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# Morphometric Analysis of Allometry and Modularity in Early Holocene Thebes and St. Charles Points of Midcontinental North America

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**ABSTRACT**
The Central Ohio Archaeological Digitization Survey (COADS) documented large samples of precontact artifacts, notably points, held by private collectors in south-central Ohio, in the United States. COADS captured two-dimensional images of several thousand points and several hundred three-dimensional images. Subjects were processed for landmark-based geometric morphometric (LGM) analysis as entire points and as stems only. Among other things, analysis can test for resharpening allometry—the possibility that preferential resharpening of blades caused change in shape with change in size of points—and related LGM concepts of modularity and integration. This study reports analysis for allometry in early Holocene COADS Thebes and St. Charles points. A clear allometric signal with fairly high modularity resides in the data; blade shape much more than stem shape varies with size, corroborated by independent reduction measures. Separate analysis of stems alone indicated no allometry, as expected since stems vary little with resharpening. Allometry must be considered before attributing variation in midcontinental whole-point shape to adaptation, drift, or other mechanisms.

**KEYWORDS**
Thebes points; allometry; modularity; Ohio; reduction; morphometrics

Projectile points are a common subject of North American archaeological study. Befitting their popularity, points are informative in many ways. Types mark intervals of past time, register activity by their inferred function, and may distinguish social or cultural groups. Their distributions reflect the distribution of populations or cultural groups. Points are superabundant and, in contrast to constructed units like “site,” possess a natural integrity; apart from the breakage many of them experienced, points are integral wholes in the limited sense that their recognition and description require no chain of inference, sometimes elaborate, as do “sites,” “cultures,” and other synthetic units. This is merely to acknowledge that points are real things, irreducible units of observation.

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Traditionally, midcontinental archaeologists ask limited questions about points. How old are they and, by association, their contexts of discovery? Where were their toolstones obtained? How were they made and used? Sometimes we ask questions like, Do the proportions of types of different age reflect trends in population size or land use? Do their spatial distributions reflect environmental or social boundaries? Such questions are reasonable to ask and useful to answer. All require inference, for instance from instrumental methods in the case of dating and sourcing or from detailed measurement and observation informed by replications in the case of manufacturing, use, and technological/morphometric properties. Even questions about population or land use that may seem to be matters of simple observation engage inference from sample methods and representativity (Shott 2005). The population question, for instance, either assumes equal numbers of points per capita in use per unit time—Schiffer's (1976:60) systemic number S—and equal use lives (his L) or requires inference as to variation within and among types in these quantities.

As valid as such questions are, they do not nearly encompass the information potential that resides in points. Further questions urge themselves. What degree and pattern of reduction of original form do points experience before discard? What are types' curation rates and use lives, and what are the form and scale of their use life distributions? How and why do these quantities vary among types? These questions are the subject of this research; others are posed in the conclusion of this article.

## Points as Wholes and Parts

Points were quotidian functional items whose value derived in part from acute tips and sharp edges secured by their stems to shafts for use with launchers like atlatls or bows or for use as knives. But the composite nature of those larger wholes pertains equally to their points and knives themselves. Traditionally, archaeologists regarded points as integral wholes, for instance by freely combining attributes of size and shape of blades and stems when assigning specimens to types. But even the smallest hafted point is made up of parts (González-José and Charlin 2012; Shott and Otárola-Castillo 2022). Different segments or "modules" of points served different purposes and, for some analytical purposes, deserve separate analytical treatment. Tip modules initiated wounds in targets, blade modules deepened them, and stems articulated the exposed blade to the composite tool. Understanding how blades and stems, or their own parts, worked as modules and together as larger wholes to propel a point or provide mass to aid thrust only improves our ability to extract information from points.

Edges could compose modules (e.g., during beveling) or perhaps components of larger modules of the tip (if edge properties assisted penetration) or of the blade (if they aided ballistics or wound expansion). If points also functioned as knives or other tools, different modules may have had joint or dual purposes—for example, blades deepen wounds, while their edges also are useful in filleting or scraping)—that forced compromises in their design. Point segments may have composed modules of particular sizes and configurations for some purposes, like use as weapon tips, and modules of different sizes and configurations for other purposes. Depending on the analytical purpose, points can be treated as wholes or as things with sometimes complexly organized parts.

How and how much used, points often suffered edge dulling and other damage in use reparable only by careful resharpening to expose fresh, sharp tips and edges. In the process, trivially, points became smaller in size and often changed somewhat in shape because more resharpening typically occurred on tips and blades than on hafts. Degree and pattern of such reduction are clues to the kind and amount of use points experienced, important details of tools' use lives the analytical potential of which archaeologists only recently began to appreciate (e.g., Charlin and Cardillo 2018; Shott et al. 2023). If, traditionally, points were treated as markers of time or culture or as gross indices of activity, today additional foci emerge: that is, points as curated and reduced objects and contexts of complex variation, including modularity and allometry.

### *Modularity and Allometry*

Usually, we define and measure whole-object dimensions (e.g., length) that crosscut modules and compromise our ability to distinguish them. Of course, dimensions may be measured separately for any modules defined. But measuring *the* length or width of points treats them as undifferentiated wholes and elides the segmentation—modularity—that may inhere in them.

Mindful of the resharpening reduction that many points probably experienced, reduction measurement engages the study of how and to what extent points were "curated" (used to depletion; Shott 1996) and what explains varying curation patterns. It also encompasses the study of *allometric* variation in points (change in shape with change in size; here change in shape as points gradually were reduced in size by the resharpening experienced during their use lives) and the allometric patterns that may characterize types. Joint change in size and shape implicates changing proportions among point modules and therefore recommends modular approaches to analysis. Changeability as an integral property of points may seem paradoxical, but specimens experienced varying reduction in use that any comprehensive treatment of types must consider. In North America, point modularity has been treated mostly in the context of lanceolate PaleoIndigenous types, which demonstrate its presence (e.g. Shott and Otárola-Castillo 2022; Thulman et al. 2023).

Pattern and degree of reduction allometry among specimens is an intrinsic, informative property of all point types (Iovita 2010; Shott 2020a) for its own sake. It has further value as noted in the following.

1. It aids typological hygiene, defining types by legitimate criteria that take allometric variation into account but do not confuse it with original design. For instance, one early Holocene Side-Notched type "appears to be the result of resharpening strategies" (Randall 2002:5; see also Hoffman 1985) of another; that is, the two type definitions encompass the range of morphometric variation of a single design.
2. Modeling bifaces as resource patches, reduction/curation distributions relate degree of utility extracted to varying hunting return rates, making allometric reduction a behavioral variable that tracks long-term adaptations (Barlow and Miller 2021; Miller 2018:55–63) and affects the size and spatial distribution of the lithic material record (e.g., Charlin et al. 2023; Gravel-Miguel et al. 2021).
3. If reduction distributions fit failure models like Weibull, theoretical explanations for the forms of utility qua survivorship distributions also are implicated, involving processes that range from burn-in failure to chance to accelerating attrition (Shott 2022).
4. Finally, resharpening allometry calibrates types' discard rates as they form archaeological assemblages and affects spatial scale of discard independently of land-use scale (Lin and Premo 2021; White 2021).

On balance, there are several good reasons to study point allometry.

In part, to illuminate the problem of parts and wholes, this study uses two-dimensional (2-D) models of points to assess the effects of resharpening allometry on the covariation between point wholes and their parts as modules. Although both blade and stem are subject to reduction, there are good reasons to believe that most reduction occurs on blades. Stems were subject to fairly narrow, near-constant functional constraints; blades were freer to vary in size and shape, were more likely to experience damage or dulling that required repair via resharpening, and evidently, functioned satisfactorily over a range of sizes. Combined with data on site numbers, distributions, and settings, allometric patterns and curation rates can be correlated with broader cultural trends and hypotheses can be tested: for instance, that higher curation rates would occur as populations became more sedentary.

