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Cultural evolutionary approaches to artifact variation over time and space: basis, progress, and prospects

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ABSTRACT

It has becoming increasingly common for archaeologists to draw on evolutionary theory and methods to analyze artifactual variation over time and space. The term "evolution" and its traditionally biological connotations, however, can provide a source of confusion, which might cause hindrance to those trying to understand the growing array of case studies that utilize these methods. Given this, a brief review of the current theoretical basis for cultural evolutionary approaches is given, which largely draws on social transmission theory. Thereafter, recent advances in the field are discussed, which have involved both methodological developments and a flourishing of empirical examples of application. Finally, future directions are considered, which, as in any developing field, will probably involve further development of both its theoretical and empirical basis, and the interaction of the two. As David Clarke identified almost half a century ago, the great strength of the archaeological record is its power to reveal meaningful patterns of artifactual variation over temporal and spatial scales, especially in statistical terms. Cultural evolutionary approaches offer a set of theoretical and methodological tools to approach, discover, and scientifically analyze this potential wealth of information about past societies. Future developments will necessarily follow, but the place of this related body of theory and techniques within archaeology is now firmly established.

1. Introduction

Recent years have seen a notable upsurge in the application of evolutionary theory and methods drawn from biology to archaeological data, a pattern of development that builds and extends earlier applications of evolutionary theory thematically, empirically, and methodologically (see e.g., Brantingham and Perreault, 2010; Charlton et al., 2010; Riede, 2011; Shennan, 2011; Tehrani, 2011; Marwick, 2012; Cochrane et al., 2013; de Voogt et al., 2013; Buchanan et al., 2014; Crema et al., 2014a, 2014b; Jennings and Waters, 2014; O'Brien et al., 2014; Okumura and Araujo, 2014; Prentiss et al., 2014; Rorabaugh, 2014; Jordan, 2015; Lycett and von Cramon-Taubadel, 2015, to cite just a sample of recent case studies). No attempt will be made here, however, to review the lengthy history of evolutionary thinking in archaeology. Others have previously examined in detail the diversity of ways in which "evolution" has manifested itself in archaeological endeavors over the long term (see e.g., Dunnell, 1980; Lyman and O'Brien, 1997; O'Brien and Lyman, 2000; O'Brien et al., 2005; Shennan, 2002, 2008). Rather, focus here is directed toward three more discrete goals. Firstly, the theoretical basis of contemporary applications of cultural evolutionary principles is reviewed. The inevitable biological connotations of the term "evolution" can potentially cause confusion when used in archaeological contexts, and fruitful discussion can only follow if basic misunderstandings of this nature are avoided. Secondly, specific aspects of recent empirical and methodological developments are briefly discussed. No attempt at comprehensiveness is made here; rather, the purpose of this is to illustrate something of the recent flourishing of applications of evolutionary theory to archaeological goals and to consider, in broad terms, the empirical and methodological directions recent work has taken. Finally, and most importantly, prospects for future development are considered.

2. Theoretical basis

The basis of biological evolution is, of course, genetic inheritance. For most of us educated in recent years, the term "evolution" is so inextricably connected with concepts of "genes" and

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"genomics" that it is difficult to think of the term without these associations. Indeed, a modern definition of biological evolution might even go as far as to *define* it as "a change in the gene pool" (see e.g., Dawkins, 1989: 45). Given these considerations, a reasonable question might be "isn't the concept of "evolution" applied to artifacts or other cultural phenomena doomed to only ever be a loose analogy—useful perhaps—but an analogy nonetheless?" Taking this further, our skeptic might add that, as only an analogy, the term has limited applicability and that the dangers of a loose analogy might be as pervasive as, if not outweigh, any perceived benefits of an illusion of "evolution." Today's intimate connection of genetics with the phrase "evolution" is, however, a relatively recent one, and genes have nothing *per se* to do with genuine definitions of the term, much less applications of a bone fide (i.e., non-analogous) theory of evolution.

Evolution, as Darwin (1859) originally identified, is simply the outcome of "descent with modification." This deceptively simple phrase cleverly encompasses the fact that all *any* genuine evolutionary system requires is: (1) the existence of variation in the entities involved, (2) the presence of a mechanism by which at least some of that variation is heritable, and (3) the differential inheritance of particular patterns of variation across time and/or space (i.e., there is an unequal inheritance of variation such that patterns of variation seen at point A are not necessarily those seen at point B). Beyond this, it matters not how inheritance occurs, how variation is generated, or how variants at point A come to be represented at point B in different frequencies. Moreover, when these three elements occur together, evolution (*sensu* Darwin, 1859) is an *inevitable* outcome, and this is no mere "analogy."

The manner in which cultural phenomena meet the necessary requirements of "descent with modification" was explored extensively over ten years ago by Mesoudi et al. (2004). Indeed, the point that evolution (*sensu stricto*) is simply the outcome of a process of "descent with modification" has been made by evolutionary archaeologists on many occasions (e.g., O'Brien and Lyman, 2000, 2003; Lycett, 2011; Shennan, 2011; Jordan, 2015). Given this, some might question whether at this point it is necessary to repeat these most basic of tenets of an evolutionary approach to the archaeological record. However, two points perhaps justify—even at this stage—their reiteration. Firstly, as hinted at earlier, the most typical manner in which the phrase "evolution" is encountered today is within the context of strictly biological evolution, with all the associated elements of "genes" and "genetics" and the (illusionary) stipulation that these are necessarily part of genuine uses of the phrase. This ensures that a major conceptual stumbling block for students of archaeology has, and perhaps always will be, overcoming the idea that "evolution" can only be genuinely applied to organic life, which inevitably leads to the false assumption that all other applications of the term are reduced to "analogies," useful or otherwise. Many undue criticisms are, therefore, likely to proceed from misunderstandings which are best avoided at the outset. Secondly, given that these *are* the essential tenets of the approach, all recent, and more importantly future, developments within the field (whether they be methodological or theoretical) will inevitably be related in some way to one or more of these elements, so necessary are they for helping us to move beyond their reiteration and toward the goal of understanding past societies. That is, future developments will help us to better understand links between processes of transmission and resultant artifactual variation, and the types of behavioral factors that influence particular patterns of variation in particular ways. Understanding this might help us better determine how evolutionary approaches to the archaeological record can be improved. This is a point, therefore, necessary to return to later.

