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Experts Also Fail: a New Methodological Approach to Skills Analysis in Lithic Industries

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Abstract
More and more contributions to the field of lithics are taking into consideration skill levels and learning processes in prehistory, with the aim of clarifying not only how individuals acted when they produced their tools but also of addressing the processes of change or continuity in the technocultural traditions of past societies and the participation of different social groups in the collective production. For this purpose, the demarcation of realistic categories of "experts" and "novices" in knapping, as well as a determination of what attributes differentiate each one, are essential. Nowadays, knapping experiments offer a more realistic approach for a comparative study in which skill technotypes can indicate the existence of different skill levels inside a particular assemblage. Through the typologies of these experimental technical entities and their comparison with the archeological record, we can deduce the presence of particular models of social production and learning processes during the Lower and Middle Paleolithic.

Keywords Paleolithic · Learning · Skill · Technotypes · Lithic technology

Introduction

In recent years, several approaches related to anthropology, psychopedagogy, and even ethology have been introduced into studies on behavior and learning in prehistory with the aim of clarifying not only how individuals acted when they produced their tools but also of addressing the processes of change or continuity in the technocultural traditions of past societies. For this reason, learning processes understood as a vehicle of cultural

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transmission become a concept fundamental to understanding behavior in the past and particularly the processes of cultural evolution that took place in our past communities. It can be generally accepted that what we are able to do at any given point in time depends not only on our natural capacities and level of maturity but also on our level of interaction with the biological, geographical, and social environment. Along these lines, many investigations have contributed to providing new approaches in archeological studies in general and, specifically, in the study of the lithic record. For the reconstruction of reduction sequences and, consequently, for the analysis of learning processes, we will distinguish two fundamental aspects of ability: (i) the variables of a technical or motor nature and (ii) the technological or logical-cognitive variables. This differentiation between the technical and the technological, together with experimental knowledge, is fundamental for the determination of the limitations of knapping skills in archeological sites and, more broadly, for the understanding of the true meaning of their presence within the archeological record.

Open-Air Quarrying Areas in the Central Iberian Peninsula

In the center of the Iberian Peninsula, studies on human occupation throughout the Pleistocene have increased significantly thanks to a number of research projects focused on occupations associated with the terraces of the main rivers, the Jarama and the Manzanares (Panera et al. 2011, 2014; Rubio-Jara et al. 2016), as well as on the interfluvial platform, where several sites have been documented in the archeological areas of El Cañaveral, Los Ahijones, and Los Berrocales. The fieldwork carried out in these locations and in the Tagus Valley, the longest river of the Iberian Peninsula, crossing Spain from northeast to southwest and emptying into the Atlantic near Lisbon in Portugal (López-Recio et al. 2015, 2018), has yielded a large number of archeological sites in stratigraphic context. These are open-air deposits that have provided abundant and exceptional archeological material consisting mainly of flint tools and knapping residues (Fig. 1). The extremely high number of objects and lithic elements present in quarries requires a different research strategy and a methodology highly modified from that used to analyze functionally distinct occupations (Gopher and Barkai 2014).

Paleolithic populations on the plateau of the Madrid area preferred flint for tool production, without preference for whether the raw material was sourced from a more or less mobilized lithogeological context. The dozens of Acheulian and Mousterian workshop sites analyzed on the extensive platform between the Manzanares and Jarama rivers are rich in debitage and *façonnage* products (nodules tested or not, cores, discards of blanks and tools, tools at different stages of configuration, and a large number of flaking products). The final tools are exceptional and are the most propitious spaces from which to ascertain the entire assembly of technical and technological processes and the existence of a collective or individual contribution to the general tool production. Equally, in these remains can be seen the different abilities of the knappers, and these variations reflect the control, or lack of it, over specific knapping processes and the ability of the knappers to overcome the difficulties they encounter during the knapping process.

