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ARTICLE

Trade-Offs in Standardizing Raw Materials: Experimental Control in Live Knapping Studies

William D. Snyder, David Boysen, Jordy D. Orellana Figueroa, Claudio Tennie, and Jonathan S. Reeves

Early Prehistory and Quaternary Ecology, Eberhard Karls University of Tübingen, Tübingen, Germany
Corresponding author: William D. Snyder; Email: wdspaleo@gmail.com

Abstract

Experimental stone tool replication is an important method for understanding the context and production of prehistoric technologies. Experimental control is valuable for restricting the influence of confounding variables. Researchers can exert control in studies related to cognition and behavior by standardizing the type, form, and size of raw materials. Although standardization measures are already part of archaeological practice, specific protocols—let alone comparisons between standardization techniques—are rarely openly reported. Consequently, independent laboratories often repeat the costly trial-and-error process for selecting usable raw material types or forms. Here, we investigated various techniques and raw materials (such as hand-knapped flint, machine-cut basalt, manufactured glass, and porcelain) and evaluated them for validity, reliability, and standardizability. We describe the tests we performed, providing information on the individual approaches, as well as comparisons between the techniques and materials according to validity and reliability, along with relative costs. We end by providing recommendations. This is intended as a serviceable guide on raw material standardization for knapping experiments, including existing strategies and ones so far undescribed in the experimental archaeology literature. The future of this field would benefit from developments in the relevant technologies and methodologies, especially for those that are not yet widely available or affordable.

Resumen

La replicación experimental de herramientas líticas es un método importante para comprender el contexto y la producción de tecnologías prehistóricas. El control experimental es importante para restringir la influencia de variables de confusión. Los investigadores pueden ejercer control en estudios relacionados con la cognición y el comportamiento mediante la estandarización del tipo, forma y tamaño de las materias primas. A pesar de que ciertas medidas de estandarización ya son parte de la práctica arqueológica, los protocolos específicos, y más aún las comparaciones entre los varios métodos de estandarización son raramente reportados abiertamente. Por tanto, los laboratorios independientes a menudo repiten el costoso proceso de prueba y error para seleccionar los tipos o formas de materias primas a usar. En esta publicación investigamos varias técnicas y materias primas (como sílex tallado a mano, basalto cortado a máquina, vidrio prefabricado y porcelana) y las evaluamos mediante su validez, su fiabilidad y la viabilidad de su estandarización. Describimos las pruebas que realizamos, brindando información sobre cada técnica, así como comparaciones entre las técnicas y los materiales según su validez y fiabilidad, al igual que los costos relativos. Concluimos el presente artículo con nuestras recomendaciones. Este trabajo tiene como objetivo servir como una guía útil para la estandarización de materias primas para experimentos de talla, incluyendo dentro del mismo las estrategias que ya existen, al igual que otras que hasta ahora no habían sido descritas en la literatura de la arqueología experimental. El futuro de este campo se beneficiaría de avances en las tecnologías y metodologías pertinentes, especialmente en el caso de aquellas que aún no están ampliamente disponibles o no son asequibles.

Keywords: knapping; raw materials; experimental archaeology; standardization; stone tool replication; lithic technology

Palabras clave: talla lítica; materia prima; arqueología experimental; estandarización; replicación lítica; tecnología lítica

Archaeologists have a long tradition of replicating the processes and end products associated with stone toolmaking (Johnson 1978). Experimental replication of stone tools (henceforth, replication studies) has generally been performed in order to better understand how those tools would have likely been produced in the prehistoric past (e.g., Johnson 1978; Schick and Toth 1994; Toth 1985; Toth and Schick 1994). Such experimental replication of prehistoric artifacts has been used to understand processes such as the mechanics of conchoidal fracture (reviewed in Li et al. 2022), the reduction sequences of specific artifact types (Moore and Perston 2016; Toth 1985), and the cognitive mechanisms that guide the production of stone tools and the acquisition of the toolmaking skill (Lombao et al. 2017; Morgan et al. 2015; Pargeter et al. 2019; Putt et al. 2014; Snyder et al. 2022). Modern experimental archaeology has placed an increasingly strong emphasis on *controlled* experiments for the study of the physical as well as cultural and biological processes inherent to knapping behavior (Eren et al. 2016; Lin et al. 2018; Whittaker 1987). Controlled experimentation is also important for studying other stone tool behaviors, especially applied to questions about lithic projectiles (Iovita et al. 2014; Neill et al. 2022). However, our own research questions relate to innovation and learning of knapping techniques (Snyder et al. 2022), so this text was written specifically with knapping in mind and not other behaviors.

Stringent experimental control can help to isolate variables of interest from potential confounds. When focusing on behavior and cognition (such as knapper skill level or learning mechanisms), extraneous physical variables (e.g., raw material quality, core shape, core size; see Lombao et al. 2017) are best controlled for via the experimental protocol. One useful means of experimental control is the standardization of raw material types, blank forms, and blank size. Researchers have previously created and utilized standardized blanks or preforms in replication studies (Khreisheh et al. 2013; Li et al. 2022; Sheets and Muto 1972; Speer 2018).[1] Standardized blanks can also be used outside the experimental setting, especially as teaching tools for public outreach or the training of archaeologists (see Shea 2015). Standardized blanks can be made from naturally occurring or synthetic materials—especially if they can fracture conchoidally—and are somehow shaped to follow a specific design concept. Standardizing blanks minimizes the potential effects of raw material geometry on any outcomes (artifactual, behavioral, or otherwise). Yet, standardization occasionally occurs in natural stone (depending on geological formation and erosive processes). For this reason, standardizing blanks has been argued to be less ecologically valid, with the usage of large samples of blanks applied instead to overcome the problems of blank variability (Pargeter et al. 2022). Nonetheless, standardization is clearly useful for pursuing research questions that are primarily unrelated to core variability. Second, standardization is still valid so long as the standardized form falls within the range of theoretically possible blank forms in real life (e.g., Snyder et al. 2022; Toth 1985). In short, there is often value in standardization, but this depends on the research question (for example, if the research question is how hominins potentially utilized the full range of blanks, standardization would be counterintuitive).

Where standardization is useful, attempts at standardizing knappable blanks will likely be focused on several aspects at once—for example, generating blanks that are consistently of the same size, shape, and material (except where size, shape, or material type are variables of interest, in which case, variation of these would still follow the same protocols described below). Here, we define two main components that must be considered when selecting raw materials and refining standardization techniques for a replication study: (1) reliability and (2) validity (Lin et al. 2018). In this case, reliability refers to the capacity for a raw material to be standardized at all (i.e., to be repeatedly created to a specific shape and size) and—by extension—the relative ease and efficiency with which the raw material can be standardized. Validity refers to the appropriateness of a raw material or blank form as an analog to raw materials and artifacts from the archaeological record (i.e., *external* validity: see Eren et al. 2016; Lycett and Eren 2013).

Although other forms of fracture can also lead to usable sharp edges, conchoidal fracture is the one *most* typically associated with prehistoric cutting tools (Cotterell and Kamminga 1987). Consequently, for our purposes, the first test of validity is whether a raw material or blank form can produce conchoidal fracture (Cotterell and Kamminga 1987; Dogandžić et al. 2020). In some cases, additional tests of validity are required—that is, standardized blanks must be suitable for the technologies,

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time periods, or sites being investigated (e.g., a study on one population's cognitive abilities is best carried out with materials similar to those available to that population, as in Stout and Semaw 2006). In the case of pure replication experiments (i.e., reproducing archaeological objects without attention to, for example, reduction processes or specific cognitive variables), standardized blanks may indeed not be suitable at all. Although reliability and validity are not necessarily mutually exclusive, it is possible that highly reliable techniques and materials are not particularly valid, and vice versa (see Discussion section). With further practical and economic restraints on what is useful or accessible, the actual application of raw material standardization to experimental designs results from a negotiation between numerous influencing factors.

Standardization processes can be either *additive* or *reductive* (Ferguson 2003; Schillinger et al. 2014). This useful distinction refers to how (via manual actions or machinery) the blanks are brought into shape from the original raw material form. An example of an additive technique is the transformation of porcelain powder into slip, which is then poured into a mold, whereas the grinding down and sawing of stone is an example of a reductive process. Additive techniques are generally more reliable than reductive ones because the resultant blanks more often resemble the ideal form. Most additive techniques require the mixing of ingredients (e.g., for concrete) and a mold to encapsulate the developing blank. Additive techniques, though reliable and often capable of producing raw materials that conchoidally fracture, do not—strictly—result in raw materials that would have been ecologically available. Steps can still be taken during production to make artificial materials more closely resemble naturally occurring ones (e.g., by varying chemical compositions, following different heat curves, generating heterogeneity in porcelain or concrete). The most basic reductive approach for making standardized blanks would be knapping by hand to shape the material until it more or less fits the prescribed size and shape parameters (as in, e.g., Bandini et al. 2021; Bril et al. 2010, 2015; Motes-Rodrigo et al. 2022; Nonaka et al. 2010). This will, however, result in reduced reliability. More advanced reductive techniques that can achieve greater reliability involve the use of machinery such as diamond grinders, saws, and rock tumblers (Dogandžić et al. 2020; Lin et al. 2016; Mraz et al. 2019). Automated machinery such as milling machines is even more reliable (Lin et al. 2021). Alternatively, stone can simply be used as it naturally occurs. This might still be considered standardized if erosive forces result in similar sizes and shapes or natural sorting into a substrate (e.g., river pebbles sorted by size).