Moving beyond these most basic of tenets to better understand the relevance of an evolutionary approach to the artifactual record, requires briefly examining in more detail the principles underlying concepts of "inheritance," "variation," and "differential replication" of variation as they apply specifically to the archaeological record. The purpose of the following is to emphasize how the presence of these three simple ingredients in composing the archaeological record, inevitably makes key aspects of the available archaeological record necessarily evolutionary in character. Indeed, it needs to be stressed that while culture represents a genuine evolutionary system in these basic terms, this does not mean that there are *exact* parallels between biological and cultural evolution in *every* respect. Some of the differences in details will be apparent in what follows.

2.1. Inheritance: social learning mechanisms, not "mechanism" of cultural inheritance

The means by which inheritance of information occurs in cultural evolution is social learning. Social learning is the means by which *lineages* of heritable continuity are formed in the archaeological record, potentially visible as artifactual traditions (O'Brien and Lyman, 2000). Social learning can be defined straightforwardly as "learning that is influenced by observation of, or interaction with, another animal (typically a conspecific) or its products" (Heyes, 1994: 207). It is important to emphasize, however, that "social learning" is something of a catchall term that can include several distinct mechanisms of information transmission between individuals. In this sense, the term "social learning" refers to a diversity of means by which individuals may learn from others: it is a series of *mechanisms* by which learning may take place, not a "mechanism." Social learning can, therefore, range from relatively simple and indirect means of information transmission that barely appear "social" in appearance, through to more direct and complex means of engagement between individuals. Even today in the archaeological literature, there is sometimes an erroneous assumption that for a trait to be classified as "cultural" in origin it must have been passed on by relatively complex mechanisms of social learning such as teaching (e.g., Li et al., 2014), but such is not the case. A coarse taxonomy of social learning mechanisms would recognize at least four distinct mechanisms of transmission, which vary in character from relatively simple to relatively more complex interactions between individuals. These are, respectively, *stimulus enhancement*, *emulation*, *imitation*, and *teaching*.

Taking these social learning mechanisms in turn, "stimulus enhancement" refers to a situation where the behavior of at least one individual leads to another individual having greater exposure to a particular "stimulus" which, in turn, leads to behavioral change in that second individual (Heyes, 1994: 216). It is important to note, therefore, that in the case of stimulus enhancement the behavioral effect of one individual on another is indirect; the learner in this instance does not directly "copy" a behavior, but is influenced in their own behavioral patterns due to greater exposure to a stimulus. A closely related process, sometimes referred to as "local enhancement" occurs when the behavior of one individual leads to greater exposure to a place or objects and is a key element in others successfully adopting that behavior (Thorpe, 1963; Heyes, 1994). Byrne and Russon (1998: 669) give the hypothetical example of one monkey learning how to crack nuts from another because of the stimulus associated with a food source, whereby attention is directed toward key elements in the process (nuts, tools, etc.), which they subsequently put into adequate operation through individual learning. Such a process repeated over the course of many individual events will lead to a veritable tradition of nut-cracking, even though no direct copying of actions has taken place. The key here is that the behavior of one has led to greater exposure of the necessary stimuli in another. It is social learning because the behavior of one individual does affect that of a second, but it is a relatively simple form of social learning. However, experiments have shown that stimulus enhancement can readily lead to the establishment of stable traditions (Franz and Matthews, 2010; Matthews et al., 2010), indicating that although it may be a relatively simple form of social causation, its potential to influence archaeologically visible instances of repeated behavior may be potent.

Emulation and imitation are relatively more complex forms of social learning. In the case of "emulation" (sometimes referred to as "result emulation") the outcome of one individual's behavior on an object or objects is copied by another, but not necessarily the exact actions used by the demonstrator (Whiten et al., 2004). In material terms, the process this could, for example, involve seeing a particular pottery form and copying that style, even though the actions of the original potter have either not been observed or are ignored during the learning process. The important role of *material* culture in social learning patterns of this form is, therefore, particularly noteworthy, as it leaves a direct physical and temporally enduring record from which others can learn, even after the artifact is made (Fragaszy et al., 2013). Indeed, the extent to which material culture—the object of enquiry in archaeology—is adequately being accounted for in these terms in current cultural evolutionary models (which are often developed by psychologists, zoologists, and other scientists from outside of archaeology) is perhaps open to question. Either way, it implies that archaeological data can shed further light on the extent to which material, "plagiaristic" copying has been an important form of social learning in varying conditions during the course of human history.

Emulation is often contrasted with "imitation," which is defined by the direct copying of the precise actions of a demonstrator potentially bringing about the same effects or result as that observed (Whiten et al., 2004). It is, therefore, a relatively more complex form of social learning, involving direct observation and social interaction between at least two individuals (the "observer" and the "demonstrator"). It is important to note, however, that there is no requirement for deliberate "instruction" on the part of the "demonstrator;" the observer merely watches what takes place in terms of behavioral action and repeats it. The term "teaching," therefore, may be reserved solely for instances of social learning that involve knowledgeable individuals actively assisting and expediting the learning process in others (Tehrani and Riede, 2008; Thornton and Raihani, 2010), the difficulties of unambiguously recognizing this in the case of wild animals notwithstanding (Caro and Hauser, 1992). It is important to note, however, that teaching does not necessarily imply linguistic instruction (Thornton and Raihani, 2010). Equally, it should not be assumed that teaching is necessarily the "default" or dominant mode of social learning in human societies; as the forgoing should indicate, much can be learned through stimulus enhancement, emulation, and imitation, and the role of these processes, even in contemporary human societies, should not be underestimated (Hewlett et al., 2011).