Fig. 1 View of the archeological excavation of Cantera Vieja (Los Berrocales) in Madrid (Spain)

Methodology

Inside lithic industry studies, the concept of the *chaîne opératoire*, experimental replication, and the practice of diacritical reading have contributed to the study of a large number of archeological sites and assemblages (Inizan et al. 1999). In this work, we combine these traditional methodologies with new approaches for the analysis of skills and the technical and technological limitations evident in the lithic materials from quarries and areas of substantial lithic exploitation.

Technological Analysis

In the mid-twentieth century, André Leroi-Gourhan raised the theoretical principles that would later be widely adopted in the interpretation of technique analysis in archeology. He asserted that "technique" is at the same time the gesture and the tool and that techniques were organized in a conceptual frame denominated as the reduction sequence (Pelegrin et al. 1988). At a theoretical level, the researcher and expert knapper Jacques Pelegrin (1990) proposes the technical terms of *connaissance* (knowledge) and *savoir-faire* (know-how) in lithic industry studies to distinguish the basic difference between mental understanding of production methods and the knowledge needed to engage in the actual expression of them. He considers "knowledge" to involve the objective understanding of forms and materials and "know-how" to do with the real implementation of a technical process that is based on a body of human knowledge, conscious and unconscious, gestural and intellectual, and collective and individual (Pelegrin 1990). He elsewhere argues that "the control of conchoid fracture is more a matter of understanding the rules than of motor skill" (Pelegrin 2005). Although his perspective introduced a revolutionary conception of lithic production and broke the traditional static perception of lithic tools, it still has limitations in helping us come to grips with the real complexity of tool production. One obvious limitation is that individual abilities theoretically increase the range of variation in lithic expressions.

Another is that formulas as simply imitation of standardized processes (which can be the case with pseudo-Levallois points) break the binomial by creating a "savoir-faire" without a real "connaissance."

For its part, technology is defined as the group of "technical choices adapted to the raw material depending on the knapper project" (Tixier et al. 1980; Inizan et al. 1995, 1999). This is a concept in which a preliminary reflexive process occurs prior to the configuration of the tool. Technology would thus encompass the knapper's study of the technical resources as well as the methods employed by the knapper in the lithic reduction. In this sense, studies of the lithic industry within a technological scope are aimed at restoring the technical dynamics in order to understand the real knapping sequence.

At an empirical level of analysis, the term "technology" has been used frequently in a similar sense to "technique" to refer to knapping processes (for example, unipolar technology or unipolar technique). However, the distinction is important in order to acquire not only a general understanding of the archeological record but in particular to possess a fuller picture of the knapper's imitations and abilities extant in the lithic remains. In the discussion to follow, we understand the concept of "technology" as having to do with the concatenation of technical procedures and conceptual or strategic decisions—in other words, of different techniques. For example, driving a car implies the knowledge of the operation of the clutch brake (techniques) but going to a particular place requires the knowledge of the traffic rules (technologies).

At a conceptual level, within the technological analysis various concepts are expressed by various methods (bifacial, trifacial, discoid, Levallois, SSDA, Quina, Kombewa, linear or recurrent) and modalities or ways of developing a method (unipolar, bipolar, convergent, centripetal). The methods are composed of common and other discriminatory criteria that differentiate them from one another (Boëda 1988, 1993, 1994; Geneste 1991), and the modalities manifest as variations that in many cases correspond to the qualities of the lithic raw materials used or the conceptual schemes of each method (Turq 2000; Boëda 2013).

Learning in the Past

From archeological sites, the transmission of knowledge in the production of stone tools has been studied, and many examples suggest that the production of stone tools clearly demonstrates the existence of teaching and learning procedures from the Lower Paleolithic to more recent periods of prehistory (Karlin et al. 1990; Pigeot 1991; Finlay 1997; Grimm 2000; Stapert 2007; Ferguson 2008; Högberg 2008; Shipton et al. 2009; Nonaka et al. 2010; Geribàs et al. 2010; Loshe 2011; Castañeda 2018; Assaf 2019).