When developing standardized blanks (as in the case studies we present below), we generally followed a stepwise program (Figure 1), beginning with a specific research question in mind (i.e., what technology, behavior, or related concept is the focus). The research question determines the ideal form(s) to be used in the experiment. This might consist of just rough dimensions, but in much of our work, we used standardized 3D forms, including ones designed using Blender 2.8 (Figure 2; Blender.org 2024). 3D models could then be printed out and used for the building of molds (e.g., for creating porcelain blanks). Once the first blanks are available, it is necessary to test them to determine whether they are valid for the intended experiment. For the main Case Studies, roughly 10–25 blanks were tested per material, whereas for the Further Materials, around 1–10 blanks were tested per material (due to time and resource constraints, no further testing was conducted after we settled on what would be used in the target study; Snyder et al. 2022). This includes determining whether the standardized blanks can be knapped at all (i.e., do they conchoidally fracture) and whether any and all desired target forms can be produced with the standardized blanks as a starting point (e.g., for studies on the Acheulean, can the blank be used to produce a biface). Given that our particular focus is on Early Stone Age technologies, all our raw material testing was performed with hard hammerstones, which were river cobbles from Germany (purchased at a building-material supplier; precise provenance unknown). If and when the standardization procedure is reliable and the blanks are suitably valid, then the full series of blanks can be produced, and the study can enter the experimental phase.

Stepwise instructions on how to make standardized blanks and comparisons of different techniques and materials tend to be rare or incomplete in the literature. The aim of the present article is to provide a general guide to raw material standardization for replication studies. Raw materials (and respective standardization technique) are ordered from most to least valid. It should be noted that the properties of the materials are not investigated here in the sense of materials science (we do not attempt to answer

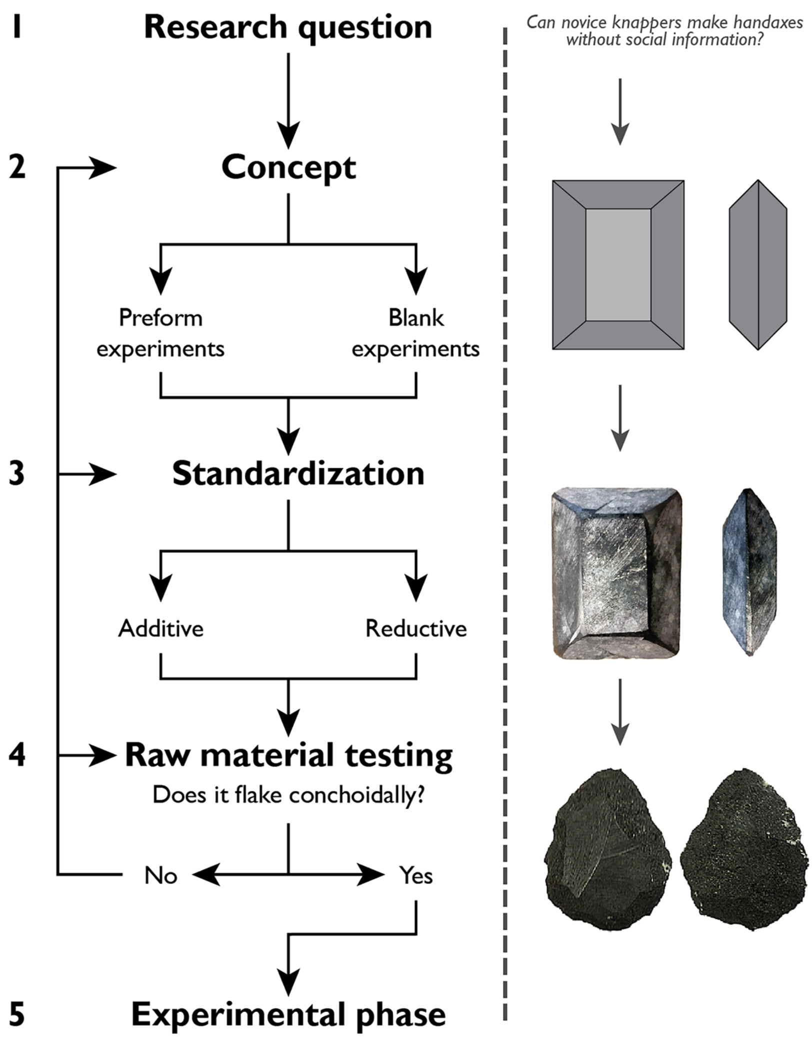

Figure 1. Stepwise program for the development of standardized blanks for knapping experiments. The concept for the knapping blank (or preform) is determined by the research question. The standardization step relates to the techniques used to make the blanks—that is, additive (such as porcelain-making) versus reductive (such as a diamond saw and grinder) techniques. The first blanks are tested to see if they produce valid, desired outcomes. Once this is verified, proper experimentation can begin. On the right is one application of this stepwise program to make blanks for Acheulean bifaces (see Machine-Cut Basalt section).

deeper geological or mineralogical questions about materials); instead, this resource presents their *relative* qualities, suitability, and logistical viability for replication studies targeting questions of behavior and cognition.

Ultimately, the presented options represent mainly what is available to use currently, but future developments in materials science and manufacturing technologies, along with the reduction in costs of relatively inaccessible materials and machinery, will allow for new—and potentially even more valid and reliable—means of creating standardized knapping blanks.

Case Studies

Hand-Knapped Flint

Flints and cherts have been used extensively throughout human prehistory, representing a primary component of European Middle and Upper Paleolithic assemblages (e.g., Schürch et al. 2022), even used scarcely during the Oldowan (e.g., at Bed II, Olduvai Gorge; Hay 1976). Largely owing to their

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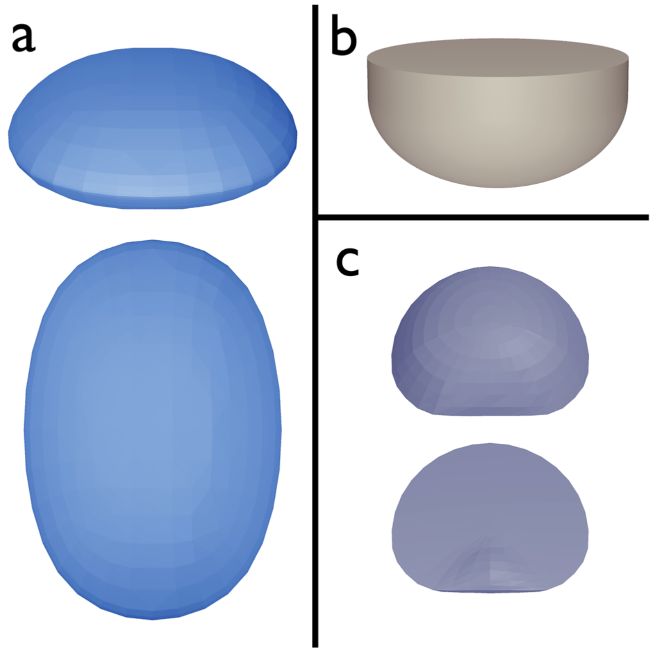

Figure 2. A selection of idealized 3D blank forms designed in Blender 2.8, including (a) an "elongated pebble" blank, (b) a "split pebble" blank, and (c) a "large flake" blank. These blank forms were designed with Early Stone Age / Lower Paleolithic toolmaking in mind.

widespread abundance across the globe (Keller 1981; Schmid 1986) and their sharp, resistant edges that can, in our personal experience, be worked with greater overall ease than other materials (such as basalts; Luedtke 1992), flints and cherts have been a staple of experimental archaeology since its very origins (e.g., Gala et al. 2023; Johnson 1978).

Although flint is ubiquitous, the quality of flint can vary massively from source to source and nodule to nodule (Oakley 1939). Due to the nature of its petrogenesis, flint can be susceptible to irregularities such as inclusions of nonsilicified material, encrustations, or cleft areas, which can all heavily affect the properties of flaking. Where good- to high-quality knapping material is required, it is necessary to identify consistent sources of flints or cherts. In our case, flints and cherts can be found across Germany (Schürch et al. 2022), including our general region in Baden-Württemberg, southwestern Germany, but we judged the local sources to be too inconsistent in quality and low in quantity for efficient material collection.

For our preparations, we identified and tested flints from two sources: pebbled nodules from Heidkate Beach near Kiel, Germany (on the Baltic coastline of northeastern Germany; hereafter, Baltic flint), and nodules quarried from chalk deposits in Norfolk, East Anglia, UK (Figure 3; hereafter, Norfolk flint).