## Morphometric Analysis of Points

Allometry and modularity can be analyzed using conventional dimensions of points like length and thickness (e.g., Shott 2020b). Yet the application of landmark-based geometric morphometrics (LGM) has revolutionized point analysis. 2-D and three-dimensional (3-D; e.g., Shott and Otárola-Castillo 2022) LGM characterize whole-object form much more comprehensively than do linear dimensions and permit more thorough analysis of point size and shape than is possible otherwise. But detail in characterization is only one of LGM's virtues. From its origins in biology, LGM has acquired a set of concepts and associated analytical methods that facilitate a modular view equally relevant to points and organisms and allometric analysis of the varying relationship between modules.

In LGM, *modules* are sets of usually contiguous landmarks (LM; 2-D or 3-D coordinates of locations on larger wholes) whose covariation is greater internally than with landmarks outside the module; they are "tightly integrated internally but relatively independent from other . . . modules" (Klingenberg 2008:116). Modules, thus, are semiautonomous components of larger wholes. During individuals' growth or over evolutionary time, anatomical modules' size and shape can vary. The strength of covariation between modules describes their *integration*, that is, the degree of covariation among modules comprising the whole: the "coordinated movement of the [modules] of the structure relative to one another" (Klingenberg 2008:117). Of course, some covariation integrates all parts of larger wholes; structured objects like points do not vary freely. Indeed, size variation via, for instance, allometry affects all parts of larger wholes, just not equally. It can, therefore, produce "global integration" that "may obscure a . . . modular structure" (Klingenberg 2009:416). As a result, modularity and integration are not absolute states; instead, "there is a gradation of degrees of integration and modularity" (Klingenberg 2009:416). Modularity measures the degree to which covariation patterns geometrically by subcomponents of the whole; integration measures the degree to which separate modules covary despite their partial independence. Modules of any size, shape, and location may be defined for any analytical purpose. Defining modules is a statement of hypothesis that requires testing in the variation that resides in study specimens.

Modularity and integration can be studied at levels from individual growth to evolutionary change, developmental/ontogenetic to evolutionary, respectively, in Klingenberg's (2008:117–119) hierarchy of analytical scales. Because "types of modularity and integration closely parallel . . . types of allometry" (Klingenberg 2008:120), they engage allometric variation and its analysis at all such scales. This study concerns allometric variation in points, analogous to ontogenetic allometry in biology. As in biology, allometry may characterize variation not only between point types but also among specimens *within* types, as a function of the resharpening that points may experience from first to last use. Like modularity and integration, therefore, allometry characterizes variation at scales from individual points used for days or weeks to types that persisted for generations to the typological transitions that occurred at the scale of centuries.

### *Allometry and Reduction in Thebes and St. Charles/Dovetail Points*

In LGM, allometry occurs as differential variation in shape with variation in size among defined modules. Modularity registers as more covariation of traits within modules than between them. Studies document allometric reduction effects (e.g., references in Shott and Otárola-Castillo 2022:3–4), usually in 2-D point models (see Shott and Otárola-Castillo 2022 for 3-D LGM). Tests for allometry are described below. Explicit tests for modularity are uncommon (but see Charlin and Cardillo 2018; González-José and Charlin 2012; Shott et al. 2021; Shott et al. 2023; Thulman et al. 2023), a lacuna addressed in this study. This study interrogates a sample of Thebes points from Ohio for allometric variation, substantially between modules.

***Thebes*** The Thebes type subsumes names like Cache Diagonal, Lost Lake, Ohio Thebes, and Plevna; some southeastern Greenbriar points also resemble Thebes (e.g., Smallwood et al. 2022:Figure 4.3j). Thebes (Justice 1987:54; Luchterhand 1970:31–32, Tables 5–6; Morrow 1996:351; White 2013:84) are originally large thick bifaces generally with straight, sometimes serrated, edges (Figure 1). Flaking on the blade often is expanding and probably soft hammer, and cross sections are flat to lenticular, trending toward rhomboidal in resharpened beveled specimens. Bases, often heavily ground, are straight or slightly concave or convex, and well-defined invasive notches typically are parallel sided with U-shaped or sometimes slightly expanding ("keyhole"; e.g., Luchterhand 1970:Figure 9; Stafford and Cantin 2009:Figure 7.1b) termini. Most Thebes are side notched. Angle of notches' long axes relative to the tool's long axis range from perpendicular (i.e., strictly side notched; e.g., Stafford and Cantin 2009:Figure 7.3a) to slightly acute (Luchterhand 1970:Figure 9a, 9b), sometimes differing between notches of the same specimen (e.g., Stafford and Cantin 2009:Figure 7.1b). Yet variants sometimes called "Ohio Corner-Notched" or "Lost Lake" are corner notched and can have tapering termini.

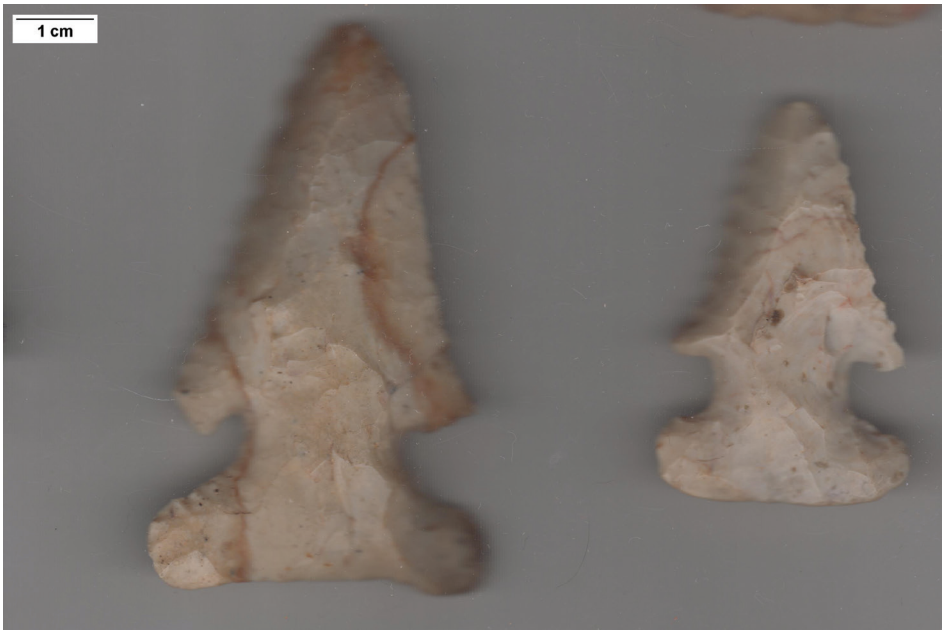


**Figure 1.** Illustration of size and shape variation among COADS Thebes points due to reuse and reduction throughout use life. Both examples are from COADS site 151 in Franklin County, Ohio. COADS 151–5 on the left is 76 mm long.

Beveling is a salient characteristic of Thebes edges. This property, along with blades' thickness and robusticity and the fact that unused specimens often are unbeveled (e.g., Luchterhand 1970:23), invites the inference that these specimens were knives. Beveling's most parsimonious explanation then invokes resharpening (Pettigrew 2015:6–7). Consistent with this view, the seven Thebes bifaces in Missouri's Soenker cache bear "no obvious traces of use or resharpening/beveling" (Koldehoff 2020:6). Pettigrew's experiments cast doubt on alternative explanations for beveling that involve ballistics, suggesting both that beveled points function well as dart tips and that beveling can enhance penetration or wound expansion; that is, it is at least consistent with use as points. Randall (2002:23) also argued that similar Early Archaic side-notched bifaces were points, not knives. Most precontact North American types are not beveled; clearly, beveling is not essential for dart or arrow points. Yet Thebes bifaces may have served as knives. For instance, some Early Archaic Early Side-Notched bifaces, similar to Thebes bifaces, exhibit a pattern of reduction that suggests lateral resharpening (Randall 2002:Figures 5, 6a, 6b), implicating less the form or angle of the tip than preservation of edge length, consistent with knife use. Edges can be dulled or damaged from use as a knife or point and repaired by resharpening in either case. Henceforth, Thebes are called "bifaces" to acknowledge uncertainty about their chief use and to accommodate the possibility of multiple uses. Only additional lines of analysis can settle the question. Another line of inquiry, which this study approximates, involves comparison of degree and pattern of possible resharpening allometry between Thebes and probable dart-point types like St. Charles/Dovetail with which Thebes often is associated in time and space, as well as in survivorship distributions.