This is particularly evident in the strategies of knowledge transmission, which may be related to the distinction between tight and loose societies (Gelfand et al. 2011). Tight societies have strict norms and low tolerance for conduct that deviates from those norms, while loose societies have weak norms and greater tolerance for alternative conduct. These differences can be recognized in all areas of behavior, but they are especially evident in the intergenerational transmission of knowledge. In tight societies, learning tends to be organized in a strict and socially controlled manner, while in loose societies it is usually less organized around shared social norms. This distinction is also expressed in terms of technological investment. Tight societies are characterized by a high investment in the transmission of knowledge, while loose societies invest less time and energy in learning. In addition, this is related to the degree of investment in technology as a whole, from the provisioning and use of resources to the disposal of waste—that is, to technological complexity.

Thus, different models of cultural transmission could have operated in past societies, and one of our main challenges studying lithics is to deduce which one occurred if multiple kinds of knowledge transmission may have existed from one region or human group to the next. We need a realistic approach to building up ancient behaviors, one that, even if it fails to yield a completely actualistic perspective, provides a more humanistic perception of the past. Whatever the approach we take or the abilities of past tool-makers, individuals are not born knowing how to knap.

However, identification of skill levels in the archeological record is not an easy task (Eren et al. 2011a; Eren and Bebber 2018). The existence of errors in the archeological record and in the output of present-day expert knappers indicates a wide variability and raises subsequent problems of recognizing them in the archeological record. At the same time, technical aspects such as trajectory direction, energy applied, adjustment, or even organization of negatives, among many others, introduce a higher level of variability in the knapping result. Nonetheless, standardized work and the ability to solve problems are key diagnostic markers in expert distinction.

Many factors have been studied and analyzed as indicators of the differences present in expert and unskilled knappers, such as raw material, symmetries on core surfaces and products, material consumption, and errors in flake production (Eren et al. 2011b, 2014), and even other social and cultural processes (Lycett et al. 2016). In any case, our contribution also tries to highlight how to discern the presence of experts through the variability in their lithic production, and particularly through the presence of certain lithic technotypes that display a competent engagement with errors and solutions during the reduction process.

For example, in our study, the comparison between experts and highly skilled apprentices is not as important as the identification of mistakes and solutions generated by expert knappers during the shaping process as a driver of the potential recognition of the learning process in particular contexts.

Experimental Archeology and Lithic Technology Recognition

Until recently, the technical ability of knappers was not considered in the analysis of lithic assemblages. If today we accept that in the same time and context different stages of skills can co-exist at the group or individual level, one of the most interesting aspects to be analyzed is the degree of variability present in our collections and in which situations they occur.

Experimental lithic reproduction has been an essential tool in the study of prehistoric technology (Amick et al. 1989; Pelegrin 1990). It has served to demonstrate the real variability of end products bearing similar morphologies and, consequently, has helped design a technological analytical system for the interpretation of the variations' significance in the lithic record (Boëda 1994). In this literalistic spirit, we intend to provide a broader methodology for the interpretation of lithic remains, retrieving aspects such as skill levels and abilities in particular assemblages. The objective of our experimental protocols will be to systematically measure and control the qualitative and quantitative parameters related to the materials used, the production methods and techniques, and the knowledge and experience of the knapper or experimenter (Brenet et al. 2011).

For this purpose, it is quite important to organize and systematize the experiments to define the relevant variables and to clearly define the high, medium, and low-skill levels of knappers. We video-recorded a three-dimensional evolution of the reduction sequence, we computed the duration of the experiment (Fig. 2), and we captured the raw material characteristics (lithology, dimensions, alterations), the final tool used for knapping (hammerstone raw material, morphology, contact areas), and the skill level defined on the basis of particular concepts and actual values, monitoring the types and products generated along the reduction sequence (Fig. 3), as well as postures, gestures, and trajectories, among many other variables.

Lastly, in the development of the experimental programs, the videographic record contributed to the later, additional, registration of many technical variables (gestures, postures, trajectories) that allow us to establish differences in such aspects as motor skills or accuracy levels.