Case Study: Baltic Flint

The Baltic flint was collected by one of the authors (Boysen) directly at the sedimentary deposits. At Heidkate Beach, the flint nodules are found among other rock-forming minerals.[2] Due to constant erosion by the Baltic Sea, the nodules are entirely rounded and occur in irregular round/oval shapes and in varying sizes, essentially pre-/semi-standardized (Morgan et al. 2014) and sorted. In the surveyed area, the flint nodules were fairly abundant, with about 10 nodules that were visually identified by Boysen, and easy to access (within 15 minutes of strolling at the beach). In terms of quality, the Baltic flint is characterized by good conchoidal fracturing, which generates flakes with long-lasting sharp edges. The rounded outer surface and relatively thick encrustations that form the cortex, however, were a major barrier to initial fracturing, so the nodules required additional force relative to nonencrusted flint nodules to be broken open.

In this case, small amounts for private use were legal to collect. Laws and regulations regarding geological and archaeological heritage in the respective countries and localities should be considered

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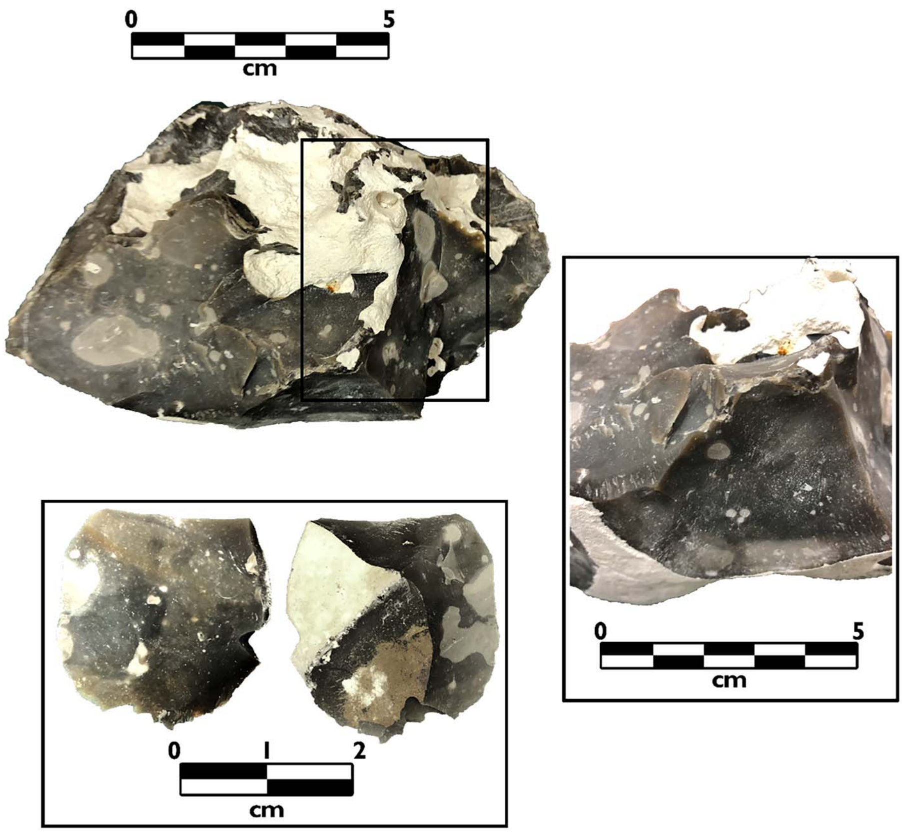

Figure 3. Flint from Norfolk, East Anglia, UK, that has been excavated from coastal chalk deposits: (*top left*) the full nodule; (*right*) a flake scar; (*bottom left*) dorsal and ventral perspectives of a flake.

before collecting naturally occurring materials. Local authorities should be informed, and the relevant permissions should be attained beforehand to prevent infraction of legal frameworks and especially to prevent endangerment of natural ecospaces and archaeological heritage. This may involve limitations on the quantity of permitted material collection, presenting a practical and logistical problem for large-scale studies.

Case Study: Norfolk Flint

The Norfolk flint (Figure 3) was imported via a stone distributor. The costs of the flint itself were low; here, the main drawbacks involve the monetary and time costs related to transportation. The Norfolk flint exists in a variety of shapes and sizes as well as quality, and it is generally at least partially encased in chalk. In its raw form, the Norfolk flint is easier to knap, with the chalky surfaces being soft and nonobstructive and the exposed flint providing more workable knapping platforms (i.e., surfaces with suitable angles for inducing conchoidal fracture). For studies on the knapping abilities of nonhuman great apes (Bandini et al. 2021; Motes-Rodrigo et al. 2022) and pre-study pilot experiments with modern humans (Snyder et al. 2022), flake blanks were prepared by simply knapping flint nodules with a hammerstone (e.g., a roughly oval river cobble). For the purpose of the pre-study pilot experiment, the knapper (Boysen) worked the flint until it was approximately the specifications required by the study.[3] Given the quality and internal dynamics of the raw material, knapping platforms could not be purely standardized for their knapper-appraised ease of flaking (hereafter, knappability). Knapping by hand involves an investment of both time and labor on the part of the experienced knapper. In addition, the tendency of flint to vary in quality due to inclusions and processes of weathering and exposure (Oakley 1939) means that not all nodules can be "molded" into suitable experimental

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blanks to distribute to subjects. Therefore, this method of standardization is neither efficient nor reliable, despite the validity of flints and cherts.

Machine-Cut Basalt

Basalt is an igneous rock that has been used to produce stone tools at many archaeological sites. Indeed, basalt was extensively used during the Oldowan of East Africa (e.g., Braun et al. 2009, 2019; Stout et al. 2005). The quality and knappability of basalts, as with other volcanic rocks, relates mainly to the size of grains, resulting from, for example, differences in the crystallization of minerals during the cooling of lava flows (Braun et al. 2009; Militky and Kovacic 1996; Stout et al. 2005). Fine-grained basalts are generally easier to work, whereas coarse-grained basalts are less suited for controlled flaking (Braun et al. 2009). However, as with other natural stone materials, basalt can vary within a single volume in terms of its density, homogeneity, and structural integrity (Farmer 2005; Klein and Langmuir 1989).

Basalt blocks (attributed to a source in Czechia) were purchased from a local wholesaler of construction materials (Natursteinpark Rongen) and had already been preshaped into rectangular prisms. Relative to other raw materials, the basalt, in this form, was extremely cost effective and easy to acquire.

Case Study

The following protocol is very dangerous and should only be executed after the appropriate training and if following the appropriate and necessary safety procedures (at best, inexperienced persons should be supervised when using heavy machinery). If one pursues this avenue (as with any other protocol), it is important to inform oneself and comply with any guidelines, standards, or requirements of the housing institution or laboratory. Purchasing this equipment is not advised, except by well-informed and experienced parties—and again, in compliance with any local or institutional safety guidelines.

We selected bricks with the approximate dimensions of $25 \times 10 \times 10$ cm, which we deemed the best starting point in terms of yield, weight, and workability. To produce semistandardized forms (envisioned as an elongated pebble but adapted into a polyhedron due to the machinery's limitations; Figure 4), the following series of steps (Figure 5) was applied by Boysen:

(1) Estimation of the most regular face and further flattening with a diamond band grinder, designed and usually used for glass manufacturing (Glaskant-S, Knopp Maschinen GmbH)

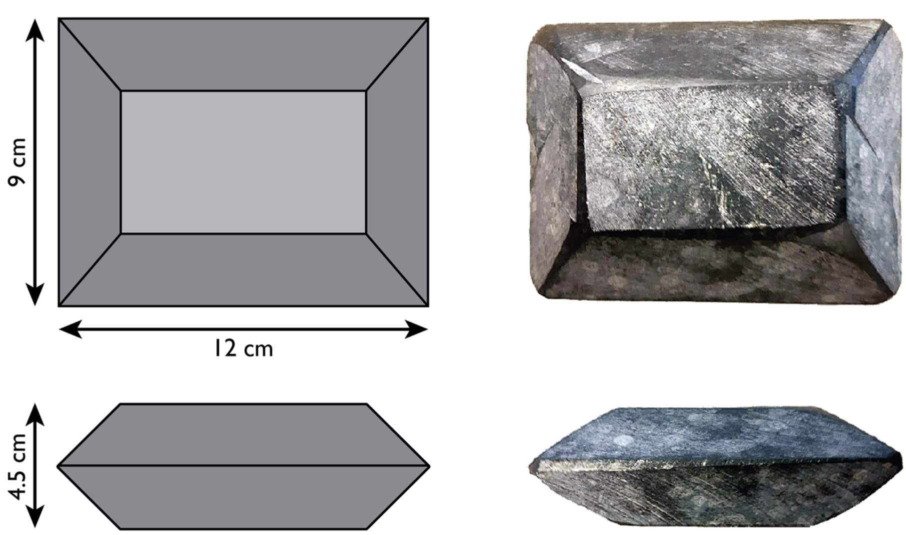

Figure 4. Schematized and actual polyhedral basalt blank made using a diamond saw and grinder.