Farnsley is the largest midcontinental Thebes assemblage. Thebes preforms were found there (Stafford and Cantin 2009:Figure 7.6), but dimensions were not reported. Original Thebes dimensions are approximated by "Stage 4" preforms at Twin Ditch, which average about 91.0 mm in length, 50.8 mm in width, and 10.3 mm in thickness (Morrow 1988:Table 1). Finished Thebes points (which may be reworked) average 73.7 mm in length, 49.7 mm in width, and 9.4 mm in thickness (Morrow 1988:Table 1, Figure 3). At Twin Ditch, obviously, width is little reduced and thickness only modestly so in finishing of preforms and resharpening of points in use; length is much reduced. Total length in Luchterhand's (1970:63) Illinois Valley–mixed sample of unused and resharpened Thebes bifaces ranged from 51 mm to 117 mm, suggesting that the Twin Ditch estimate of original length from late-stage preforms is conservative. Most reworked specimens retain relatively wide shoulders and therefore blades that taper to tips, sometimes rounded, but Thebes bifaces can be resharpened as drills (e.g., Stafford and Cantin 2009:Figure 7.2). (Neither the Thebes nor the St. Charles/Dovetail samples studied here include drills or beveled scrapers.)

***St. Charles*** St. Charles/Dovetail points ("St. Charles" henceforth, in recognition of its favor in the professional literature, although "Dovetail" remains common in popular discourse) are originally long and relatively thin (Justice 1987:57; Luchterhand 1970:31–32; Morrow 1996:351; Scully 1951:4), generally with ovate to straight-sided edges and thin lenticular cross sections. Blade faceting often is collateral, presumably pressure flaked. St. Charles points bear narrow, well-defined side notches (Justice described them as corner notched, but most specimens are side notched or nearly so) nearer to the base than is the case for Thebes; consequently, St. Charles points have thinner, more gracile bases than do Thebes bifaces. Above (proximal to) the notch, base edges are parallel or contracting toward the base, which can be straight or convex. Stems that bear contracting sides and concave bases have the fan-shaped form captured by the term *Dovetail*. Whether base edges are parallel or contracting, the distance from notches to the base itself can be short (e.g., Morrow 1996:Figure 3b), intermediate (e.g., Martin 2001:Figure 6c), or long (e.g., Stafford and Cantin 2009:Figure 7.11a). Bases and notches usually are ground. Bases occasionally bear centrally placed broad shallow notches. Fractures on St. Charles points are "consistent with their primary use as projectile points" (Morrow 1996:351).

At first use, St. Charles points can be quite long, well exceeding 100 mm in maximum dimension (Bowen 2020; Ohio History Connection 2007). They also can be resharpened laterally as drills (e.g., Bapst 2002; unfortunately, the accompanying illustration is unscaled, so length and other dimensions cannot be approximated), and broken blades possibly can be recycled as beveled scrapers. Total length in Luchterhand's (1970:64) mixed sample of unused and resharpened St. Charles points ranged from 42 mm (all but one were ≥60 mm) to 129 mm.

***Type Distributions in Time and Space*** Across the midcontinent, Thebes and St. Charles points are reasonably well dated to the early Holocene. They are associated with dates of 9480 ± 300 rcybp and 9290 ± 400 rcybp at Graham Cave (Klippel 1971). No fewer than five intact Early Archaic deposits yielding Thebes points are reported for western Illinois (Nolan and Fishel 2012:423), but only Twin Ditch among them is well documented. There, several Thebes and one St. Charles point (Morrow 1996:Figure 3b, 3c) are associated with a suite of $^{14}C$ dates ranging from 9510 ± 100 rcybp to 8740 ± 70 rcybp (Morrow 1996:347). A St. Charles base fragment directly overlies a date of 8925 ± 28 rcybp at Hester in northeastern Mississippi (Miller et al. 2023:5). At Farnsley, a St. Charles zone underlies several Kirk deposits and bears radiocarbon dates between 9350 rcybp and 8780 rcybp (Stafford and Cantin 2009:7). That deposit is stratigraphically linked to a "workshop" zone in which Thebes and St. Charles points occur (Stafford and Cantin 2009:285–286, 291) and that yielded two thermoluminescence dates averaging 10750 ± 512, judged "consistent with the calibrated radiocarbon" (Stafford and Cantin 2009:8) dates from the St. Charles zone.

Yet Farnsley hints at greater time depth for Thebes bifaces. Underlying the stratigraphically linked Thebes workshop and St. Charles zone, the "Early Side-Notched" zone returned a date of 9950 ± 90 rcybp and two side-notched bifaces that appear to bear what are acknowledged as "stylistic characteristics . . . [of] the Thebes Cluster" (Stafford 2021:24, Figure 2.3a; Stafford and Cantin 2009:295, Figure 7.17). A third diagnostic specimen there appears to be a Kessel (Stafford and Cantin 2009:Figure 7.18b) or possibly a Kirk Corner-Notched point. A possible St. Charles point with left beveling was found overlying Clovis deposits at Kimmswick (Graham et al. 1981:Figure 2j).

Thebes bifaces are abundant in Ohio and, perhaps to a lesser degree, in Indiana (e.g., McCord 2007:Figure 81, Tables 34 and 35) and Illinois (e.g., Koldehoff 2013; Nolan and Fishel 2012). Their Ohio distribution seems centered on the east-central part of the state (Colucci 2017:Figure 4.17; see also Bowen 2020; Seeman et al. 2020:Figure 5b; White 2013:85), but both Thebes and St. Charles points are common elsewhere as well (e.g. DeRegnaucourt 2002; Payne 1982:Figures 13, 15, 39). Whether the documented distributions are artifacts of archaeological sampling, modern land use, or surface geology or are faithful reflections of precontact patterns remains unclear. Among other things, curation rates influence the number (e.g., Gravel-Miguel et al. 2021) and spatial scale (Lin and Premo 2021) of empirical artifact distributions as much as does distance to source. This realization further underscores the importance of curation and survivorship (Shott 2022) in lithic analysis broadly. Thebes and St. Charles points are common in southwest Illinois, although not as abundant as earlier Dalton or later Kirk and bifurcate-base points (Koldehoff 2013). One St. Charles point was found in a cache with Hardin Barbed and Rice Lake points near St. Louis (Martin 2001:Figure 6c), although the association was considered secondary. A small Thebes assemblage and one St. Charles point were recovered at Carrier Mills in southern Illinois (Jefferies and Butler 1982:1356–1358, Plate 161). Variants of Thebes and St. Charles points are documented in western Tennessee (McNutt et al. 2008:50–55, Figures 12–13) and in the Falls of the Ohio region in Kentucky (e.g., Collins 1979:167–168). Bolen is a capacious type label used mostly in Florida for varieties of early Holocene notched points, some of which resemble Thebes points (Bissett 2003:Figure 4, specimens 12, 31). Thebes and St. Charles specimens occur in modest frequencies in southern Ontario, either as taphonomic effects because Early Archaic beaches may have been submerged by isostatic rebound or for functional or historical reasons (Jackson and Krist 2019:5); a fragmentary possible Thebes point was found at McKean on the south shore of Georgian Bay (Lennox 2000:43, Figure 19d). Thebes bifaces and St. Charles points occur as far northeast as western New York State (Smith et al. 1998:14–16). In sum, Thebes and St. Charles are Early Archaic types fairly widely distributed in eastern North America.

### *Thebes Biface Resharpening Allometry*

Presaging the explicit recognition of modularity and allometry, earlier studies documented allometric resharpening effects on Thebes and St. Charles bifaces, disproportionately on blade modules. Stafford and Cantin (2009:285), for instance, noted evidence of the reworking of Thebes blades. The most noteworthy previous study is Luchterhand's (1970) of Thebes, St. Charles, and other Early Archaic types in Illinois. It foreshadowed this study in two salient respects: by using relatively large samples from private collections and by documenting pattern and magnitude of tool reduction from first use to discard.