Technotypological Analysis

To account for the variability of the lithic assemblages recognized in experimentally derived records, it became necessary to define and recognize different "technotypes" (Turq 2003) that indicate skills according to the different knapping methods and systems. This technotypological systematization contemplates skill types by the identification of technical and technological errors and solutions to those errors to detect differences in the technical and technological skill levels of a particular assemblage. In the context of quarries, this definition is also the first step in the recognition of the social organization of the group by identification of particular strategies in the territory, the existence of learning processes, and individual contributions to the lithic production.

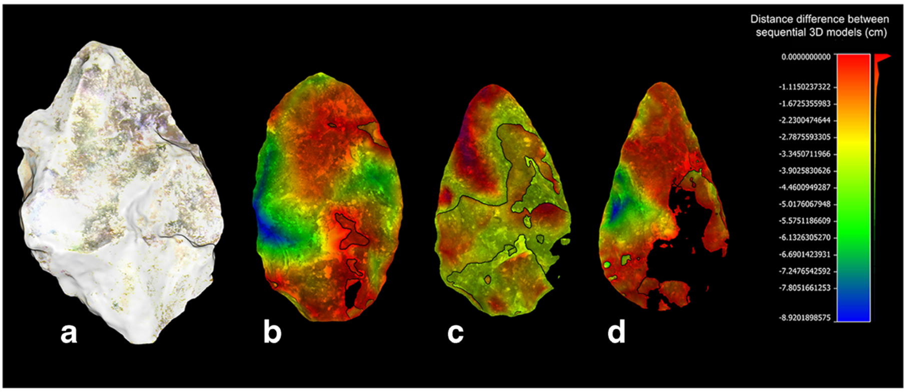

Fig. 2 Models of topographic analysis of changes between stages in the experimental bifacial reduction. Models compute with a height function (quadric) a cloud-to-cloud distance on the generated point clouds obtained in 3D after scanning in sequential stages in the bifacial reduction. Scale corresponds to the difference in distances between each stage and transparent areas correspond to common surfaces between models. A. Large flake; B. Initial thinning, C. Secondary thinning; D. Final biface (CloudCompare, v. 2.6.1)

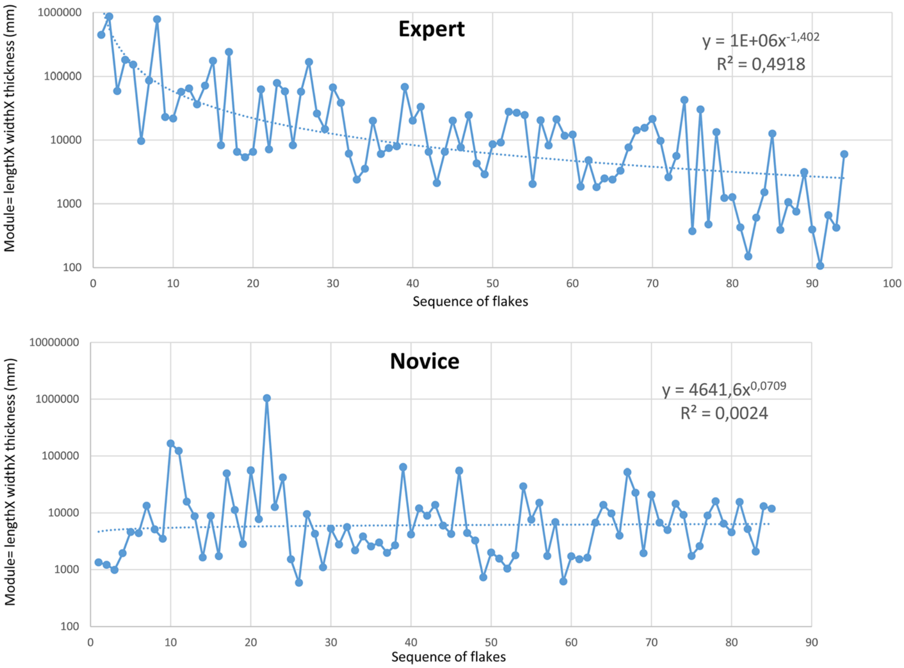

Fig. 3 Dimensional shaping of flakes: evolution of two experiments produced by experts and novices. Notice the different value of the adjusted results to the potential trend line function

Experimental lithic reduction protocols must also respect the technical and technological level recorded in the archeological record. Definition of the highest levels is deduced by aspects such as symmetry, dimensions, absence of errors, raw material quality, tools, and evidence of use, in all cases in comparison with the rest of the assemblage. In this regard, technical and technological reading is the first step in the later reproduction of the experimental materials and drives the techniques and methods employed in the experimental knapping. These specific types produced are markers of each moment and must necessarily be studied according to each archeological site and technocultural period.