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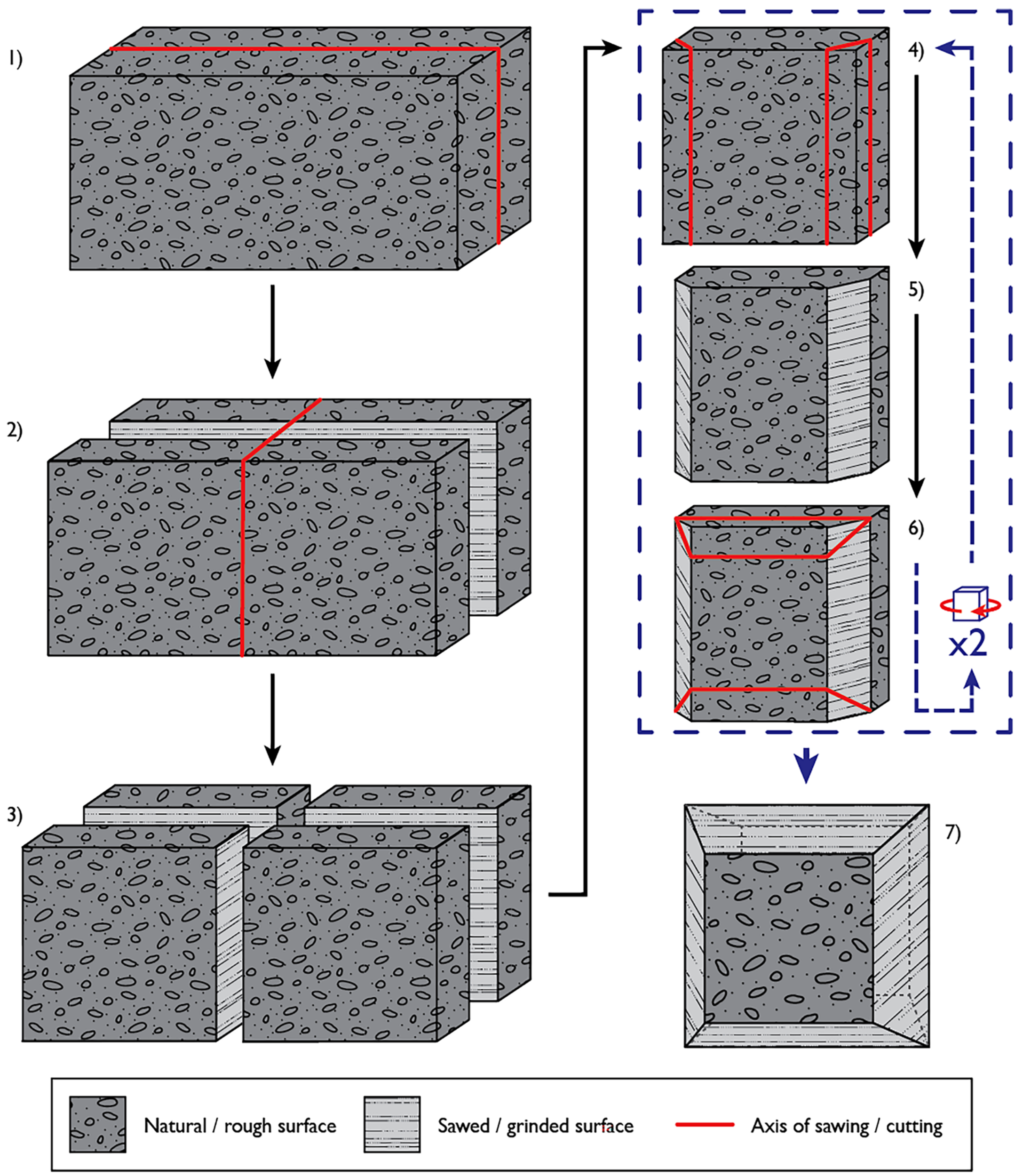

Figure 5. Visualization for protocol used to created standardized basalt blanks (which would also apply to other types of stones).

(2) Cutting the brick in half along the longitudinal axis with the use of a diamond blade saw, designed and usually used for glass manufacturing (Sägboy-I by Knopp Maschinen GmbH; saw blade made of a steel-copper alloy and coated in diamond dust)
(3) Alignment along the created flat surfaces (~25 × 10 × 5 cm) to saw and grind the irregular, lateral surfaces, resulting in a semiregular cuboid
(4) Sawing into two halves (each ~12.5 × 10 × 5 cm) of the cuboidal form
(5) Fixation of the cuboids into a wooden frame, angled at 45°, and sawing of the angled blank to create a 45° edge around the corners and up to the medial axis of the 5 cm lateral surface (done to all sides and from both surfaces)

(6) Fine finishing of the object by grinding the rough edges and rounding the corners into a more regular shape, as in the example form with dimensions of $12 \times 9 \times 4.5$ cm (deviations from these dimensions resulting from the thickness of the saw blade and the material lost while grinding)

Security precautions were an essential element; Boysen constantly wore personal protective equipment—such as safety glasses, gloves, ear protection, and an apron—while sawing and grinding the basalt (or other material). Due to the constant water flow of the blades' cooling and dust-bending system, he also wore closed-toed shoes with good traction to prevent slipping and to be equipped in the event of a need for quick reactions. Importantly, the machinery was housed in a separate, enclosed room with tiled flooring. In the process of cutting basalt, different types of grinding bands and sawblades were tested and even partially destroyed. In some cases, especially when halving the blocks, the saw was likely to become tense and get stuck due to the heating and slight expansion of the saw blade, in combination with momentum and vibration caused by the motor and sawing movement itself. The best results were achieved when moving the sledge (upon which the material is placed) slowly and allowing the saw to "find its way" through the material in a gentle, guiding fashion. Using this technique, the saw required between two and four minutes for a single cut. If tension (see above) built up while cutting near the edges of the mass, the material sometimes broke apart and was ejected outward like a projectile.

Key Takeaways

Even with preshaped knapping platforms as generated by our sawing and grinding protocol, basalt is still very strong and therefore requires more force from the knapper to produce suitable flaking outcomes (Figure 6) relative to, for example, flints. When one knaps basalt with larger grains, the resulting flakes can have somewhat jagged edges (rather than the smoother cutting edges of finer-grained basalts, flints, and cherts). Nonetheless, knapping basalt results in usable cutting edges for real and simulated extractive foraging tasks.

To determine whether it was safe to give these standardized basalt blanks to novices for the main experiment (Snyder et al. 2022), we performed pilot tests with novice individuals (i.e., archaeologists and primatologists with little to no hands-on knapping experience). This reaffirmed our prior observation that basalt is relatively challenging to flake. We deem that this coarse-grained basalt is not an ideal material for teaching or experimental contexts involving novice toolmakers (unless necessary for external validity, or when testing the mastery of difficult-to-knap materials).

Figure 6. A "handaxe" produced by knapping one of the machine-cut basalt blanks, demonstrating the validity of the blanks for experiments related to Acheulean toolmaking.

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The described standardization protocol of shaping basalt by sawing is more widely applicable to other naturally occurring stone materials (such as flint), as well as to glass. However, the ease of standardization, efficiency of the process, and safety protocols need to be attuned according to the differing characteristics of the material. Here, we describe mainly the process for basalt, although glass was also shaped by Boysen using roughly the same protocol.

Manufactured Glass

Volcanic glass—namely, obsidian—has been extensively used by prehistoric knappers, and it was exploited early on in the Acheulean in Ethiopia (Mussi et al. 2023) and in the Lower and Middle Paleolithic of the Armenian Highlands (Adler et al. 2014; Frahm et al. 2020). Due to its model properties of conchoidal fracture, glass has been an important and reliable material for controlled knapping experiments. Using soda-lime glass, experimenters have previously been able to control for extraneous variables in order to study what determines the characteristics of flakes (Li et al. 2022). Glass is also especially suited for replication studies due to the reproducibility of same-sized and -shaped glass blanks (Dogandžić et al. 2020; Li et al. 2022).

Standardization Options

Premade glass forms can be purchased from online retailers and glass manufacturers (Figure 7). These glass forms can be either clear or colored with additives, which does not affect their fracturing properties. Glass forms can also be made to order (Dogandžić et al. 2020). We had contact with multiple companies offering this service, but an order of glass blanks based on a 3D model of our own design (an elongated pebble form) did not come to fruition. The process of molding solid glass from scratch requires high temperatures and can be extremely volatile, and in our case, it resulted in the mold breaking apart. Other manufacturers did not have the capacity to produce the forms we required (e.g., completely solid without any hollow space; molds large and stable enough to produce the required volume). Therefore, it is important to ensure beforehand that the manufacturers possess the infrastructure necessary to create the commissioned blanks.

An alternative is self-made glass blanks, which can conceivably be created at lower temperatures by melting together recycled glass pieces, though this does not allow for the same control over material quality and homogeneity as with freshly formed glass at higher temperatures (based on knapping of recycled glass by author Snyder). As with premade glass, it can be colored with additives.

Although we did not work with natural volcanic glass in our efforts, previous documentation exists for its standardizability. Sheets and Muto (1972) used a machining method not unlike the one we applied above (see Basalt section) to create blanks for blade-making. We also used the method described above to generate aesthetically similar standardized blanks from colored glass bricks (rectangular prisms, $\sim 10 \times 10 \times 3$ cm). Coloring of the glass creates at least a superficial resemblance to naturally occurring volcanic glasses (our samples were actually not black, but a deep purple). Additional grinding of the glass surface can be used to produce a rougher cortex not dissimilar to what can be found on volcanic glasses.