It is also important to emphasize that combinations of these mechanisms may be engaged in the learning of just a single activity, and indeed a combination of both social and asocial learning mechanisms is feasible. Hypothetically, for instance, consider an individual learning to play a musical instrument over a period of time. Initially, they may be inspired to learn to play by listening to digital recordings of others playing the same instrument (i.e., stimulus enhancement). Thereafter, they may try to match the sounds they are hearing (i.e., emulation) while on other occasions they may watch video recordings of their favorite musicians and try to learn the exact sequences of actions and or notes by monitoring their movements of playing (i.e., imitation). They may also receive bouts of active instruction from more proficient individuals in the form of "lessons" (i.e., teaching). To become proficient at playing the instrument they will also likely engage in many hours of practice, sometimes perhaps entirely out of sight (and earshot) of others (i.e., asocial learning, or what is sometimes referred to as "trial and error learning"). This hypothetical example demonstrates that caution should be taken not to glibly categorize the learning of a particular skill as requiring only one specific form of social transmission (e.g., imitation or teaching), and also cautions against a mutual exclusivity of social and asocial forms of learning when considering traditions such as pottery production, basket making, weaving or stone tool production. Indeed, recent work highlights that chimpanzees (*Pan troglodytes*) might also draw on combinations of at least some (but not all) of these mechanisms when learning behaviors such as tool use patterns in the wild (Lonsdorf, 2013).

In sum, a variety of different social learning mechanisms provide a means by which information can be inherited, so creating material traditions in the archaeological record. This variety of social learning mechanisms, either singularly or in combination, thus provides one of the three essential ingredients for an evolutionary approach to the archaeological record.

2.2. Variation: the fuel of evolutionary change

As crucial as inheritance is for cultural evolution, it is variety that provides the fuel for evolutionary change—no change can occur in the absence of variation. In viewing the archaeological record from an evolutionary perspective the role of variation is, therefore, as important as the role of variation in biological evolution (O'Brien and Holland, 1990). One of the primary means by which this prerequisite variation will enter the archaeological record is through copying error (Eerkens and Lipo, 2005; Hamilton and Buchanan, 2009; Kempe et al., 2012; Schillinger et al., 2014a). The role of copying error in this sense would be much analogous to that of "mutation" in the case of genetic inheritance. Interestingly, in the case of artefacts, this was recognized some time ago by Harrison (1930: 111) who noted:

> "it is clear that the size and form of any one-piece artifact, or of any such component of a compound artifact, may be altered very considerably by the cumulative effect of a number of changes each small in itself … In some instances, variational modifications arise through the copying from other artifacts of features of form, with resultant changes in shape and proportions; … It also plays a part in mutational progress."

Importantly, however, different artifacts may have different mutation rates depending on factors such as their process of manufacture and/or the time pressure that a particular manufacturer is facing (Schillinger et al., 2014a, 2014b).

Not that error is the only means by which variation will enter the archaeological record. Axiomatically, we can also expect that deliberate, intentional modifications to artifacts will have taken place in the past just as they do today (see e.g., Ziman, 2000 and chapters therein). Perhaps more importantly, however, the presence of intentionally (or "nonrandomly") produced variation is not in contradiction to an evolutionary approach (see Mesoudi, 2008). Again, it is worth emphasizing that evolution, via the process of descent with modification, does not require a single means by which variation must be generated (O'Brien, 1996: 12). The only stipulation required of the process is that variation is present, regardless of the means by which it is generated.

2.3. Differential replication or "sorting" of artifactual variation by multiple processes across time and space

While social learning and variation are necessary ingredients in the process of cultural "descent with modification," it is the differential replication of variation that creates new forms, traditions or "patterns" in the archaeological record. Leonard and Jones (1987) referred to this parameter as the "replicative success" of given artifactual patterns through time. Their phrase effectively references the idea that just because artifacts (or traits of artifacts) are produced in particular frequencies by their makers at point A in time, they may well not produce them in those exact frequencies at point B in time. The key role of *differential* persistence of variation, as opposed to merely the *existence* of variation, is also usefully emphasized in O'Brien and Bentley's (2011: 311) distinction between "invention" as merely the appearance of novel variation and "innovation," which can more strictly be used to refer to the spread of novelty in terms of its eventual statistical prevalence over alternative variants through time. In terms of frequencies or continuous patterns in archaeological data, differential persistence of existing variation may lead to "directional" change (where mean and modal patterns shift statistically in a particular direction through time), "disruptive" change (where mean and modal statistical patterns diverge to create a bi-modal or multi-modal pattern) or "stabilization" (where trimming of variation leads to statistical stability in mean patterns over time). In the case of discrete traits, differential persistence will lead to the statistical dominance of one or more form(s) of trait(s) over others through time. Indeed, the way in which archaeological data will tend to reflect statistical dynamics of this sort due to the differing contextual conditions (one might say "environments") in which artifacts are made and used was recognized some time ago by David Clarke (1968).

In biology, patterns of genetic and phenotypic variation may reflect neutral forces of evolution (i.e., drift) and selective factors (either natural or artificial) to varying degrees. In the case of neutral evolution, variation is structured by mutation rates, gene-flow, dispersal, and chance sampling effects (Wright, 1931). Conversely, selection in trait frequencies is reflected wherever specific patterns of variation are related directly to increased survival and fecundity. Of course, in the case of cultural attributes such as artifacts and their traits, statistical trends over time might be related to the survival and reproductive success of their makers, but could also reflect other choices or factors not related to natural selection. Indeed, one of the curious things about cultural traits is that they may well increase in number even though from a purely biological perspective they might typically be thought of as "maladaptive" (see e.g., Richerson and Boyd, 2005 for discussion of a range of examples). "Drift" in artifact traits may also occur as a result of nonbiased copying or because of stochastic (chance) sampling effects (Neiman, 1995; Shennan, 2000). As a result, Gould's (2002: 659) general term of "sorting," is helpful as a means of referring, in a collective sense, to the range of processes that may affect artifactual variation through time. This inclusive term emphasizes that the differential representation of transmitted elements may potentially occur via a variety of processes such as natural selection, cultural (i.e., human directed) selection, and/or drift (i.e., chance) without assuming the priority of any one mechanism of variant "sorting" *a priori*.