After defining the specific techniques employed in the assemblage and the main knapping sequences registered in the material, we selected the relevant technotypes (Turq 1989, 2003) related to the skill levels (experts, all apprentices, and novices). Those types created the comparative collection for the study of the archeological elements and allowed a dynamic comparison via a complete experimental sequence. In all the models, the archeological material drove experimentation and in particular the generation of the skill types.

Diacritical Analysis

In our objective of reconstructing the knapping sequences, the diacritical analysis (Dauvois 1976; Story 1983; Young and Bonnichsen 1984; Bradley 1991; Sellet 1993; Baena and Cuartero 2006) allowed us to chronologically order the negatives into different phases or series and to compare those collections of sequences across different materials. This sequence analysis applied to specific lithic categories (retouched tools and cores, among others) and in particular to refitted cluster pieces were the main source from which to analyze the skill levels and the learning processes in our assemblages.

As regards skill-level recognition, the final forms found in the archeological record incorporate a varying degree of knapping difficulty and requirements for knapping dexterity, but the overlap of the last phases of the reduction sequence sometimes hides the identification of the skill level, mainly those from initial phases (Eren et al. 2011a). Together with the added difficulty of the possible existence of different skill levels in the same knapping process, this means the detection of variations is not straightforward (Johansen and Stapert 2003; Assaf 2019). These limitations notwithstanding, the diacritical analysis of preforms, finished pieces, and refits is an extremely powerful procedure for the interpretation of skills, since it is possible to read changes in the technological strategies from the beginning: adaptations to particular circumstances of the raw material, presence of recycling or reuse, failed attempts, and repetition of failures and application of solutions, as well as unique catchment exploitation strategies, which would complete the cultural significance of the analyzed lithic sets.

Refits

The technological analysis and spatial distribution of the refitted lithic industry is another tool that allows us to analyze longer sequences than those simply offered by the size of by-products (Schurmans and De Bie 2007). Since in many cases the refit limited in its number of pieces, whether by the original number of refits produced or by the circumstances of archeological recovery, we combine the diacritical reconstruction of the reduction process with the refit, thereby obtaining a longer sequence. This method of analysis contributes not only to the study of paleo-economic aspects (material production and other related activities) but also of social aspects such as the skills' contribution to the global production (Schurmans and De Bie 2007, p. 31), as demonstrated in the study of the Magdalenian site of Pincevent and Trollesgave (Karlin et al. 1990; Karlin and Julien 2019), Olduvai Gorge (De la Torre et al. 2018), Abric Romaní (Romagnoli and Vaquero 2016), and TRD10 in Atapuerca (López-Ortega et al. 2011), among other sites.

The value of the majority of Paleolithic assemblages for the reconstruction of reduction sequences through refits is very limited (Bar-Yosef and Van Peer 2009), but when obtained, the results are highly advantageous in terms of the recognition of technical and technological changes along the sequences analyzed.

Experimenters: Who Is the Expert and Who Is the Novice?