Yet the effects of reworking may not be identical across types, depending on their original morphometrics, manner of use, and/or pattern of reworking. In Luchterhand's sample, "reworking affects different sets of attributes in different point types" (1970:23). For instance, only weight differed between reduced and unreduced Thebes bifaces, while total length, blade length, weight, and other variables differed among St. Charles points (Luchterhand 1970:24). Luchterhand did not make this argument, but perhaps difference is owing to the possible use of Thebes bifaces as knives and St. Charles ones as points. Yet, Luchterhand's data set (1970:63) qualifies the limited variation reported in Thebes bifaces because only 4 of 41 bifaces were not reworked. Reduction-sensitive dimensions—total length and blade length—differed substantially and in the expected direction; reworked bifaces had lower values (Table 1). Dimensions relatively unaffected by reduction—thickness, stem length, and shoulder and base width—differed negligibly between unreduced and reduced bifaces. Whatever the limitations of Luchterhand's sample, variables that approximate gross size and that are expected to diminish with reworking—weight, blade length, and by extension of the latter, total length—differed substantially between subsamples, while dimensions that are only slightly if at all affected by reduction differed little. Luchterhand's St. Charles data (1970:64), not shown in Table 1, yielded similar means and differences in them between subsamples.

Early Side-Notched points (e.g., Graham Cave, possibly Big Sandy) are not identical to Thebes or St. Charles points, although, as above, bifaces in Farnsley's Early Side-Notched assemblage closely resemble Thebes bifaces there. Early Side-Notched points from northern Alabama show a range and pattern of variation interpreted as a reduction continuum (Randall 2002:Figure 4–2), and reduction measures (ratios between selected dimensions) pattern by segments of that continuum in ways consistent with the presence of distinct stem and blade modules and differential reduction effects on the latter (Randall 2002:Table 5–6).

On balance, earlier studies of Thebes/St. Charles and other Early Archaic notched bifaces suggest that they are divisible into somewhat distinct stem and blade modules and that reworking of specimens during use differentially affects

**Table 1.** Mean Dimensions (mm) and Weight (g) of Unreduced and Reduced Thebes Bifaces.

| Condition | Total Length | Blade Length | Weight | Stem Length | Shoulder Width | Base Width | Thickness |
|---|---|---|---|---|---|---|---|
| Unreduced | 91.3 | 72.3 | 46.6 | 19.0 | 49.3 | 38.8 | 9.8 |
| Reduced | 77.0 | 58.4 | 33.6 | 18.6 | 47.0 | 37.4 | 9.4 |

*Source*: Luchterhand 1970:63.

blades. Combined, these observations implicate allometric patterns of variation. The matter deserves further study using new samples and additional analytical methods, as reported below.

## Central Ohio Archaeological Digitization Survey

The Central Ohio Archaeological Digitization Survey (COADS) documented the distribution and abundance of precontact remains across a nine-county area traversed by the Scioto River and encompassing the Ohio Hopewell core (Figure 2). Despite a long history of professional research in the region, the number of "sites" and especially the number of stone tools from professional research were insufficient for COADS's goals. Accordingly, collection of point data from private collections in the region was integral to COADS.

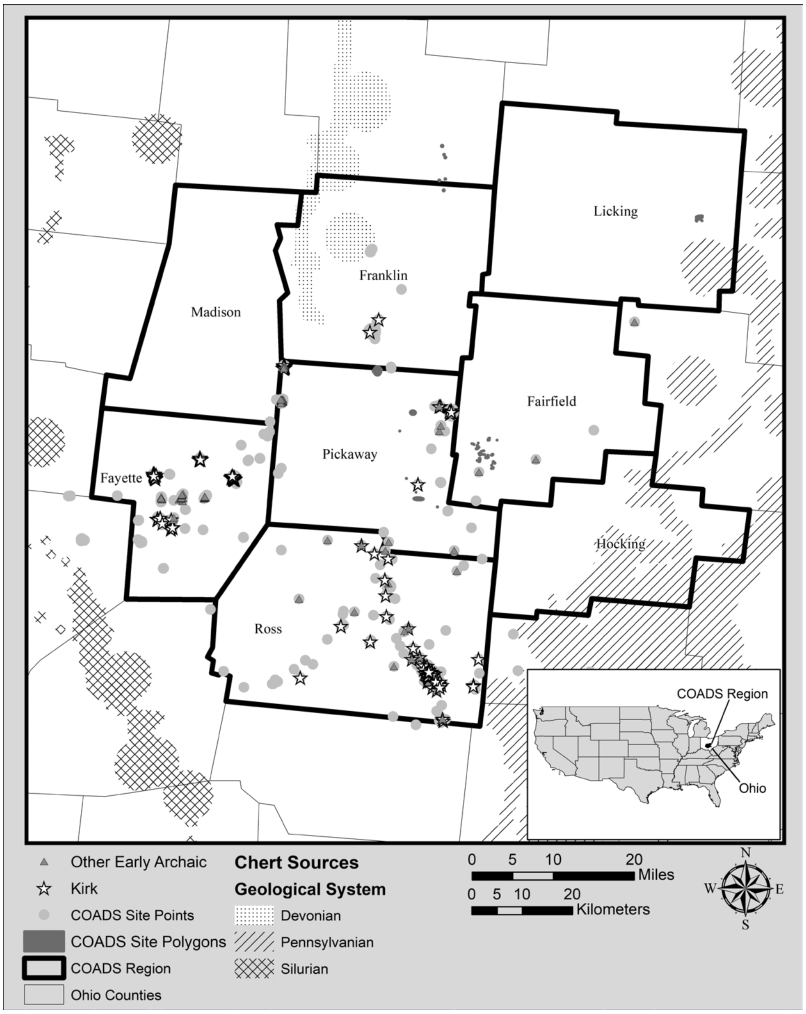


**Figure 2.** The COADS study area, showing Thebes, Dovetail/St. Charles, and other Early Archaic point locations. Chert source maps from Lutz and Nolan (2020).

Used merely to date any context, one Thebes or St. Charles is as good as one thousand. Large sample size is not a virtue in the abstract but is only when it documents informative dimensions of variation. In this spirit, we leveraged the large sample sizes of private point collections from the region. Nolan and colleagues (2022) described the project and its ethical standards; Shott and Pitblado (2015), among others, justified the use of private collections. In all, COADS documented over 10,000 artifacts from 490 collector-defined locations, at least an order of magnitude more than in any single professional project in the COADS area and more than all points recorded for the study region in state site files. Several thousand of these artifacts are intact diagnostic points; 69 of that number are intact, analyzable Thebes specimens and 70 are St. Charles points. (For some analyses below, data were available only for some points; for instance, some lacked values for resharpening indices.) In gross size, this study's Thebes sample averages about 64 mm in length (approx. range = 28–103 mm), which nearly encompasses Luchterhand's values. Its St. Charles sample averages about 77 mm in length (approx. range = 33–147 mm), somewhat exceeding Luchterhand's sample at both extremes.

In Ohio, most Thebes and St. Charles points are made of Upper Mercer or Flint Ridge chert (Colucci 2017:86; Seeman et al. 2020:Table 1) and most of the rest, from Delaware and other local sources. The fewer nonlocal specimens derive from sources that include Onondaga in Ontario and western New York, Wyandotte in southern Indiana, Attica in northwest Indiana, Paoli in eastern Kentucky, and Bayport in central Michigan. Correspondingly rare Flint Ridge Thebes and St. Charles points occur in southwestern Illinois (Koldehoff 2013:21).