Our Final Study

Ultimately, we ordered a large series of clear glass hemispheric paperweights (Figure 7b; diameter: 10 cm; height: 4 cm) to be used mainly as "split cobble" blanks for least-effort flaking experiments (Snyder et al. 2022). These glass hemispheres were spray painted to generate a "pseudo" cortex. Only a thin paint layer was required to cover and adhere to the glass, and this was applied in two spray sittings for full coverage; the round side was sprayed first and allowed to dry for a few hours (or as needed, depending on environmental temperature and humidity), and then the flat side was sprayed and left to dry again. A fraction of the half-spheres required repainting due to chipping or scratching of the paint, but otherwise, the process was relatively seamless. The creation of the cortex on glass, whether via grinding or painting, has multiple benefits, given that it (1) can create a more naturalistic appearance, (2) hides the fact that it is glass (temporarily, at least), and (3) facilitates attribute analysis and refitting of artifacts post hoc. Still, reflectivity of glass, clear or colored, can be

Figure 7. Manufactured glass hemispheres, including “black” glass and (a) spray-painted clear glass and (b) hemispheres and flakes made from each (*center left and center right*).

problematic for imaging and analysis. Furthermore, platforms and edges are crushed very easily by novice knappers, resulting in blunt edges or unusable cores.

Key Takeaways

As expected, and in all cases, the glass was extremely easy—and consistent—to flake, resulting in bountiful sharp and acute cutting edges. We deemed that the layer of spray paint did not impact the knappability of the glass surface.

Porcelain Slip and Porcelain Body

The history of ceramics being used in flint-knapping experiments dates back several decades ostensibly (Johnson 1978). Recently, increased attention has been paid to porcelain as an alternative to stone that can be easily standardized for replication studies (Khreisheh et al. 2013; Ranhorn 2017; Speer 2018; Stade 2017; for projectile points, Neill et al. 2022). Furthermore, ethnographic records from the early twentieth century indicate that Indigenous Australian knappers used porcelain

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telegraph insulators as an alternative to naturally available chert (Balfour 1903; Cotterell 2010; Spencer 1928).

Powdered clay (in white) and moldable porcelain (in white and black) were ordered from an online ceramics distributor and then processed internally by Snyder to create standardized forms. Material costs for porcelain production were relatively low, given that reasonably priced porcelain clays and bodies, plaster of paris for molding, and basic mixing tools and containers were fairly accessible. We also pursued the option of 3D-printed ceramics, but this avenue was abandoned because individual blanks would be extremely costly (>$100 USD per blank) and would need to be hollow, and the firing temperature was well below that required for the correct material properties (800°C; see Discussion section).

Case Study: Porcelain Slip

We selected porcelain (Figure 8) that could be heated in the range (Cone 6) achieved previously by other researchers (Khreisheh et al. 2013; Ranhorn 2017; Speer 2018; Stade 2017). For early trials, we used porcelain clays that required the addition of water to form a slip (Figure 9). Mixing of the clay powder into the water (one part water to two or three parts powder) for the formation of the slip lasted approximately one hour, after which the slip was allowed to mature for one to two days. The slip was then poured into the predetermined plaster mold (i.e., with forms based on cereal

Figure 8. Some porcelain objects created during these case studies, including (a) black porcelain flakes and exploded blanks and (b) "breakfast bowl" blanks made with white porcelain slip.

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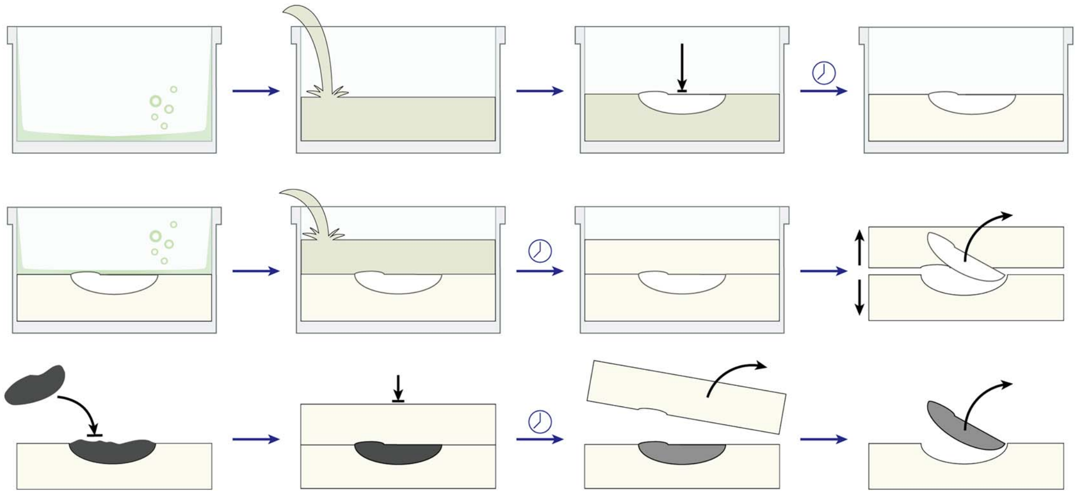

Figure 9. General procedure (as described in the main text) for production of porcelain blanks (before firing).

bowls and 3D-printed cores used in experiments, as in Li et al. 2022) until the slip was slightly overflowing. At this point, the porcelain slip was allowed to sit, during which time there was a loss of volume. Volume loss is related to the shape and the size of the desired form, due to the relationship between water loss, water retention, and surface area (see Khreisheh et al. 2013). In the case of a single-piece mold and slip-form clays, the drying of the slip results in lipping on the upper edges, which can be avoided by modification to the mold design or removal of lipped portion with, for example, piano wire.

Figure 10. Unfired porcelain blanks.

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Case Study: Porcelain Body

Solid porcelain bodies can be used instead of slip. The porcelain body only needs to be pressed into the plaster mold and allowed to solidify at room temperature (Figures 9 and 10), therefore not resulting in the same extreme volume loss. The pressing of the porcelain body, however, has the disadvantage that internal fissures can form, potentially causing pieces to explode in the firing phase. Again, this might be avoided by using more material than necessary when pressing. The excess porcelain body can then be removed with a tool or wiring; just by happenstance, we discovered that removing excess body with gardening wire can create impressions in the porcelain that mimic the ripples on natural flakes (Figure 13).

After at least two days of settling, the porcelain blanks were fired in a kiln. If the blanks are not allowed to settle for enough time before firing, then water molecules will not have fully escaped, and the blanks might either explode in the kiln or simply develop fissures and air pockets that reduce knapping quality. The same may be true if the blanks contain any fissures that form during the process of pressing them into form (as with porcelain bodies) or if the blanks are heated for too long (e.g., one batch of porcelain exploded after being kept in the kiln for approximately 48 hours, because overnight ambient temperatures were too high to allow for safe removal). The pieces of porcelain were heated to a maximum heat of 1,240°C (with distinct heating curves for porcelain slip versus porcelain body; Figure 11) and then left to cool overnight. The heating curves were determined to be effective for reliably producing blanks with excellent knapping qualities. The firing method for porcelain slip is also more expedient than previously reported methods (cf. Page 2014), whereas samples of porcelain body require more prolonged heating to prevent fracturing of the material (Figures 8 and 12). As

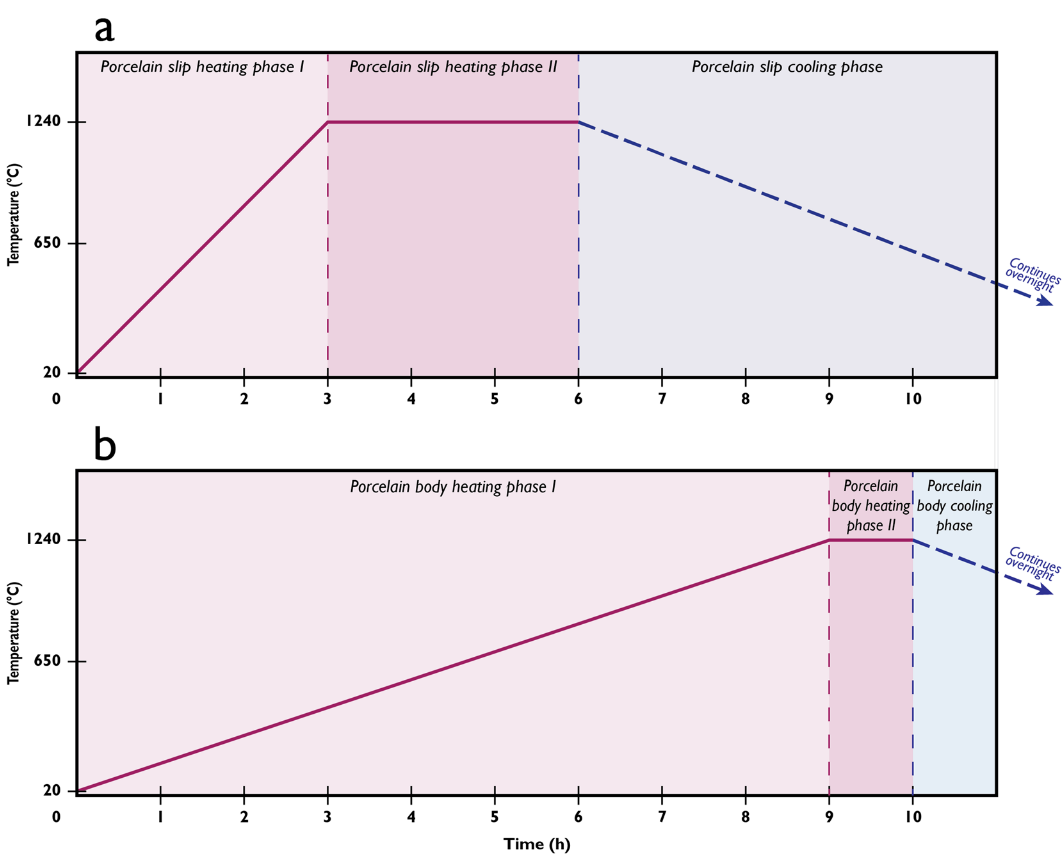

Figure 11. Heating curves for the firing of porcelain blanks, including the curve used for (a) white porcelain slip and (b) black porcelain body.

