often are heavily influenced by publication review processes that assume that one's position in a list of authors implies the level of participation and responsibility in a project. There is a stigma attached to all but first or sole authorship. This state of affairs is prohibitive to cooperation.

It is difficult to imagine changing the structure of academia, but important modifications are presently possible. Although the numbers are still small, in the past 15 years the ranks of archaeologists with interdisciplinary specialties in ceramic analysis have grown materially over the few pioneers who preceded them. With formal training in both humanities and the physical or natural sciences, they embody the beginning of an interface between archaeology and archaeometry. As scholars like Anna Shepard and Frederick Matson provided pioneering efforts to combine science and the humanities in their own archaeological investigations, new researchers offer the opportunity for the growth of interdisciplinary archaeological and archaeometrical research through example and teaching within and across their respective major fields.

Their role in training is especially important. Given the structure of archaeological curricula in the United States, many archaeologists feel poorly prepared to commit to this level of interaction with archaeometrists; they have not had enough exposure to the sciences to be able to communicate effectively. For these people, it is easier to give the analyst some samples and to let the scientist determine what is appropriate to investigate. But, as we have seen, this approach is likely to produce less effective interpretive results than those that can be obtained through communication. Because the need for scientific data is becoming more routine in archaeology, we must remedy this gap in our training programs.

That is not to say that we think that every archaeologist should also become an archaeometrist, no matter how the field is defined. However, we do think that courses in archaeological methodology should make students aware of the research issues we have raised in this chapter and should prepare them to interact with their colleagues in the physical or materials sciences.

In addition to this fundamental level of education, there is a need for short- and long-term specialist interdisciplinary programs. A few institutions provide training for some advanced students, and a number of professional archaeologists would like to hone their cross-disciplinary skills; however, technical resources are usually limited so that access to equipment for training is scarce. In response to this need, some institutions have provided intensive workshops and training programs. More opportunities are needed, and teaching support is essential. One possible solution is to form interinstitutional cooperative links so that instructional continuity can be maintained between visits to analytical facilities. The more we can make such programs available, the faster we will see the kind of integration that will change the products at the interface between archaeology and archaeometry from analytical and particularistic to synthetic and holistic.