Colucci reported roughly 3:1 ratios of Upper Mercer to Flint Ridge chert for her Thebes sample (2017:Figure 4.2) and that Upper Mercer and Flint Ridge together comprised about 60% of her sample, other local sources (e.g., Delaware, Ten-Mile Creek) about 30%, and nonlocal sources about 10% (Colucci 2017:86). The COADS sample's Upper Mercer:Flint Ridge ratios are 0.4 for Thebes (i.e., there are over twice as many Flint Ridge as Upper Mercer specimens) and 0.5 for St. Charles, and their combined percentages are 66.7% and 77.0%, respectively. Proportions among the two major toolstones differ greatly between Colucci's and the COADS's samples, while combined Upper Mercer and Flint Ridge proportions are broadly similar. Differences are possibly owing to the more northerly—nearer to Upper Mercer sources—distribution of Colucci's sample compared to COADS's.

Points were weighed individually, measured for thickness, and coded for common toolstones. Intact diagnostic points were scanned in two dimensions (2-D). Blade and stem length, shoulder width, and tip angle were extracted from scaled 2-D images. Possible reduction measures were then computed for most specimens (Supplemental Material 1). These include the Flaking Index (FI; Miller and Smallwood 2012) that rises with amount of edge resharpening and therefore should vary inversely with point size; the ratio of blade to stem length (IBR for its Spanish initials as defined by Iriarte [1995]; see also Charlin and Cardillo

2018); and the length-thickness ratio (L/T; Shott et al. 2007), both of which decline with reduction, so should vary positively with point size. Using tpsDig (Rohlf 2017), seven landmarks (tip, shoulders, neck, base corners) and 55 semilandmarks ("landmarks" henceforth) were placed on 2-D models of intact diagnostic points for LGM analysis (Supplemental Material 2). A 5% sample of most point types also was drawn for three-dimensional (3-D) scanning (not considered here; see Shott et al. 2017). 2-D images of specimens were assigned to types by two authors.

LGM analysis was conducted in MorphoJ (Klingenberg 2011; Supplemental Material 3). Procrustes superimposition by generalized Procrustes analysis (GPA) translates all specimens to a common centroid (in 2-D models consisting of x-y coordinates, the centroid is found at $x_{\bar{x}}$-$y_{\bar{x}}$), rescales them to common size, and iteratively rotates them to minimize summed-squared differences between landmarks and sample centroid. Each specimen's resulting centroid size (CS) is the square root of summed-squared distances of all the landmarks from their centroid, itself often rescaled to its natural logarithm (lnCS). CS is a measure of the specimen's size in 2-D Procrustes space. Principal-components ordination of superimposed landmarks then extracts orthogonal dimensions of variation. Procrustes superimposition can remove size effects from shape, the latter typically attributed to the first principal component (PC1) of ordination of superimposed landmarks. Yet, in specimens that are subject to ontogenetic processes, superimposition removes only isometric size effects, those *unrelated to* shape. This is so in biological data, human (Oxnard 1978:233) and otherwise. In a meta-analysis of biological studies, "size often explains a large fraction of total shape variation" (Outomuro and Johannson 2017:1449). If resharpening allometry contributes significantly to ontogenetic size-and-shape variation in points, then PC1 correlates with, is not independent of, CS or other size measures. Thus, correlating PC1 and CS is a test for allometry, with significant correlation indicating allometry.

For modularity analysis, all landmarks from shoulder-to-shoulder along the stem comprise a stem module and those from shoulders to tip, a blade module. Following Klingenberg (2011), links were made conservatively, confined mostly to adjacent landmarks and omitting all that fell outside the specimen's outline; selected links were specified at neck, at shoulder, and on the blade (e.g., Figure 3

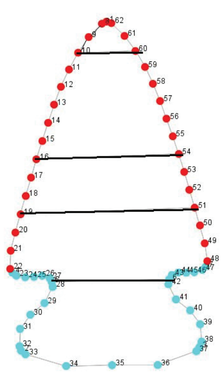

**Figure 3.** Landmarked COADS Thebes biface showing links (stem module in blue, blade module in red) selected for modularity analysis. All landmarks linked to their neighbors on the point outline; additional specific links shown as straight lines.

for Thebes). Of course, modular allometry does not mean that stems never experienced change in use. Scenarios of wholesale stem modification (Flenniken and Raymond 1986) may be uncommon, but unquestionably, Thebes and St. Charles stems could be modified at least modestly in use.

## Analysis

### *Non-LGM Reduction Measures*

Following Procrustes superimposition and CS calculation as described above, prospective reduction measures FI, IBR, and LT were plotted and correlated with lnCS in Thebes specimens, whose range of variation more nearly approximates dependent variables' than does CS. All results were highly significant in expected directions (FI r = –0.87; IBR r = 0.44; LT r = 0.69, all $p < 0.01$; omitting two outliers, FI r = –0.87; IBR r = 0.62; LT r = 0.73, all $p < 0.01$; e.g., Figure 4); reduction measures track specimens' diminishing size with use and resharpening. The St. Charles sample yielded similar results (FI r = –0.87; IBR r = 0.78; LT r = 0.76, all $p < 0.01$; e.g., Figure 4).

### *Allometry*

Landmark Procrustes coordinates were ordinated by principal-component analysis (PCA). As above, when allometry obtains in-shape variation among objects structured as modules, Procrustes superimposition cannot remove correlated size variation. On the contrary, LGM is well suited both to reveal allometry if sought and to measure its strength when present. Among COADS's Thebes bifaces, for instance, PC1 accounted for 57.9% of variance. It patterned with lnCS (r = 0.51,

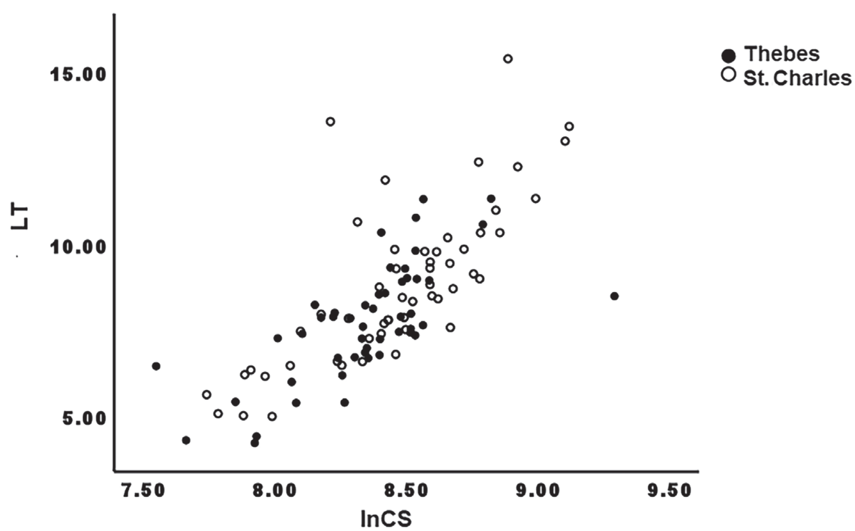


**Figure 4.** LT versus lnCS for Thebes and St. Charles.

$r^2 = 0.26$, $p < 0.01$; excluding two large outliers, $r = 0.60$, $r^2 = 0.36$, $p < 0.01$; Figure 5a). Among St. Charles points, PC1 accounted for 70.2% of variance and also patterned with lnCS ($r = 0.67$, $r^2 = 0.45$, $p < 0.01$; Figure 5b). One-quarter to one-third of shape variation in Thebes—and nearly half in St. Charles—points is explained by size, with figures near or above 36% found in analyzing a sample of Clovis points (Thulman et al. 2023) and higher than the mean of 25.4% found in 300 biological ontogenetic studies that ranged as high as 87% (Outomuro and Johansson 2017:1449). A clear allometry signal resides in these data, yet it is stronger for St. Charles than for Thebes specimens. Strength of allometry's signal varies between types; whether this difference is significant and perhaps relates to distinct functions are for future research to determine.