One of the first premises we assume in our approach to skill levels and learning processes present in the lithic record is that we all want to do things well and that doing so requires a more or less prolonged process of instruction and training (Dean et al. 2012). It is through a mixture of practice and quality instruction that we achieve dexterity or what is, with time and constant learning, expertise. Now, what is an expert knapper? One of the most frequent problems in experimental studies is the use of comparative materials from "expert knappers" who were considered as such based on erroneous criteria. Currently, there are many individuals who approach experimental knapping with different motivations: from the mere replication of objects through non-orthodox techniques to others who consider that experimental analysis applied to the lithic industry provides a methodological basis for an ideal interpretation of the lithic remains found in the archeological record (Newcomer 1971; Callahan 1979; Baena et al. 2019). These different motivations lead in both cases to the acquisition of impressive skills in lithic knapping. However, we consider that the differences between a proficient knapper and an expert are considerable because, although all current knappers have a wide background in techniques and methods, and are capable of reproducing the same tool, we consider an expert knapper to be one who:

a) Has an intense and prolonged experience in lithic knapping (Roux and David 2002)
b) Can predict the shape of the proposed product beforehand (Tixier 1956; Tixier et al. 1980; Nonaka et al. 2010)
c) Knows and applies a range of techniques and methods in an orthodox way (Khreisheh 2013, p. 71); because he/she
d) Knows the techniques and methods of knapping through the analysis of the archeological record with diachronic accuracy and thus can reproduce them in a manner properly adjusted to the record

The first premise (knapping a long time and of advanced age) has been frequently considered sufficient to accord the experimental knapper the rank of expert (Roux and David 2002, p. 94). However, it is an insufficient feature if it is not accompanied by the rest of the above criteria that define the expert. Khreisheh (2013), in his work on skills, presents the current expert knappers as highly experienced researchers capable of performing the three technologies required for their study (Olduvaian, Acheulian, and production of Levallois preferential flakes). We agree with Bar-Yosef and Van Peer (2009) in considering F. Bordes, J. Tixier, J. Whitaker, J Pelegrin, and B. Bradley as the best-known knappers (Bar-Yosef and Van Peer 2009), who also possess the greatest experience and skills in lithic knapping of the academic world. But many others can be considered as experts, as a result of perfect knowledge of the techniques and methods registered in particular archeological materials (Callahan 1979).

One of the most significant factors in the creation of experimental comparative collections related to learning processes and skill identification is the use of appropriate skill categories in the experimental replication. When using, for example, medium-skill-level knappers as real experts to recreate models or comparative materials, we can be completely confused in our interpretations upon comparison with the archeological remains. Furthermore, we must be aware that perfection is not possible, and the archeological material at its highest level must register some degree of "humanity" in its lithic expressions; this is the key aspect to keep in mind when experiments are designed. Based on our experience, the simplification of skill levels in the experiments limits our ability to identify the most characteristic features of each skill level. With this in mind, we incorporate in our experimental protocols the existence of four different levels:

a) Experts, as previously defined
b) Highly skilled apprentices, knappers with high skills in technique and medium technological abilities
c) Apprentices, with medium skills in technique and low technological capabilities
d) Novices, with low talents in technique and merely the ability to recognize lithic types

From our experiments in Acheulian handaxe reproduction, differences can be clearly identified at the end, mainly if we compare experts with low-skilled apprentices and novices (Fig. 4). In any case, our aim was, using a comparative and technotypological identification, to systematize the errors presented in expert reductions.

In any case, at a technical level, experimental replication allows for better identification of differences between expert and novice knappers and even low-skilled apprentices (Baena 1998; Brenet et al. 2009, 2013; Sacchi 2010, 2014; Geribàs et al. 2010; Buonsanto 2012; Putt 2015). The experimental record generated in the past by experts and knappers of other skill levels has been essential for the analysis and determination of errors and technical solutions in the archeological record. From the products generated by modern experiments, Shelley (1990) analyzed errors, corrections of errors, and the final morphology of the materials and discovered that the novice