In the case of cultural evolution, a range of selective "biases" have been identified as potential means by which behavioral variants can be sorted in nonrandom ways (e.g., Boyd and Richerson, 1985). Henrich and McElreath (2003) have usefully distinguished between what they term "content" biases versus "context" biases in classifying these types of biases into groups. Their schematic for distinguishing between the various types of biases that influence cultural evolution is shown here, modified and extended somewhat to reflect a more artifact-centered view of these processes (Fig. 1). "Content" biases refer to differential copying or replication of a behavioral variant due directly to outward features that it exhibits. In the case of artifacts, two obvious instances of content bias would be "functional" bias and "aesthetic bias" (Fig. 1). Functional biases would be where one form of an artifact (or an individual attribute) is either functionally beneficial or inferior to that of an alternative form, subsequently leading to differential replication. "Function" in this sense could refer to any function (symbolic, practical, mechanical, etc.) to which its features are applied in meeting human requirements. Aesthetic biases may reflect human psychological predispositions (e.g., for symmetry) and/or culturally instilled attitudes toward the visual, "aesthetic" properties of the artifact. "Context" biases refer not directly to physical features of individual artifacts, but the social and material context in which they are used. This broad class of biases can be further subdivided into "model-based" biases and "frequency-dependent" biases (Fig. 1). Model-based biases are where the artifact maker or user leads to a bias (either positive or negative) in the chance of the artifact being replicated in the future. Biases of this sort could be due to the perceived "prestige," "success-rate" or social group to which an individual artifact maker or user belongs (Fig. 1). Frequency-dependent biases could arise due to the frequency with which an artifact is used and/or represented within a particular social group; rare items might be shunned or favored under various circumstances, for instance. Likewise, "conformity" as a particular form of frequency-dependent bias, would be where there has been a tendency for individuals to copy the most common element or practice within the group. Key points to emphasize here are that biases may be either functionally or nonfunctionally related, and also that "bias" may be consciously or unconsciously exerted by artifact makers over time. In this sense, statistically identifiable cultural patterns may reflect either functional parameters or nonfunctional parameters, or may be the result of conscious or unconscious actions on the part of human individuals and communities. There is no stipulation on these matters for a particular statistical pattern to qualify as "cultural" or be the product of "cultural evolution."

3. Ongoing developments in the application of evolutionary theory to archaeological issues

Only a relatively short time ago, even some of the most prominent proponents of evolutionary archaeology began to note that if empirical applications of evolutionary theory to archaeological data did not increase in number, then, the merits of the approach would be called into question (e.g., O'Brien and Lyman, 2000: 22). The recent growth in the number of studies explicitly applying evolutionary thinking ensures that a lack of empirical examples is no longer an easy criticism to level. Other than simply looking at a numerical increase in published examples, however, the vitality of a particular approach to the study of the archaeological record could be assessed on the basis of the geographic and/or temporal diversity of situations to which such tools are being applied. Equally, the range of examples of material culture to which these principles are being applied might give insights into the current vitality of the approach.

In terms of the geographic and temporal extent of recent case studies, there is clearly a wide distribution. Within just the last few years, for example, explicitly evolutionary studies have examined artifactual data from North America (e.g., Buchanan et al., 2014; Jennings and Waters, 2014; O'Brien et al., 2014; Prentiss et al., 2014; Jordan, 2015), South America (e.g., Okumura and Araujo, 2014; Cardillo and Alberti, 2015), western Asia (e.g., de Voogt

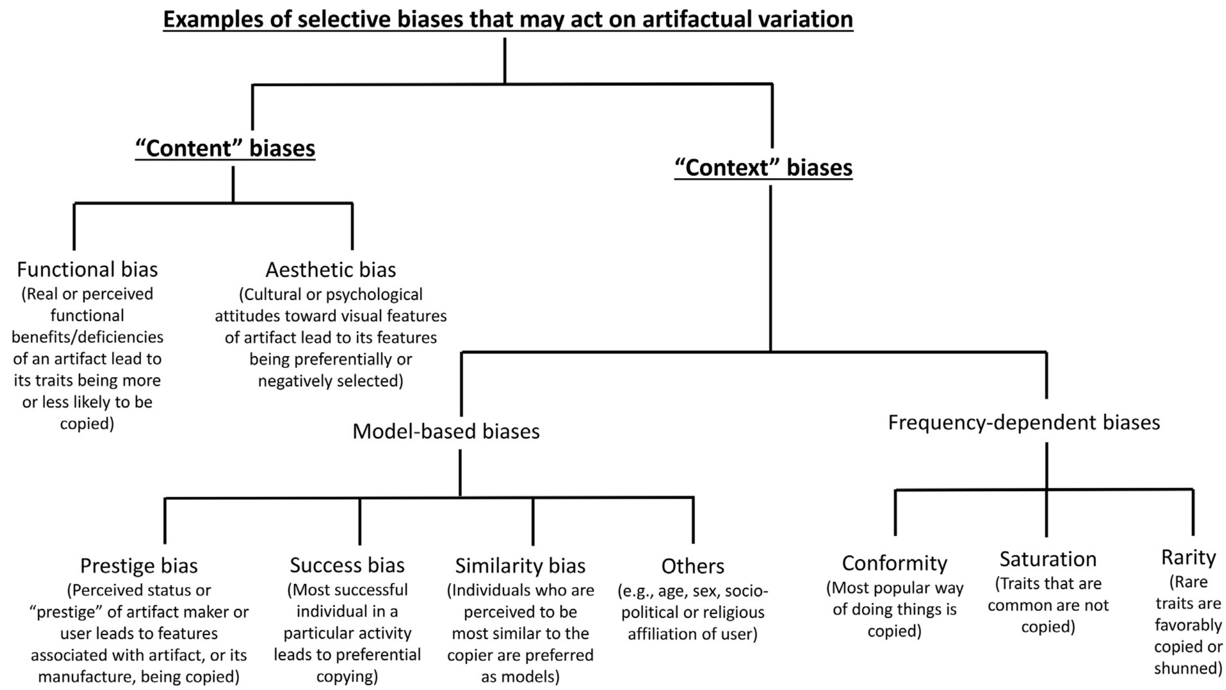

Fig. 1. Various types of selective "bias" that, in combination with drift, may influence frequency and variation in artifacts and their traits through time. Redrawn and modified after Henrich and McElreath (2003).

et al., 2013; Tehrani and Collard, 2013), northern Asia (Jordan, 2015), southeast Asia (e.g., Marwick, 2012), Europe (e.g., Charlton et al., 2010; García-Rivero and O'Brien, 2014), Australasia (e.g., Cochrane et al., 2013), and Polynesia (e.g., Rogers et al., 2009; Lipo et al., 2010). Notably, this listing exercise reveals that there has been something of a dearth of studies undertaken in Africa (particularly using data from recent millennia), which is perhaps surprising given the wealth of ethnographic and archaeological data from that continent. It would, therefore, be beneficial if more studies from this region were generated in the coming years.