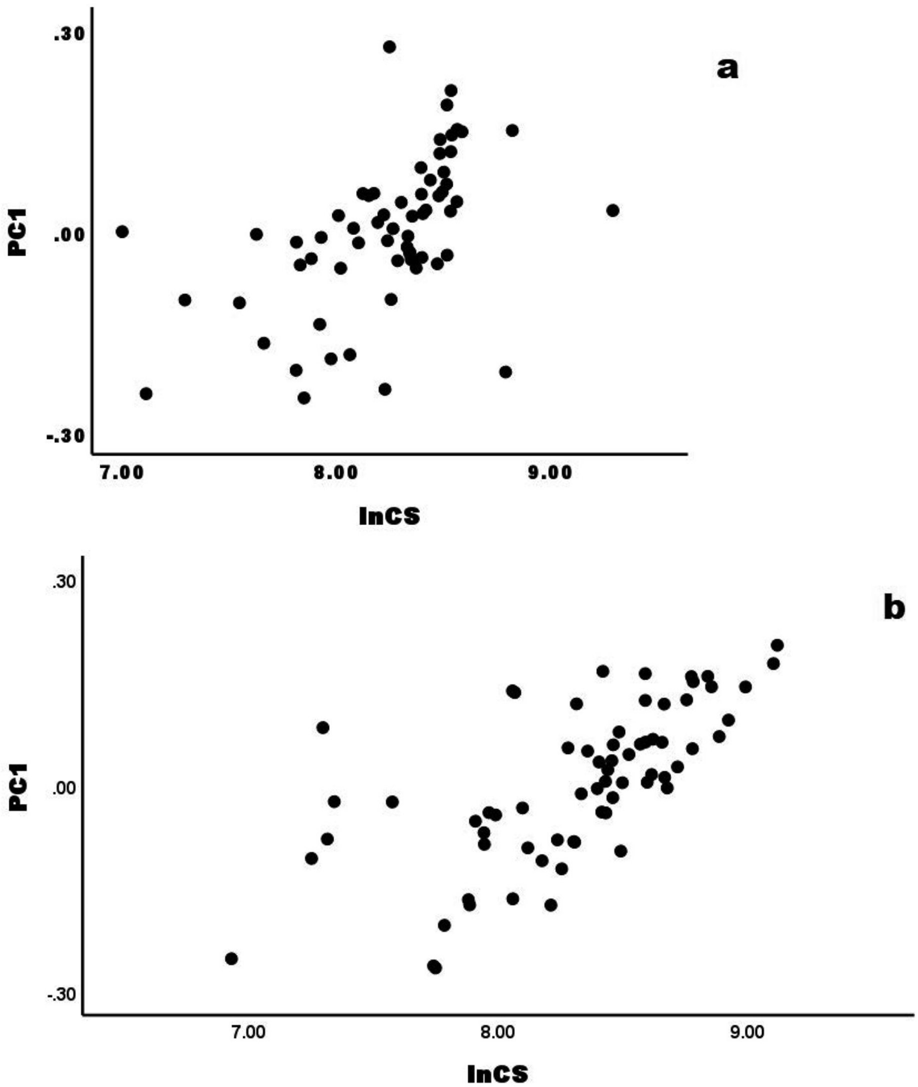


**Figure 5.** Procrustes-coordinates PC1 versus lnCS for (a) Thebes and (b) St. Charles.

### *Modularity and Integration*

MorphoJ tests for modularity by comparing the strength of covariation between hypothesized blade and stem modules (described above) and alternative partitions of the same numbers of landmarks in the hypothesized modules. The COADS's Thebes-sample test statistic RV = 0.83 ($p < 0.01$) is much lower than the entire distribution of values in 1,000 simulated partitions (Figure 6a). In the St. Charles sample, RV = 0.85 ($p < 0.01$), again lower than the distribution of 1,000 simulated partitions (Figure 6b). Like allometry, modularity is strongly indicated in COADS Thebes and St. Charles specimens.

Partial least-squares (PLS) regression, measuring covariation between two or more sets of variables, is one way to test for integration between modules. Some consider the MorphoJ test statistic RV sample-size-dependent, alternatives preferable for modularity and integration tests. Yet RV and the CR statistic produced nearly identical statistical inferences in controlled tests (Cardini 2019:94, Table 2). One control for RV's possible size dependence, at least for analysis of integration, is to compare results using within-configuration or separate-block approaches (i.e.,

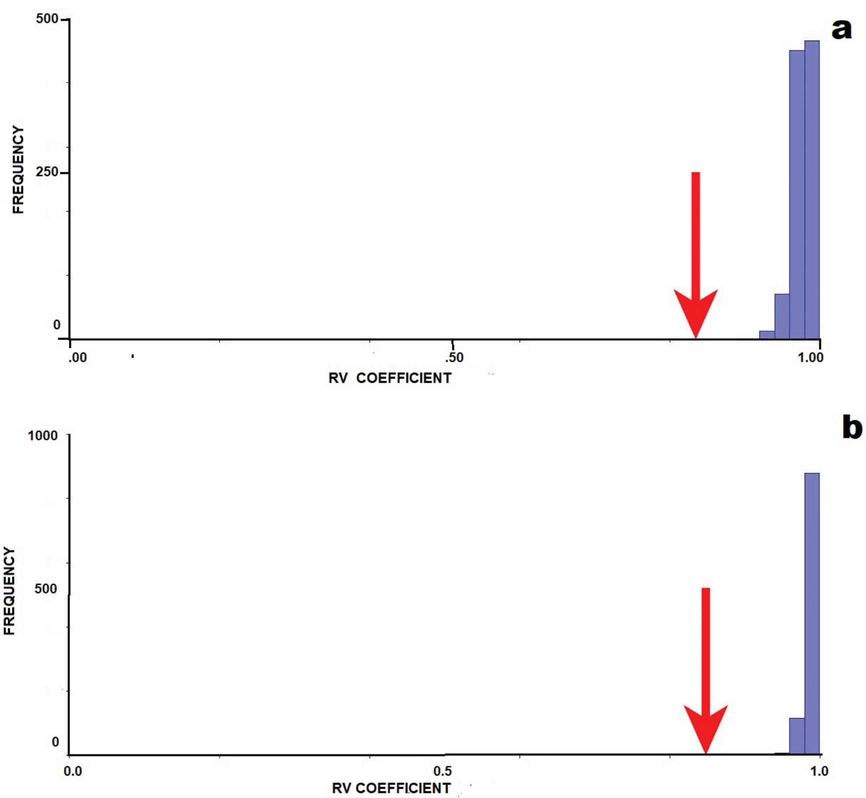


**Figure 6.** Stem-blade modularity test result for (a) Thebes and (b) St. Charles. RV value indicated by arrow, compared to distribution of RV values in 1,000 iterations of random landmark partitions.

comparing modules superimposed within the same configuration or as separate submodules). If results agree, they corroborate inference (Klingenberg 2009:408).

For COADS data, accordingly, PLS was conducted using both methods. Cardini (2019:92) questioned the statistical validity of within-configuration PLS and suggested that it may yield false-positive results, while acknowledging complementary doubts about the separate-block alternative. His simulation suggested that within-configuration PLS often shows significant integration but that separate-block PLS often fails to indicate integration (Cardini 2019:Table 2). Cardini recommended reporting RV but also %-covariance explained by PLS1, correlation between blocks in PLS1 scores, and attained significance. Applied to COADS's Thebes bifaces, cross-plots of block PLS1 scores differed considerably in pattern and strength between within-configuration and separate-block methods (Figure 7). Unlike Cardini's test, however, both approaches yielded significant statistical results. In within-configuration PLS, RV is obtained as in the modularity test, so it equals 0.83 ($p < 0.001$, 92.2% of total shape covariance explained by PLS1, r = 0.94, $p < 0.01$). In separate-block PLS, RV = 0.113 ($p < 0.01$, 84.5% of total shape covariance explained by PLS1, r = 0.41 $p = 0.03$). In the St. Charles sample, cross-plots of block PLS1 scores (not shown) again differed from one another, in a