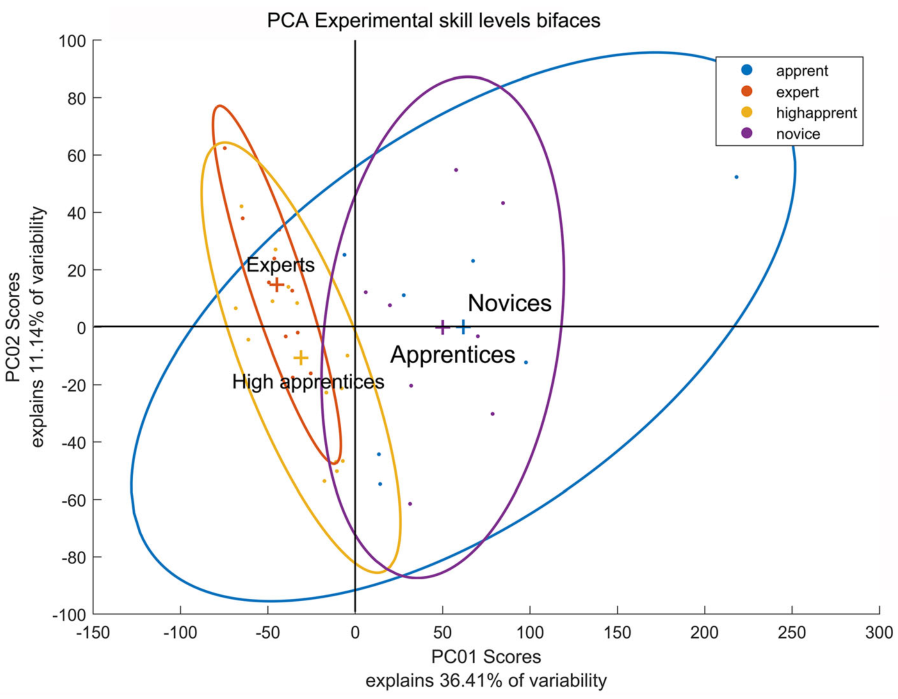

Fig. 4 Principal component analysis of bifaces produced by four different skill levels: experts, highly skilled apprentices, low-skilled apprentices, and novices ($n = 40$). The output produced by experts and highly skilled apprentices, which overlaps, contrasts significantly with the output of novices and low-skilled apprentices, as indicated by the Wilcoxon rank sum test (AGMT3-D (Artifact GeoMorph Toolbox 3-D), v. 3.1) (Herzlinger and Grosman 2018)

made more irreparable mistakes, produced a greater accumulation of steps and hinges, and did not prepare the platforms (Shelley 1990).

Common Errors Related to Skills Level

In setting the levels of the analysis, we have described a group of indicators that can be used in general to determine skill levels, especially for bifacial reductions (Table 1). These indicators can be recognized and counted in archeological and experimental material in knappers of any skill level (Faulkner 1972; Cotterell et al. 1985; Cotterell and Kamminga 1987; Bertouille 1989; Odell 2004; Tsirk 2014). These technical markers should be examined in a broader context and, in particular, in relation to the "decision" indicators (Table 2) that have to do with the kind of choices made by the knapper when selecting materials, tools, type techniques and how to concatenate them, and the like (Table 3).

Experts Also Fail

In general, it has been considered that the expert knapper does not leave stigmas of low skill in the archeological record—in other words, does not make errors produced by their knapping behavior but by the raw material quality and condition (Bamforth and Finlay 2008). However, we have tried to avoid this simplistic vision, and by analyzing experimental and archeological materials in a comparative way, we consider that good and even expert knappers make mistakes that are not always attributable to low-quality raw material (Fig. 5). Room for error expands even further if we take into account that the distance between experts' and apprentices' products is not always easy to determine (Eren et al. 2011a), opening up the possibility that what is deemed the output of "apprentices" may in fact be the less masterful pieces of an expert.

From our experimental experience, the significant difference is that in the case of the expert:

a) Errors are usually reversible and can be solved

Table 1 Indicators associated with low technical or motor skills

Technical errors
Dulling edges
Cascades
Crushing areas
Steps
Fractures (oblique, distal, incomplete…)
Plunging termination
Hinges
Multiple cones
Flakes with deviated technical axes