Chronologically speaking, these published examples also evince a broad range. Indeed, recent published examples have considered the evolution of material culture using ethnographic data and artifacts from historical periods (e.g., Rogers et al., 2009; Tehrani et al., 2010; Jordan, 2015), while some of the oldest data sets examined are from the Palaeolithic and Paleoindian periods (e.g., Buchanan et al., 2014; O'Brien et al., 2014; Lycett and von Cramon-Taubadel, 2015). In terms of the range of artifactual material, there is again considerable diversity archaeologically speaking. For example, evolutionary theory has been used to empirically examine board games (de Voogt et al., 2013), carpet designs (e.g., Tehrani, 2011), storage boxes (O'Neill, 2013), iron-smelting waste (Charlton et al., 2010), housing designs (Jordan and O'Neill, 2010), statues (e.g., Marwick, 2012), engraved stone plaques (García-Rivero and O'Brien, 2014), basketry styles (Jordan and Shennan, 2009), watercraft (Rogers et al., 2009), pottery (e.g., Cochrane et al., 2013), and stone tools (e.g., Jennings and Waters, 2014; Okumura and Araujo, 2014; Eren et al., 2015).

This brief description of only a portion of the most recent case studies serves simply to highlight the diversity of geographic, temporal, and artifactual contexts in which archaeologists are now looking to evolutionary theory. On these grounds, therefore, evolutionary approaches appear to be finding a firm footing in a wide range of archaeological endeavors. Over recent years, however, the focus on empirical applications of evolutionary theory to the archaeological record has led to increased focus on quantitative and statistical means of analyzing artifactual data patterns. Perhaps some of the most prominent of these have been increased adoption of methods and principles of analysis from evolutionary biology, notably explicit use of methods of phylogenetic reconstruction and the incorporation of principles from the field of population genetics. In a groundbreaking paper, O'Brien et al. (2001) highlighted that a long recognized problem in archaeology (see e.g., Kroeber, 1931; Binford, 1968; Clarke, 1968) was determining instances of analogy from instances of convergence, due to the fact that people may produce objects, designs, decorations etc., which look similar to others but are not directly related (i.e., they are the product of convergence). O'Brien et al. (2001) also noted that evolutionary biologists were faced with the same problem of analogy (or "homology") and convergence (or "homoplasy") when trying to determine the evolutionary relationships between different taxa. Moreover, they pointed out that biologists had developed formal, quantitative means of testing hypotheses of homology based on the principle of parsimony (i.e., economy of assumption) and the identification of shared-derived character changes—a method more formally known as "cladistics." The method emphasizes some of the key aspects of the archaeological record, including character-state changes over time potentially linked by social transmission, but examines them within an historical framework that takes account of the "messy" *evolutionary* nature of such a record, in which instances of social relatedness and convergence must inevitably be tackled (O'Brien et al., 2008; O'Brien, 2010).

O'Brien and colleagues initially illustrated the applicability of this method empirically using analyses of Paleoindian projectile points (O'Brien et al., 2001, O'Brien and Lyman, 2003). The utility of the method for archaeologically relevant questions was again emphasized by Tehrani and Collard's (2002) analysis of ethnographic data in the form of Turkmen textile designs, and also by Jordan and Shennan's (2003) analysis of 19th/early 20th century basketry traditions in California. Following O'Brien et al.'s (2001) pioneering exposition of the technique archaeologically, however, formal application of phylogenetic analysis has been among one of the most active areas in the evolutionary analysis of archaeological data over the last decade (e.g., Harmon et al., 2006; Buchanan and Collard, 2007, 2008; Lycett, 2007, 2009; Cochrane, 2008; Riede, 2008, 2011; Coward et al., 2008; Jordan and O'Neill, 2010; O'Brien et al., 2012; O'Neill, 2013; Marwick, 2012; García-Rivero and O'Brien, 2014; Jennings and Waters, 2014; Jordan, 2015). Additional techniques of phylogenetic reconstruction such as Bayesian methods, maximum likelihood, and network analyses are also now being experimented with by those studying material culture (e.g., Jordan, 2009; Matthews et al., 2011; Prentiss et al., 2014). All of these different methods possess their own strengths and weaknesses (see e.g., Lemey et al., 2009; Nunn, 2011) and, accordingly, archaeologists may well find that different methods have differing merits depending on the archaeological circumstances and questions they are dealing with.

Inevitably, at the core of many evolutionary analyses in archaeology is an effort to study patterns of assemblage variation statistically (see e.g., Neiman, 1995; Lipo et al., 1997; Bettinger and Eerkens, 1999; Kohler et al., 2004; Lyman et al., 2009; Mesoudi and O'Brien, 2008a, 2008b; Hamilton and Buchanan, 2009; de Voogt et al., 2013; Jordan, 2015). This can take place in terms of looking at artifactual variation and/or attribute variation, within and between different spatially and/or temporally organized units of analysis. This focus on statistical variation in evolutionary studies is the natural outcome of the fact that evolution is, by definition, a process based on the differential replication of variation over varying spatio-temporal scales. The study of any evolutionary process is, therefore, the study of the factors that marshal variation into quantifiably different patterns. In biology, population geneticists use quantitative models to consider the effects of microevolutionary processes such as selection, drift, and migration on statistical patterns of genetic variation on the population level. In this sense, the statistical study of within- and/or between-assemblage patterns of variation within an explicitly evolutionary framework has direct parallels with the field of population genetics in biology (Cavalli-Sforza and Feldman, 1981; Neiman, 1995; Shennan and Wilkinson, 2001; Eerkens and Lipo, 2005; Lycett, 2008; Shennan, 2011). As an outcome, a further aspect of growth over the last two decades has been the direct application of models, methods, and principles from the field of population genetics to consider a range of questions concerning the evolution of material culture (e.g., Neiman, 1995; Shennan, 2001; Bentley et al., 2004; Mesoudi and O'Brien, 2008b; Hamilton and Buchanan, 2009; Rogers et al., 2009; Lycett, 2014). Indeed, although archaeologists have for a long time recognized that multiple factors will influence artifactual variability (Schiffer, 1976), it has recently been proposed that evolutionary analyses of artifacts might profitably draw on specific biological models that take greater account of both heritable and nonheritable sources of variation in order to look at the physical outcomes of evolutionary processes (Lycett and von Cramon-Taubadel, 2015; Lycett, in press). Further development of models that take greater account of the *physicality* of the archaeological record, and some of the unique factors that influence trait variability, will perhaps help better link microevolutionary processes to the macroevolutionary effects that are more readily detectable in archaeological data.