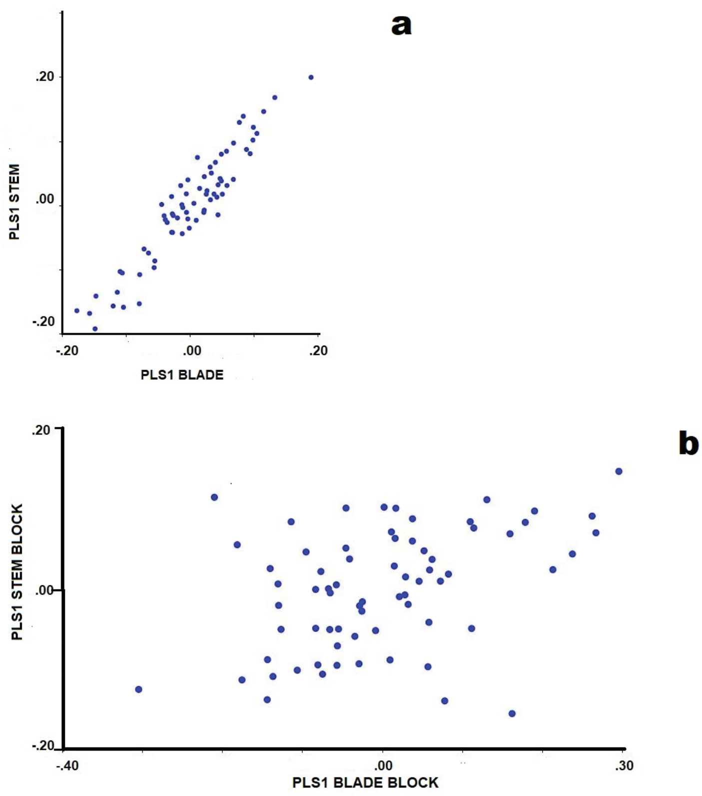


**Figure 7.** Thebes biface stem-blade integration test result by PLS analysis (a) within configuration and (b) as separate blocks.

similar pattern to the Thebes case. In within-configuration PLS, as above, RV = 0.85 ($p < 0.01$, 97.1% of total shape covariance explained by PLS1, r = 0.94, $p = 0.04$). In separate-block PLS, RV = 0.132 ($p = 0.003$, 92.9% of total shape covariance explained by PLS1, r = 0.43, $p = 0.017$). As in controlled tests (Cardini 2019), separate-block PLS may be the more robust method. Like allometry and modularity, integration of Thebes and St. Charles blade and stem modules is indicated.

Again, modules are geometric components of larger wholes whose landmarks' covariation among themselves exceeds covariation with landmarks in other modules. Recall also that integration is the degree of covariation *between*, not within, modules. These definitions seem mutually contradictory but are not. As above, modules are *relatively*, not absolutely, independent components of larger wholes; functional constraints (e.g., blades with tips sufficiently sharp to penetrate targets and sufficiently long to create serious wounds, stems of size and shape sufficient to secure the whole to the larger armature), allometry, and other factors act on modules to limit their independence and ensure necessary degrees of integration. There is no paradox in inference to both modularity and integration. COADS Thebes bifaces and St. Charles points are integrated wholes that consist of semi-autonomous modules. LGM methods reveal both qualities in ways that conventional methods cannot.

### *Further Analysis*

Results are significant in themselves but can be extended in several ways. For example, allometry was tested in a different subset of data for both types, drawn from stems only rather than from whole-object outlines. These are LM models of stem or haft elements only. Because these elements—modules—of points are not expected to change much—some, not much—during use, their analysis should *not* yield significant results in testing for allometry by plotting and correlating PC1 scores of PCA analysis of GPA-transformed LM coordinates against lnCS. In effect, this is a test of an $H_0$ of allometry's absence in stems. Results support this hypothesis and, therefore, the absence of allometry in stems (for Thebes, r = 0.02, $p = 0.83$ [Figure 8]; for St. Charles, r = 0.06, $p = 0.58$ [the cross-plot differs in detail, of course, from the Thebes one but not in substance so is omitted]).

Separate reduction measures FI, IBR, and LT can be synthesized as a single "multivariate" (Shott and Seeman 2017) reduction index (MVRI) by correlation-matrix PCA, with higher values indicating less reduction. The result serves as a global reduction index for these samples and, by extension, the curation and use (Shott 1996) that specimens experienced. MVRI correlates positively with lnCS (for Thebes, r = 0.87, $p < 0.01$; for St. Charles, r = 0.89, $p < 0.01$; Figure 9). That is, larger Thebes and St. Charles specimens as measured by lnCS are less extensively reduced as measured by MVRI. MVRI's correlation with lnCS is somewhat higher than are original indices' correlations; extracting their common main axis of variation creates a

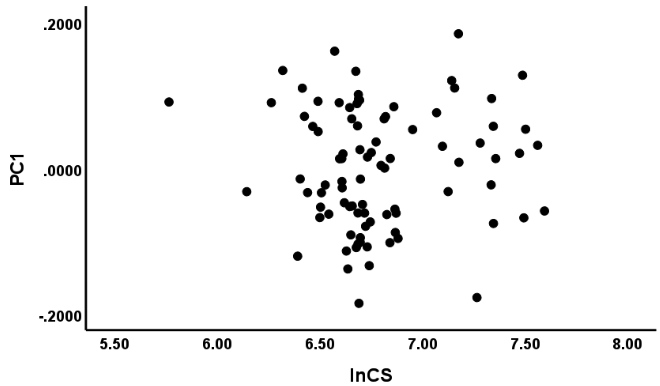


**Figure 8.** Thebes biface stem-only Procrustes-coordinates PC1 versus lnCS.

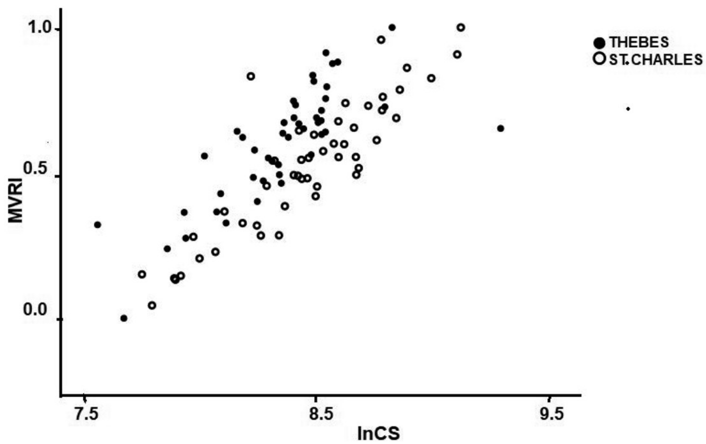


**Figure 9.** MVRI versus lnCS for Thebes and St. Charles points.

single index that may measure slightly better the effect of resharpening allometry on points.

For discussion's sake, assume perfect correlation between MVRI and age at discard. Assume as well that highest MVRI value indicates no use and lowest the maximum use that triggers discard. For discussion, that is, cumulative-survivorship curves are approximated by the number of tools that fall in specified ranges of MVRI. Using MVRI deciles and, therefore, further assuming 10 episodes of resharpening, rough cumulative survivorship curves are broadly similar between types (Figure 10). Yet the upper, Thebes, distribution is more convex to the seventh decile, indicating greater resistance to discard, that is, higher curation. Again, and further assuming that the difference in distributions is significant, this may be owing to possible use of Thebes bifaces as knives. All else equal, knife use is apt to be less hazardous than is use as a projectile tip, although the possibility must be tested experimentally. As elsewhere (Morales 2016; Shott and Seeman 2017), cumulative-survivorship distributions generated from MVRI

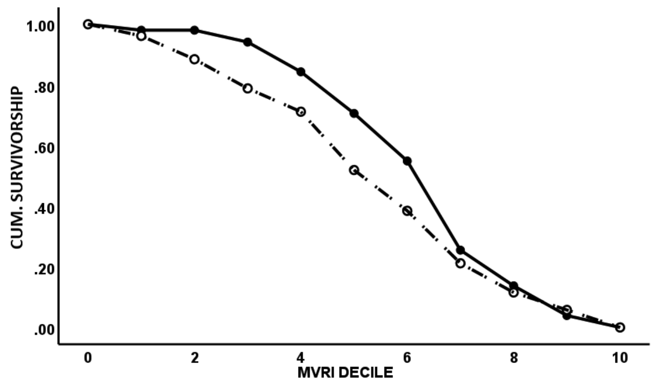


**Figure 10.** Thebes and St. Charles MVRI cumulative-survivorship curves. Solid, upper, more convex line represents Thebes points; lower dashed line represents St. Charles points.

values or other data can be fitted to the Weibull failure model. Besides ease of calculation, Weibull model fitting compares data sets like COADS Thebes and St. Charles samples in continuous terms, estimating a scale parameter—α—that correlates with use life and a shape parameter—β—that identifies failure causes (Morales 2016; Shott 2022).