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Figure 12. Fragments of exploded porcelain blanks showing "pot-lids" (Abdolahzadeh et al. 2023), as can be found on naturally occurring geofacts.

noted previously (Khreisheh et al. 2013; Page 2014), we observed conspicuous volume loss due to firing.

Key Takeaways

Although porcelain blanks are highly standardized, the process required to produce them was inefficient. Given enough molds and clay, the blanks can be produced in large quantities, but this still requires relatively lengthy periods for mold creation, slip formation, drying, and heating. The largest bottleneck in the production process is at the firing stage. Space inside the kiln determines how many blanks can be fired at once without major quality differences between blanks. There is no guarantee that the blanks will have the required properties in the end, given that errors due to drying or firing

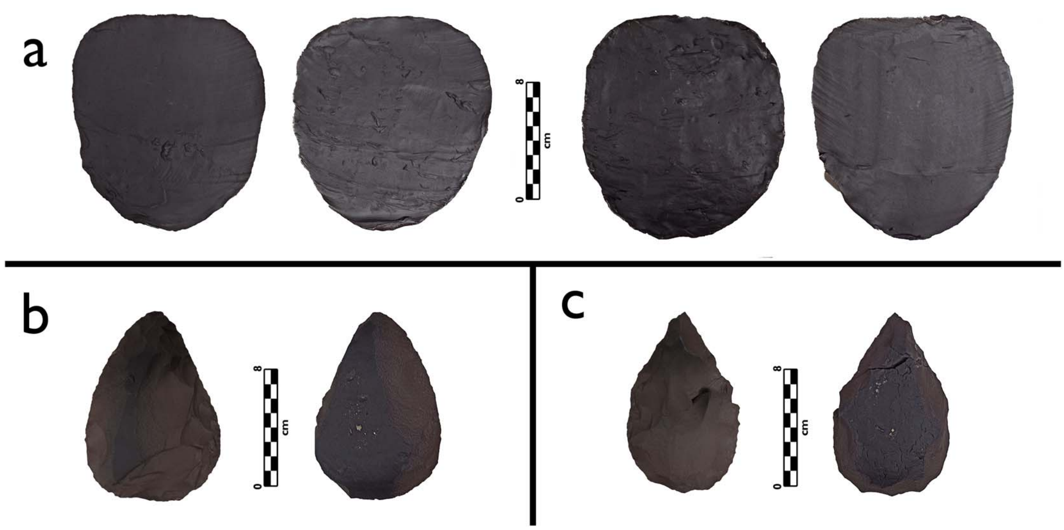

Figure 13. (a) Four fired black porcelain blanks in the form of large flakes with the (b, c) ventral and dorsal view of two said blanks knapped into simple bifaces..

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may not be immediately apparent. The likelihood of low-quality blanks lowers, however, with practice and greater adherence to a careful and meticulous protocol. All steps require attentiveness and intensive labor investment.

Porcelain produces fracturing patterns (conchoidal) that are similar to natural materials, and it has a high ease of flaking—on par with flints—with very little dust and small shatter (see also Khreisheh et al. 2013). The resulting flakes are sharp and usable. Porcelain cores are lighter than stone or glass cores of similar size, making them safer and more accessible for novice knappers. Visually, standard white porcelains can be very similar in hue to light-colored cherts; it is also possible to color porcelain or buy it precolored. The black-colored porcelain body superficially looks like volcanic materials (such as basalt) after firing (Figures 8, 12, and 13). We also observed that the outer layer of porcelain becomes molten, essentially creating a cortex (Figure 13). When heated longer, not only do the blanks have a lower likelihood of exploding, but the resultant cores also knap more like, for example, a fine-grained basalt than a higher-quality flint, as with the fast-heated white porcelain slip.

Further Materials

We also performed smaller-scaled trials of other materials (Figure 14), with and without explicit standardization protocols.

Sandstone

As with the basalt, naturally occurring sandstone (Figure 14a) broken into slabs or cut into rectangular prisms were purchased from a local construction wholesaler (TOOM Baumarkt, Germany). Sandstone was utilized for tool production in the Paleolithic (e.g., Hernández et al. 2012; Kuman et al. 2005; McNabb et al. 2004), but for our purposes, we determined it to be too difficult to fracture for human novices. 3D-printed "sandstone" was also tested. Two samples were ordered from an online 3D-printing retailer (Shapeways, New York City), but they were not found to conchoidally fracture[5] in the desired manner (the samples simply snapped when struck), were too small (limitation of a rather novel technology), and were too expensive relative to the volume. Therefore, it was not possible to produce material in either the right blank size or quantity needed for experimentation.

Brick

In addition to sandstone, we also tested the properties of mass-produced construction materials. Masonry bricks (Figure 14b) are one human-made material with an established usage in archaeological experiments (Geribàs et al. 2010; Lombao et al. 2017). Bricks have been described as having the "same mechanical properties (conchoidal fracture)" as natural stone while being homogenous, standardizable, and safe for novice knappers to use (Geribàs et al. 2010:2858). Bricks were purchased from a local hardware store (TOOM Baumarkt, Germany) and selected based on the maximum available continuous volume that could be exploited. Bricks that have cavities or slots are problematic, given that these predetermine and limit the breakage. They are advantageous because they are cheap and can be purchased in an already standardized format. Their ubiquity further means that an enormous variety is available for selection. Bricks are still quite hard and their shapes typically do not allow for good knapping platforms (although shapes with better exterior angles could be made to order). Therefore, controlled flaking of bricks is not particularly easy. Bricks are also often stored outdoors, which can reduce the quality of the material.

Concrete

Not unlike bricks, concrete (Figure 14c) is another human-made raw material with flaking potential. Here, we tested mainly case-burned limestone, a simple mixture of burned limestone with plaster and other elements in varied ratios. Given its abundance and cost-effectiveness, we also tested concrete for its appropriateness for knapping experiments, finding evidence of conchoidal fracture and production of effective cutting edges. Like the bricks, concrete was purchased from a construction supplier (TOOM Baumarkt, Germany). We purchased concretes with varying compositions to assess a range of possibilities. In every case, these concretes performed fairly similarly in terms of knappability.