Diversification in statistical techniques is likely, therefore, to be an ongoing part of evolutionary studies, as new means of looking at the available patterns of variation are considered (Crema et al., 2014a). However, before variation can be analyzed statistically, it must be accurately quantified. Recent evolutionary studies are also, therefore, understandably taking advantage of new methods for capturing and analyzing artifactual variation morphometrically, looking at patterns of size and shape variation in greater detail and examining attributes that are more difficult to capture using traditional methods (e.g., Clarkson, 2010; Buchanan et al., 2014; de Azevedo et al., 2014; Okumura and Araujo, 2014; Selden et al., 2014).

3.1. Radiating questions

Listing examples of chronologically, temporally, artifactually, and methodologically diverse case studies—as in the preceding section—indicates a healthy "pulse" for evolutionary work at the current time. However, these simple listings inevitably gloss the most important issue of all: the range and diversity of *anthropologically important* questions to which evolutionary theory and methods are being applied. Space precludes anything like a full discussion of this, but even a few examples might illustrate something of the range of questions currently being tackled and raised by evolutionary approaches. For instance, consider Charlton et al.'s (2010) analysis of the chemistry of slag produced during iron-smelting at the late medieval site of Llwyn Du in Wales. Here the analyses by Charlton and colleagues found that iron-making "recipes" showed a reduction over time in the variability of reducing conditions, a factor that can be specifically related to a bias (i.e., selection) in the choice of particular fuel–ore ratios. However, using a series of multivariate (Principal Component) analyses to examine temporal trends, they also found that the iron workers at this site eventually developed and deployed two distinct recipes for iron, one that would have yielded a harder, more steel-like product than the other. Charlton et al. (2010) consider a range of possibilities to explain this pattern, including that two different types of iron were used to make distinct products. However, they also consider the possibility that either in combination with this, or as a separate factor entirely, the iron makers of Llwyn Du were responding directly to the specifics of their economic environment given that they were charged rent in the form of a certain percentage of their iron product. An economically strategic response to this on the part of these iron-workers may, therefore, have been to develop a cheaper product for paying rent costs while producing a higher quality product for market. Charlton et al. (2010) note that further work is necessary to further evaluate these possibilities, but the study amply illustrates the role of evolutionary theory in structuring a set of analyses that can be linked to wider concerns such as specific market dynamics driving selective trends through time.

In contrast to empirical trends characterized by change in levels of variability and diversification, instances of relative stability have also been identified in recent studies, relating to other dynamics of locally-specific conditions. Okumura and Araujo (2014), for instance, examined morphological variation in stemmed bifacial projectile points from the Garivaldino Rodrigues rockshelter in Southern Brazil. Examining a temporal series over a timeframe of 11,660–7540 cal BP, multivariate analysis of geometric morphometric data did not detect trends in point shape variation through time. Such stability is surprising given the time frame considered and potential for copying error, but Okumura and Araujo (2014) note that it is consistent with the operation of stabilizing selection, as might be expected under the environmental conditions that broadly characterize the region at the time. However, they also note that while shape variability is statistically stable, size variability appeared to increase over time, a finding that can be related to the impact of drift relating to copy-error (i.e., cultural mutation) associated with such traditions (Eerkens and Lipo, 2005; Hamilton and Buchanan, 2009; Kempe et al., 2012; Schillinger et al., 2014a). As Okumura and Araujo (2014) are keen to note, it is, therefore, locally-specific dynamics of social transmission that must be called upon to explain these patterns, emphasizing the essential role of evolutionary theory in any future attempts to test these factors further. Hence, what Okumura and Araujo's (2014) analyses ultimately demonstrate is the useful role that evolutionary theory can play in helping to structure a set of analyses directed toward an empirical data set (i.e., fine-scaled patterns of morphological variation and stability in a single class of artifacts), such that the analyses can be related to factors such as ecological dynamics.

Interestingly, in this regard, other evolutionarily-orientated morphometric studies of projectile points from other regions are identifying shape trends that might indicate diversity relating to differing ecological circumstances across spatial gradients (Buchanan et al., 2014). As evolutionary studies of this type progress, therefore, it is probable that a range of subtle—but statistically patterned—responses by different populations in differing conditions will be identified, which can ultimately be tied to the particular circumstances of the history of cultural “descent with modification” in those regions.