### *Summary of Analysis*

Overall, LGM analysis reveals clear allometry and modularity in COADS Thebes bifaces and St. Charles points. These tools were structured as modules and experienced allometric variation in use, probably because blades were disproportionately reduced compared to stems. Reduction measures FI, IBR, and LT all pattern with lnCS. In Thebes and St. Charles, as in other types (e.g., Shott and Otárola-Castillo 2022; Shott et al. 2021; Shott et al. 2024), modularity and allometry must be considered before morphometric variation can be attributed to design or other factors. Fortunately, LGM facilitates modularity analysis and, with other straightforward approaches, tests for allometry.

## Discussion

COADS leverages the enormous information that resides in private collections from south-central Ohio. Collectors and professional archaeologists do not always agree, but responsive or responsible collectors (sensu Shott and Pitblado 2015:12) are a resource for information about and allies in at least limited preservation of the archaeological record. If ever there was a time to oppose collectors categorically, it has passed.

The responsive and responsible collectors who collaborated with COADS deserve thanks, obviously. Yet they are merely the latest generation of artifact collectors in a tradition that stretches back well over a century in Ohio and other midcontinental states. Residents of Ross County, where many COADS Thebes and St. Charles points were found in recent decades, have compiled collections of similar artifacts since the nineteenth century (Ohio History Collection 2007). It is impossible at this remove to gauge the magnitude and effect of earlier undocumented collection, although studies elsewhere estimated conservatively that collectors held over 95% of all points ever found on the ground surface (Shott 2017). Yet the more that we can learn from what amounts to collections "taphonomy"—documenting collections and their proveniences, identifying the practices that collectors followed, gauging their aggregate effects on the accumulated record, estimating the "half-life" of assemblages before they vanish into flea markets and auction houses—the better our knowledge of the precontact period, in south-central Ohio and elsewhere.

## Conclusion

Fairly large samples like COADS's reveal a fuller range of morphometric variation than in traditional archaeological studies. In original design, most Thebes bifaces and St. Charles points were fairly large and long bladed. At loss or failure, most—but not all—stems remained unchanged, but many points were considerably shorter and narrower. The morphometry of complete original design is not always, or even often, preserved in size and shape at discard. Certainly, original design is informative but no more than the pattern and degree of allometric variation that characterized the partly integrated but distinct modules of Thebes bifaces and St. Charles points.

Narrowly, this study merely discovered the increasingly obvious: Allometry accounts for considerable size-shape variation in midcontinental Thebes bifaces and St. Charles points. Moreover, possible difference between the types in allometry's strength and in cumulative survivorship, despite their similar time distribution, suggests different functions, with Thebes used as knives and St. Charles as points. This matter deserves more research, using a range of evidence. But the allometric conclusion is broadened by registering the complementary role of modularity in clearly defined landmark subsets that demarcate the context for allometry, that is, resharpening having occurred mostly on blade modules. It is further enhanced by the correlation between independent allometric measures—LGM and the FI, IBR, and LT indices—and their ability to measure fairly precisely allometry's degree and its variation by toolstone and other dimensions. Finally, the narrow conclusion about allometry is broadened by comparison to other types, for instance Kirk Corner-Notched (Shott et al. 2024) and Clovis (Shott et al. 2021; Thulman et al. 2023) points. Similar analysis of the full range of point types in COADS's database may chart long-term trends or cycles in degrees of allometric resharpening and related curation rates. Relevant theory (e.g., Miller 2018) can test hypotheses of land use and economic practices by comparing curation rates as measured by MVRI or otherwise between types and the time periods they may represent.

This analysis is relevant for additional reasons. Before we seek synchronic social groups defined by typological variants or diachronic trends in the morphological transitions between point types, we must control for modularly regulated allometry. In part, this means attending not only to whole-object shape but also to less variable modules like stems. When studying whole-object shape or form, this means, in part, the control of allometric variation before identifying and attempting to explain other sources of variation. Further analysis, for instance, could test alternative modular hypotheses, like González-José and Charlin's (2012) tip-versus-rest-of-point modularity. It also could explore in greater detail morphometric variation by major toolstone types. Similar analyses will be conducted in the 2-D samples of many other types and in the smaller samples of 3-D Thebes, St. Charles, and other bifaces in the COADS data set.

Allometry and modularity must be sought—tested for—explicitly. When found, which should be often, their presence is no counsel of despair, no reason to fear that adaptation, history, and other factors cannot be read from points. Allometry and modularity, and the morphometric variation they generate, are inherent properties of point types that are worth knowing and are revealed by straightforward analysis. But any analysis that seeks adaptation or history from points first must control for allometry and modularity, not elide them.

Modularity, integration, and allometry were the study's focus, but the broader COADS data set can be investigated for other purposes. We also can study how point types of earlier periods might have morphed or "evolved" into later types by long-term processes of intelligent trial-and-error experimentation. Despite the abundance and analytical popularity of points, archaeology still cannot determine if any point-type transitions (e.g., Thebes/St. Charles to Kirk) occurred by morphing or evolution or, instead, by replacement. If by morphing, we cannot explain, despite reasonable suggestions (Kimball 1996:157; White 2013:86), how or why this might have occurred. That is, we cannot distinguish between sequences of point types characterized by in situ development or "evolution" and the abrupt replacements following population shifts or sudden, dramatic environmental change.

More broadly, why do types begin and end? That is, what explains any type's technology and morphometry (both original and as specimens of the type experience reworking and reduction), and why did they arise when they did? How many types were contemporaneous, and did the number of such types vary over long time? Why did some types suffer abandonment and others evolve into successors? How can we distinguish between these possibilities or resolve the tempo and mode of evolutionary changes? Archaeology lacks a theory of the point (Shott 2020a) that at once identifies its essential properties and their patterns of covariation and explains those properties and their changes across time, all in service to the "macroarchaeology" (Perreault 2019) that frees archaeology from its dependence on anthropology's synchronic perspectives.

Answering such questions will be the work of researchers over decades. At the outset, though, several things are clear. First, we need much larger samples of points than customarily available. The project from which this article derives demonstrates one way to obtain such samples. Second, we need new kinds of analysis informed by theory, not of the properties or actions of reified cultures or abstract analytical individuals but of irreducible units of observations like points.

By applying LGM analysis and complementary methods to the COADS sample and other large data sets, we can address issues like, Can we distinguish anagenesis (one type morphing into a single descendant type) and cladogenesis (one type branching into two or more descendants) in point-type transitions? Do Bauplan constraints channel the direction and magnitude of morphometric transformation from one type to a descendant? Can we measure the correlation, if any, between direction, rate, and magnitude of paleoenvironmental trends and morphometric changes in points, at least at point-type transitions (e.g., Cardillo et al. 2016; Conolly 2018)? Such questions begin to expand and develop a theory of the point, which morphometric analysis, among other approaches, can facilitate.

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## Supplementary Materials

Supplementary material for this article can be found at https://www.midwestarchaeology.org/mcja/supplemental-materials.

Supplemental Material 1. Thebes and St. Charles CS, lnCS, FI, IBR, LT, and Other Variables
Supplemental Material 2. Thebes and St. Charles Raw Data (Landmark Coordinates)
Supplemental Material 3. MorphoJ Results

## Declaration of Interest

The authors have no competing interests to declare relevant to the content of this article.

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