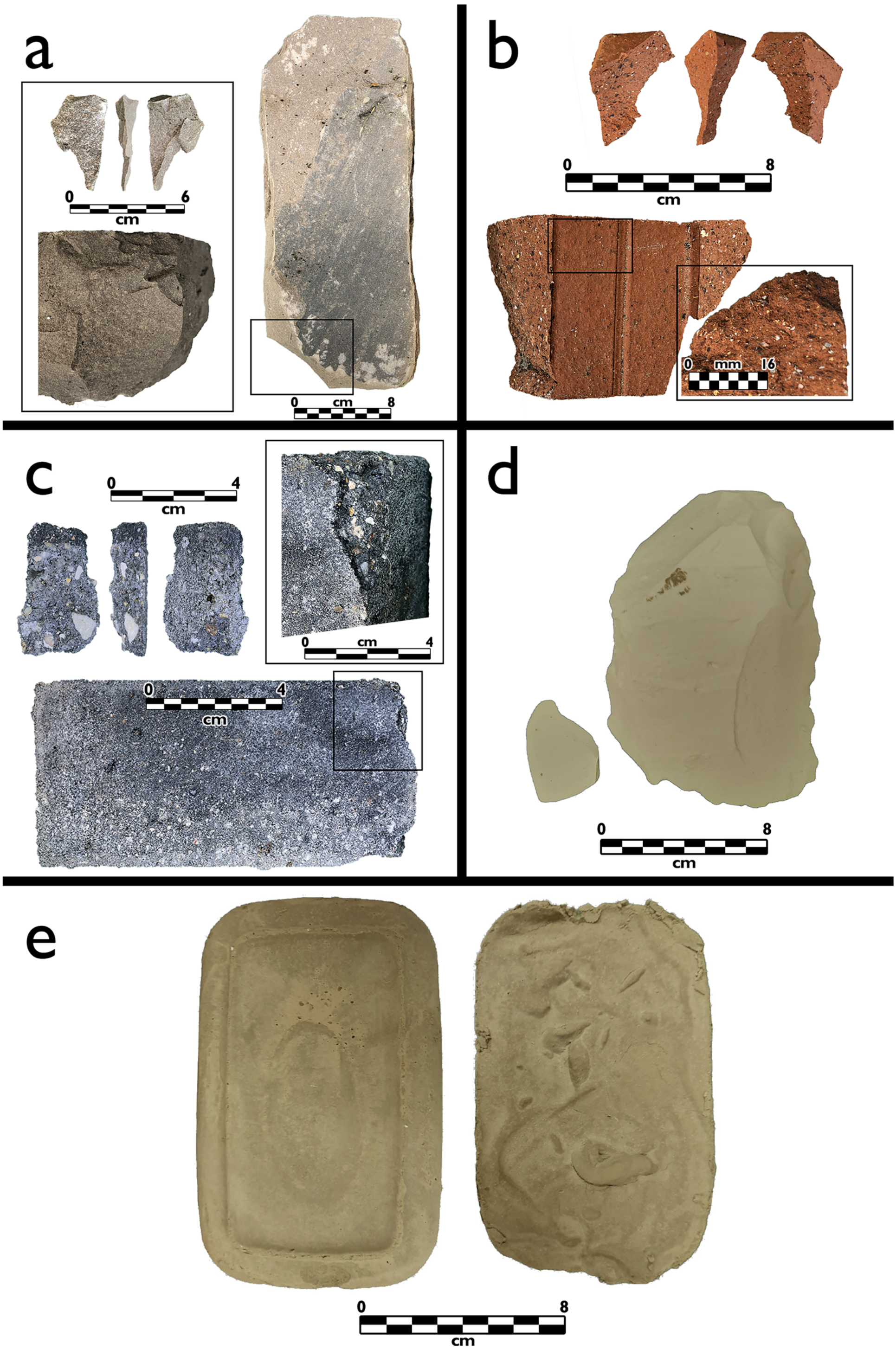

Figure 14. A selection of other tested materials including (a) sandstone, (b) brick, (c) concrete, (d) plaster of paris, and (e) hobby concrete.

Although the concrete was already premade in simple rectangular prisms for our short trials, the usual process of concrete production means that it can be made into many potential desired forms, especially those with better knapping platforms.

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Plaster of Paris

Plaster of paris (Figure 14d), or gypsum plaster, is traditionally used in construction or decoration—or in the case of the porcelain-making, molding. As with porcelain slips and bodies, plaster of paris in its powdered form was purchased from an online ceramics supplier (KERAMIK-KRAFT). The powder was mixed with water (a ratio of two parts powder to one part water), a desired form (e.g., 3D print) was fixed to the bottom of a container, and then the liquid plaster mixture was poured into the container until the positive was sufficiently covered. After a few hours of drying, plaster is usually cold and solid to the touch, indicating that the mold is finished and can be removed from the frame. Opportunistically, we knapped failed, disused plaster molds. When struck with a hard hammer, the plaster fractured conchoidally, resulting in flakes that were not sharp or stable; therefore, they were not usable cutting tools. Plaster may still be useful for educational purposes, for example (see Clarkson 2017; Shea 2015), because it is easy to make and readily standardized.

Nonconchoidally Fracturing Materials

In addition to the preceding materials, we tested two more that did not fracture conchoidally, therefore failing our minimal validity requirement. The first was a craft concrete (Figure 14e; containing Portland cement) that, when mixed with water, can be hand-kneaded or pressed into a mold and air-dried. Although the craft concrete fractured when struck with a hammer, it contained filamentous structures that hindered the fracturing and, especially, the detachment of flakes. The detachments intermittently resemble conchoidal flakes but lack usable cutting edges. Thicker forms fractured better than thinner ones. Craft concrete is inappropriate for actual knapping studies but may be functional for educational purposes (e.g., for public outreach, at schools; see Clarkson 2017; Shea 2015).

Acrylic resin was also briefly tested, given that it can be filled into a mold and that it dries at room temperature without additional steps. The resin was found to be too hard and therefore unsuitable for knapping. It is not a valid raw material in any context.

Discussion

General Overview of Materials

Above, we presented the results of various standardization attempts and raw material tests performed over a multimonth period. This procedure inspired us to report our findings and observations so that those interested in the possibilities of raw material standardization would have access to replicable protocols and basic comparisons between potential techniques (see Table 1).

Validity

Experimental blanks must be made externally valid to some degree (minimally sufficient for a study's design). External validity is the justification for generalizing beyond the context of the study—for example, via analogy between experimental processes and archaeological processes (Eren et al. 2016; Lycett and Eren 2013; Mesoudi 2011). Validity is optimized when the experiment uses *the same raw materials*, in the same forms, that were available to the original toolmakers. The next degree of validity involves material *from the same categories* as those naturally occurring stones, minerals, and glasses that were utilized in prehistory. At a minimum—and as we present here—materials should be knappable to be valid, even if these materials may not have been available to the respective hominins. We therefore exclude nonknappable materials (e.g., Styrofoam or Plasticine, as in Lycett et al. 2015; Schillinger et al. 2014; potatoes, as in Clarkson 2017; or acrylic resin, as described above) given that they require distinct action patterns to be modified and also lack ecological validity (i.e., producibility of sharp edges for extractive foraging; Toth 1985; Wynn and McGrew 1989).

Valid materials (i.e., those that fracture conchoidally) vary in their knappability (as in "ease of working," e.g., Khreisheh et al. 2013). The way we have discussed knappability is not so much in materials science terms (cf. Tsirk 2014), based on quantitative measures of *just* the physical properties, but rather in a more subjective, experiential sense (e.g., the amount of force a knapper feels they need to apply, the ease of finding workable platforms, the consistency with which a knapper can produce flakes). From this perspective, knappability should measure the *interaction* between the properties

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Table 1. General Overview of All Materials Tested.

Material	Archaeologically Valid?	Knappable?	Reliability	Notes
Basalt	Yes	Yes	• Low when knapping by hand or using a rock tumbler • Medium when using a saw and grinder	• Cheap • High labor costs • Safety concerns
Flints	Yes	Yes	• Low when knapping by hand or using a rock tumbler • Medium when using a saw and grinder	• Cheap • High labor costs • Potentially high transportation costs • Near-universal standard for knapping experiments
Sandstone	Yes	Yes	• Low when knapping by hand or using a rock tumbler • Medium when using a saw and grinder	• Cheap • High labor costs • Safety concerns
Glass	Yes	Yes	• Medium when using a saw and grinder • High when self- or premanufactured	• Easily accessible • Can be made to order • Exceptional reliability • Ideal mechanical properties
Porcelain	No (as far as early prehistory is concerned)	Yes	• High when using slip • High when using body	• Cheap • Time-consuming, inefficient production • Labor intensive • Highly reliable
Brick	No	Yes	• Low when knapping by hand or using a rock tumbler • Medium when using a saw and grinder • High when self- or premanufactured	• Cheap • Easily accessible • Good reliability • Knapping quality not as good as glass and porcelain
Concrete	No	Yes	• Low when knapping by hand or using a rock tumbler • Medium when using a saw and grinder • High when self- or premanufactured	• Cheap • Not time consuming • Reliable • Can be difficult to knap
Plaster of paris	No	Yes	• High	• Cheap • Quick, low-effort process • Reliable • Useful for demonstrations but not useful for experiments due to lack of sharp edges
Craft concrete	No	Yes	• High	• Cheap • Quick, low-effort process • Reliable • Useful for demonstrations but not useful for experiments due to lack of sharp edges

(*Continued*)

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Table 1. General Overview of All Materials Tested. (*Continued.*)

Material	Archaeologically Valid?	Knappable?	Reliability	Notes
Acrylic resin	No	No	• High	• Cheap • Quick, low-effort process • Reliable • No conchoidal fracture
3D-printed materials	No	Unclear	• High	• Expensive • Too thin or too little volume • Often hollow

Note: This table includes raw material validity and reliability of standardization techniques, as well as comments on costs and recommendations. To be archaeologically valid, a material was used by prehistoric or historical stone toolmaking groups. To be knappable, a material is shown that is capable of producing conchoidal fracture when struck with a hard hammerstone.

of the material *and* the actions and abilities of the living agent. We adopted the grading system (Table 2) first created by Whittaker (1994) and further developed by Khreisheh and colleagues (2013) as a basic frame of reference for comparing material knappability. Grading of knappability was performed by both first authors for reliability.[7] As previously reported, porcelains were similar in quality to finer flints and cherts. Plaster of paris also knaps well, but the material is chalky and not sharp. The various types of concrete we tested were fairly similar in knappability to natural raw materials such as quartzites, rhyolites, and basalts, whereas brick was closer to coarser flints. Plaster of paris and craft concrete are useful where external validity does not need to be maximized—that is, for teaching and public outreach (see Clarkson 2017; Shea 2015). For science communication and teaching or for certain novice-related research questions, one might use a more knappable material even if that might be less strictly valid. Where highly standardizable materials are preferred (see next section), it may also be possible to prioritize artificial materials that are most similar in terms of knappability to the naturally occurring materials in order to maximize the achievable external validity.

Table 2. Knappability of Raw Materials from “Most” to “Least” Knappable.