Ecological and economic variables are not, however, the only factors that might govern patterns of variability and stability in items of material culture. de Voogt et al. (2013) have recently examined variation in two board games that were played over a period of almost two millennia and were transmitted across different cultural, linguistic, and economic boundaries of various city states and empires in the ancient Near East. The game of “twenty squares,” for example, is archaeologically attested over a wide area of the Near East and the eastern Mediterranean (i.e., present-day Iraq, Iran, Israel, Syria, Jordan, Turkey, Cyprus, and Crete) and appears throughout the first and second millennia BC. The game of “fifty-eight holes” had a similar geographic distribution during the second and first millennia BC, but was invented in Egypt at the end of the third millennium BC. de Voogt et al. (2013) hypothesized that despite their temporal and geographic extent, factors related directly to the social transmission of these board games, such as distinct rules and the necessity of mutual understanding of those rules between players, would lead to a relatively high fidelity of transmission. To test this, they quantitatively examined variation in a number of physical features in these games (e.g., board shape, board style, number of squares, square variations, number of holes, among others) over their temporal and spatial distribution. Analyses of these data, including comparison with other categories of archaeological material (e.g., pottery) indicated relative stability and persistence of traits over time and geographic distribution. Hence, in accordance with their theoretical predictions, de Voogt et al. (2013) conclude that this relative stability is related to the particular dynamics of transmission involved in the effective replication of rules and procedures involved in board games of this nature, even transcending known linguistic divisions and boundaries of inter-group hostility. What these analyses ultimately suggest, therefore, is that the nature of interaction between people during the course of cultural transmission events—in this case, a particular social dynamic that relies on mutual sharing and understanding of distinct rules—somewhat ameliorates rates of change and innovation, even in circumstances that ordinarily might be expected to generate cultural diversity. Perhaps most importantly, this study emphasizes that while the dynamics and operation of cultural evolution may be of increasing interest across wide areas of the social sciences (see e.g., Boyd and Richerson, 1985; Rogers, 1995; Mesoudi, 2011a; Nunn, 2011; Ellen et al., 2013; Spisak et al., 2014), archaeological data can bring important, empirical insights to bear on these questions, adding temporal breadth and culturally unique sets of circumstances to this wider debate.

Hypotheses relating to symbolic interpretations of material culture might also be testable using evolutionary principles. Consider, for example, García-Rivero and O'Brien's (2014) recent analysis of engraved slate plaques from the Neolithic of southwestern Iberia. It had previously been suggested that engraved motifs on such plaques acted symbolically as genealogical (mnemonic) recording systems, and so were linked with specific lineages and/or clans (see e.g., Lillios, 2008). García-Rivero and O'Brien (2014) used cladistic (parsimony) analyses of the variety mentioned earlier to examine the direction (polarity) of character-state changes in over 1400 Neolithic examples of these plaques to determine if parsimony supported a pattern of change consistent with the genealogical hypothesis proposed. The results of these analyses found that specific instances of character-state change were inconsistent with the “genealogical” hypothesis and, moreover, that multiple instances of convergence (homoplasy) were evident, which were also inconsistent with this interpretation. As García-Rivero and O'Brien (2014: 2) note, their analyses do not rule out entirely that slate plaques in this region functioned as mnemonic devices. What the analyses do show, however, is that expectations relating to a symbolic hypothesis that are clearly “genealogical” or “phylogenetic” in character are not supported. Hence, these analyses show the role of evolutionary methods bringing in precision and testability to a set of assumptions regarding this supposed symbolic function.

Critics might retort that these types of questions have long been of interest to archaeology and that countless discussions of related themes have taken place over many years. Ironically, evolutionary archaeologists probably would agree, noting that due to the fundamental nature of cultural data such as artifacts, they inherently have evolutionary dynamics that relate them directly to these longstanding themes (see e.g., O'Brien and Lyman, 2000, 2003; Shennan, 2000; Eerkens and Lipo, 2007; O'Brien et al., 2008; Lycett, 2011; Jordan, 2015). In short, because culture is inherited, transmitted, and shared, yet has a variety of factors that will “filter” cultural variability in particular ways, then, evolutionary theory is inevitably a key tool in making sense of these historical patterns. Openly framing questions and analyses in evolutionary terms, however, brings assumptions and underlying logic that have frequently gone unstated out into the open and makes them explicit. Perhaps more importantly, in so doing it provides a direct means of linking theory to methodological and practical tools of formal analysis for addressing these questions.

4. Future challenges and prospects

One of the leading proponents of evolutionary theory in archaeology noted recently “for evolutionary archaeology to attain its promise, those involved in its formulation are going to have to be clear about such basic issues as what it is that evolves and how evolutionary change is to be measured” (O'Brien, 2013:553). This relates to a point made earlier; that is, some of the most key advances in evolutionary approaches over the coming years are likely to center on increased empirical understanding of the links between processes of transmission and resultant artifactual variation, and moreover, the types of behavioral factors that influence patterns of variation in particular ways.

There are several ways in which the field might effectively respond to this challenge, but three avenues of enquiry will likely play a key role: simulation, experiments, and ethnographic research. Computer simulation based on explicit mathematical models, for instance, has been gaining increased recognition as an important tool in archaeological research for a number of years (see e.g., Brantingham, 2003; Surovell, 2009; Costopoulos and Lake, 2010; Grove, 2010; Madella et al., 2014). In the case of evolutionary endeavors, however, this set of tools has particular utility because of its ability to model key dynamics within temporally and spatially explicit frameworks, the effects of which are difficult to practically evaluate in other ways (e.g., Neiman, 1995; Shennan, 2001; Bentley et al., 2004, 2014; Eerkens and Lipo, 2005;

Mesoudi and O'Brien, 2008b; Premo and Kuhn, 2010; Mesoudi, 2011b; Premo and Scholnick, 2011; Kempe et al., 2012; Crema et al., 2014b; Rorabaugh, 2014). Likewise, experiments can play an increased role in terms of better understanding how artifactual attributes are affected by key parameters within evolutionary models (Eerkens, 2000; Mesoudi and O'Brien, 2008a; Derex et al., 2013; Schillinger et al., 2014a, 2014b). Ethnography could also be drawn upon, as it long has been in archaeological research (Lane, 2014), but with renewed emphasis on understanding the outcomes of social transmission, selective biases, and/or other key evolutionary variables on statistical patterns of variation seen in the attributes of artifacts (see e.g., Gandon et al., 2014). Such approaches might also reveal insights into how dynamics of transmission interrelate with other (nonheritable) causes of variability, which also need to be accounted for in evolutionary models (Lycett and von Cramon-Taubadel, 2015; Lycett, in press). Hence, while neither ethnographic studies nor experiments and computer simulations are by any means strangers to archaeological enquiry, evolutionary approaches will ask new questions of these types of studies, especially when it comes to better understanding links between the mechanisms of transmission, potential biases, and resultant patterns of variation in artifactual attributes.

The use of methods and principles drawn heavily from the biological sciences may continue to raise other challenges for evolutionary approaches in the coming years. One specific methodological aspect of evolutionary approaches that is notable, even in the all-too-short review of recent works in the previous sections of this paper, is the extensive use of expressly mathematical and statistical methods of analysis. This is emphasized keenly in some of the most recent developments in the genre as evolutionary archaeologists consider new quantitative methods of analysis and increasingly make use of computer simulation in their work. Not that the application of such methods is exclusive to evolutionary approaches, but in combination with other factors, this does perhaps raise specific questions concerning directions the approach might take in the future. For instance, "scientific archaeology" is commonly defined as the application of techniques from the natural, chemical or physical sciences to archaeological questions. Unlike other scientific techniques that might simply involve the intermittent participation of an outside specialist from another field, or the input of a discrete "technique" alongside a wider set of data in a collaborative study, evolutionary approaches are a definite theoretical stance regarding how archaeology more widely should be undertaken (see e.g., O'Brien and Lyman, 2000; Eerkens and Lipo, 2007; Shennan, 2008). Moreover, they do so by drawing explicitly on a set of principles and methods largely drawn from another discipline (i.e., evolutionary biology). Arguably, therefore, if evolutionary approaches to material culture are to face a curb on the rate and extent of their future application, this may lie in the fact that many of the theoretical and methodological devices on which the field draws are not typically part of a "mainstream" archaeology education but are more commonly found in other departments.

It is perhaps reasonable to ask, therefore, what all this implies for the future of "evolutionary" approaches. Imagine, for instance, if a substantial portion of evolutionary biology were suddenly to rely extensively on its theoretical and analytical basis from say, nuclear physics or for that matter, archaeology. Options for major expansion away from its traditional base would be limited; a fractioning away from the mainstream might be one option, while simply becoming a subfield of these other disciplines might be another. However, for obvious reasons neither of these are desirable. A third, less partisan, option is simply to continue to make the case for the incorporation of these elements into the existing array of theoretical and methodological tools, especially via empirical examples. With the latter, however, compatibility of elements becomes an issue. The history of science shows that there tends to be a constraint on the extent to which particular approaches may flourish, partly due to incompatibilities between alternative views on how the goals of a field are best achieved (Hull, 1988). The history of archaeology obviously exhibits similar, well-known tendencies for skirmish in this regard (Trigger, 1989; Dunnell, 1996; O'Brien et al., 2005). And yet, given even the brief review of the current status of "evolutionary archaeology" undertaken here, it seems unlikely that the approach will disappear in the short term. For these particular reasons, pronouncements on the future of cultural evolutionary approaches to archaeological data are perhaps more complex than might normally be the case for a review of a given "technique." Given all this, one of the most interesting developments to watch over the next 20 years or so will, therefore, be to examine to what extent many of the principles and methods employed in the evolutionary analysis of archaeological data move from being labeled as something distinct (e.g., as the designation "evolutionary archaeology" might imply) to simply being seen as part of the "normal" process of archaeological enquiry.

This endeavor will perhaps be aided, however, by the fact that although use of the term "evolution" is sometimes misinterpreted to mean otherwise, at the heart of evolutionary approaches are goals that are widely shared in archaeology, and indeed, anthropology more generally: what is the character and outcomes of interactions between people, between people and material culture, and between people and their wider "environment" in its most broadest of senses. As others noted some time ago (e.g., Clarke, 1968), the archaeological record provides unique potential to explore these factors scientifically over large tracts of time and space, largely because patterns of variation in material remains are empirically measurable and can be analyzed in statistical terms. Evolutionary principles allow the structuring of a range of questions in a manner that takes explicit advantage of some of the most prominent aspects of this physical data base—most notably measurable, quantifiable patterns of variation—while also facilitating a theoretical link between this unique empirical resource and practical tools of analysis (O'Brien and Lyman, 2000; O'Brien and Lyman, 2003; Eerkens and Lipo, 2007; Shennan, 2011; Lycett and von Cramon-Taubadel, 2015). Archaeology has previously and successfully assimilated theoretical and methodological tools originally developed in other fields and the same can, therefore, happen with explicitly evolutionary tools. As shrewd commentators have noted elsewhere (e.g., O'Brien and Lyman, 2000: 392; 2003) this does not mean that the field does not have considerable work to do in re-writing certain specific aspects of evolutionary theory in terms that are more suitable for archaeological purposes, nor that it can answer *all* of archaeology's questions. What it does, however, mean is that there is a firm basis for development that is worthy of further exploration. If the flourishing of recent "evolutionary" case studies is anything to go by, then it appears this task is well under way. Regardless of ongoing controversies in terms of specific sets of results produced in the geographic regions and time periods it is being applied, arguably the most prominent "success" of this body of work in recent years is its determined, systematic attempt to explore the potential of this body of theoretical principles and practical techniques of analysis.

5. Conclusions

Evolutionary approaches to the archaeological record have moved in recent years from being a fringe pursuit to an endeavor that has an increasingly large number of empirical case studies to its name. This has perhaps been aided by an increased interest in "evolutionary" approaches within anthropology more widely, if not across the social sciences in general (see e.g., Mesoudi, 2011a, 2011b). However, earlier arguments that at least some of archaeology's key questions can productively be phrased in evolutionary terms, directly because of the particular characteristics of archaeological data (e.g., O'Brien and Lyman, 2000), appear to have found increased acceptance. The biggest challenges for the future lie in two specific areas. One of these is to better understand how evolutionary processes act upon material artifacts and relate to the patterns it creates in material data, such that theory can interact with empiricism with increased precision. The other challenge lies in the fact that these approaches draw on a related body of techniques and theoretical principles that are largely drawn from outside the discipline; a factor which raises a range of questions concerning the future of evolutionary thinking within archaeology, if only with regard to training in certain practical skills of analysis. The latter issue will perhaps be ameliorated as archaeology takes these seemingly "foreign" techniques and makes them increasingly its own, modifying them to its own ends as it does so. Regardless of these challenges, the recent notable surge in empirical case studies in the published literature indicates that discussion concerning the role of evolutionary thinking within archaeology will continue, if not increase, in coming years.

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