Grade	Previously Reported Materials	New Additions
0.5	“Ice, some hard candy, some cold asphalts”	
1	“Good obsidian, glass”	
1.5	“Coarse obsidian”	
2	“Heated finer flints and cherts”	
2.5	“Finest basalts and rhyolites”	
3	“Finer flints, cherts, and porcelain”	Plaster of paris, porcelain
3.5	“Most lithic materials: ordinary cherts, flints, chalcedonies, jasper, petrified wood, etc.”	Porcelain, brick, concrete
4	“Coarser cherts, finer quartzites, industrial porcelain, quartz crystal, agate, jasper, siltstone, silicious limestone”	Porcelain, concrete
4.5	“Some quartzites and rhyolites, argellite”	Porcelain, concrete
5	“Coarse quartzites, coarse rhyolites, most basalts”	Concrete

Notes: Adapted from Khreisheh et alia (2013:39; based on Whittaker 1994), with the first two columns here as presented originally. The third column includes additions based on our own observations on the “ease of working” of materials. In this case, all tests were conducted with hard hammerstones, so we do not report here on differential “effective tool limits.”

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Reliability

Another important factor in the selection of materials for knapping experiments is reliability. The relative ease, efficiency, and consistency of standardization varies widely between techniques and materials. Many factors play a role in determining just how reliable standardization protocols for a material are; therefore, many factors must be considered in the process of designing knapping experiments with standardized blanks.

Logistics is one such factor. Although some materials might otherwise be valid and reliable, it may not be feasible to use them for reasons such as limitations on transportation, labor investment (hand-based labor or individual expertise), time, and availability of equipment. Equipment and machinery are major obstacles, given that devices such as diamond saws, rock tumblers, and milling machines can be expensive and require transport and installation costs, regular upkeep, and energetic demands such as electricity. In addition, the processing of materials can be highly dangerous or require a certain degree of experience with similar machines and tools. Certain technologies are only affordable to researchers from a limited set of manufacturers, and these manufacturers may not be accessible where the researchers are.

Material quantity and quality is the next major consideration. Essentially, one must determine not only if the quality of the material is suitable and valid but if enough units of blanks can be ordered or made consistently to the necessary standard. When ordering natural stone in bulk, due to variability in quality, it is necessary to buy more material than is actually needed for final implementation in a study. Furthermore, samples should be attained and tested beforehand to ensure their suitability so that insufficient quality, impractical, or unusable material is not inadvertently stockpiled.

Another part of this equation is the steepness of learning curves for standardization techniques. In cases where someone involved is already very familiar with the technique, this problem is negligible, but if the experimenter(s) are unfamiliar with it, an adjustment period for learning the proper application of the technique is needed. This results in costs pertaining to investment of time, labor, and materials for practice. Given the wide range of factors that affect the reliability of materials and techniques (this being just a handful of examples), the trade-offs of different variables balanced against each other must be considered. Reliability is in essence that: the balance of all variables related to easy, efficient, and consistent production of standardized blanks.

Prospects

In our preparations, we were not able to exhaust all available or potential options. We considered, for example, the possibility of using a rock tumbler to generate polished—albeit not truly standardized—stone pebble blanks; gardening companies already do this in order to create (unusably small) pebble-like forms for decorative purposes. For our purposes, it would instead be intended to roughly replicate the process of erosion that produces pebble forms in rivers but in a fraction of the time. Other possibilities would include the pouring of concrete into a specified mold, the pouring of molten glass into a specified mold (with obstacles related to mold fabrication and gaining access to an oven capable of achieving the appropriate melting temperatures), and the cutting of harder materials such as basalt or granite into shape using a water jet rather than a diamond saw (we had contact with one company capable of performing this).

Automated milling machines may be the best option overall for consistent production of uniform blanks across material types. These can be programmed to cut material according to a preconceived 3D design, but individual blanks require many hours to be shaped, and the technology is not particularly affordable (Lin et al. 2021). Nevertheless, using milling machines can eliminate human-made errors in blank preparation. We were unable to acquire one, but we hope that more companies will be able to affordably produce the proprietary technology so that experimental archaeologists can make wider application of its potential.

3D printing is another avenue that we pursued. Currently, companies offer printing of objects in glass, porcelain, and sandstone, among others. Given that these are relatively new technological developments, the processes and the products are still being refined. Indeed, the process for printing porcelain, as far as we were informed, does not meet the requirements for producing knappable material.

The maximum firing temperature for 3D-printed ceramics is 1,200°C (just below the required temperature for knappable porcelain). Furthermore, a hollow inside the form is required for it to be printable, which is problematic for effective knapping. Another company provided 3D-printed sandstone, which proved too thin and porous for knapping. In addition, it was quite costly, with a single printed blank costing more than $100 USD (in 2019). Despite the current drawbacks, 3D printing could still prove to be a useful process for reliable production of standardized knapping blanks, assuming technical advancements are made and accessibility increases.

Ceramics generally provide one of the best options for achieving standardized knapping materials. Our observations already show that variation in the type of porcelain and the heating procedure can result in blanks of differing qualities, which roughly resemble different natural material types (such as chert versus fine-grained basalt). By adjusting chemical compositions and heating procedures, it should be possible to generate porcelains that mimic specific stones and minerals, thereby increasing the porcelain's ecological validity. This validity can also be improved by increasing the heterogeneity of the blanks (e.g., by intentionally introducing controlled variation within the blank or adding inclusions to mimic those found in natural stone; this could also be done with concrete). Besides increasing the external validity of the test materials, this would also allow for controlled experiments on knapping cognition where novice and expert knappers can be presented with the same exact raw material imperfections that they must then "solve" (a deeper level of control compared to preexisting investigations into the strategies knappers employ to deal with material impurities and their own knapping mistakes, e.g., Shelley 1990; Torres and Preysler 2020).

Conclusion

Controlled experimentation is an important tool for developing our understanding of the prehistoric knapping phenomenon, from the mechanics of fracture to the cognitive processes residing within the knapper (Johnson 1978; Li et al. 2022; Lombao et al. 2017; Moore and Perston 2016; Morgan et al. 2015; Pargeter et al. 2019; Putt et al. 2014; Schick and Toth 1994; Snyder et al. 2022; Toth 1985; Toth and Schick 1994). By limiting the influence of confounds, we can more readily identify those processes involved under experimental conditions and—by extension—the processes guiding the formation of archaeological assemblages that we wish to better comprehend (Eren et al. 2016; Lin et al. 2018; Whittaker 1987). One way that experimental control can be attained in archaeology is with knapping blanks that are standardized in material, size, or shape (e.g., Dogandžić et al. 2020; Khreisheh et al. 2013; Li et al. 2022; Sheets and Muto 1972; Speer 2018). Although it is not without difficulties (we tried for months before settling on a solution), raw material standardization is a worthwhile pursuit. We have summarized all raw materials and techniques we tested in preparation for our experiments, and this summary serves as a basic framework for how standardized blanks can be selected and how further techniques and materials might be imagined and developed. Emergent technologies offer new possibilities for blank standardization, but these have not reached the degree of accessibility and refinement to be currently viable (e.g., 3D printing of glass and porcelain). There is no "one-size-fits-all" solution for blank standardization. No single material or technique or blank design can meet the demands of every research question in this field. Instead, researchers must balance the various facets involved in experimentation—from the research question to the accessibility of resources, the inherent costs of materials, and production techniques. It should be ensured that the materials and techniques used are both valid and reliable to the highest feasible extent. This guide is intended to reflect this by providing information relevant to the planning of research projects for not only new and prospective experimenters but also those with more extensive research. With more exploration of currently available options and with future advancements potentially opening up new opportunities, we hope that future efforts will expand on what we have outlined here and that the expanding field of experimental archaeology will continue to improve as a discipline devoted to earnest scientific methodologies (Eren et al. 2016; Lin et al. 2018).

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Notes

1. Here, we draw a distinction between blanks and preforms. Blanks are raw materials of suitable dimensions at the beginning of or just prior to the reduction process, whereas preforms (e.g., Bisson 2001; Khreisheh et al. 2013; Shipton and Clarkson 2015) are shaped raw materials that already visually imply the final target form of the reduction process.
2. In many areas, the "wild" collection of bigger amounts of stones—in this case, flint—must be approved by local authorities, due to conservation laws of cultural and natural environments.
3. In Motes-Rodrigo et alia (2022), for example, the blanks were required to have workable edges with angles in the range between approximately 90° and 35°, whereas the weight varied between 0.8 and 1.5 kg.
4. Rock-cutting machinery such as diamond band grinders and diamond blade saws are not necessarily readily available to working experimental archaeologists. Though we do not necessarily recommend for working groups to purchase such machinery, costs are estimated to be around €5,000 for used devices and €10,000–€12,000 for new ones.
5. This does not exclude the possibility that further advances in 3D-printing technology might enable knapping of materials like this "sandstone."
6. We did not test this, but we are predicting low standardizability given the erosive qualities of natural stone.
7. Boysen has good experience replicating diverse Lower and Middle Paleolithic technologies with various types of flint (e.g., tertiary, Baltic, cherts), volcanic glass (obsidian), manufactured glass, porcelain, chalk, ice, bone, ceramic, basalt, rhyolite, granite, quartz, plaster, and limestone. Snyder has experience knapping volcanic glass (obsidian), manufactured glass, porcelain, flint, chert, basalt, and rhyolite. This includes mainly replication of Oldowan and Acheulean (i.e., handaxe) technologies.

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