Table 2 Indicators associated with the knapper's decisions

Decision mistakes
Bad selection of blank (dimension, quality, morphology, state...)
Bad selection of knapping tools and the contact areas (dimension, quality, morphology, state...)
Knapping tool gripping and holding position
Bad selection of the percussion plane (angles higher than 90°, concavities…)
Bad selection of postures for knapping
Reiteration
Perseverance

b) When produced, errors generated by experts are not determinants for future stages of the reduction sequence (controlled errors limited in dimension and extent)
c) Repetition of errors is quite rare, and the superposition of mistakes is infrequent
d) More importantly, an expert knapper, at the moment of analysis, has adequate technical/technological resources for each case that permits a solution to the majority of errors
e) There are intentional errors (for example, steps, hinges, and cascades in the prehensile area of a biface, or overpass flakes in the *mise en forme* phases of a volumetric configuration of a core in a Levallois reduction)
f) Behind a technical fatal error we can find an adequate method but an irresolvable singularity event (Fig. 6) (i.e., it is just an isolated incident in the complete and otherwise successful process due to unforeseen blank limitations or human misadventure)

First of all, expert knappers can produce reversible errors along the reduction sequence. Those errors evident in the archeological record, in many cases, have gone unnoticed in the analysis of skill levels. We can detect those errors by identifying particular lithic products in which error captures occur. These are products or skill

Table 3 Indicators associated with low technological or logical-cognitive skills

Technological errors
Asymmetric thicknesses in 2D view (irregular topography between faces)
Asymmetric thicknesses in profile
Twisted volumes in profile
Sinuous edges in profiles
Central or peripheral residual cortex
Asymmetry in planes
Disorganization of negatives
Percussions on the major axis or in erroneous locations
Absence of technological resources to solve technical problems
Marginal negatives

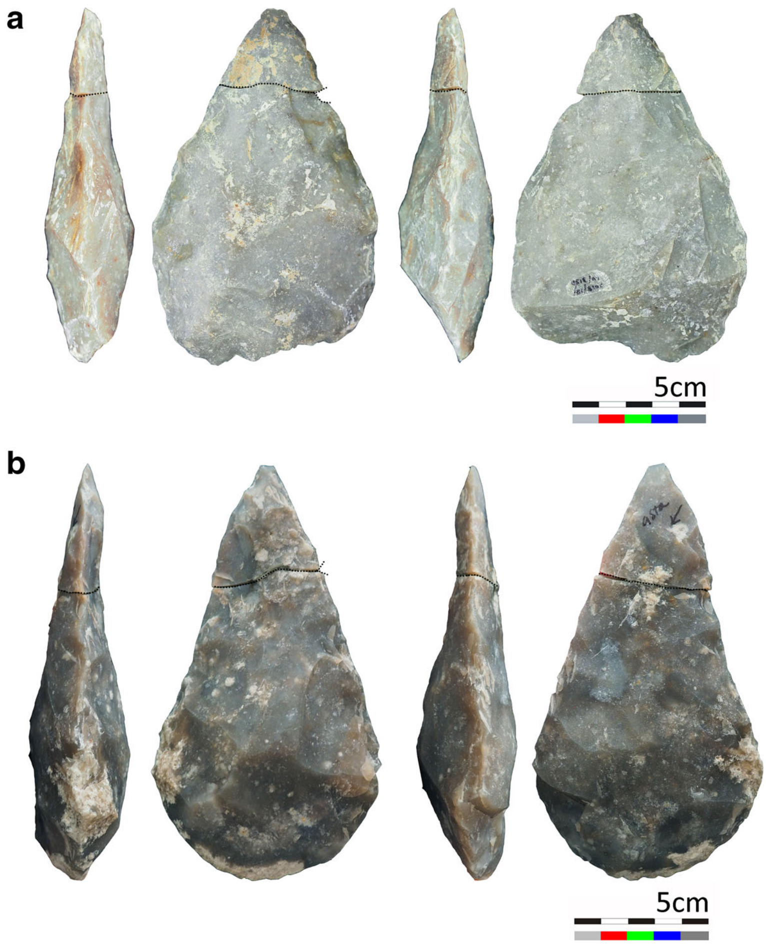

Fig. 5 Bifacial point breakage produced by expert knappers in the final stages of shaping. **a** Archeological refitted handaxe from Cantera Vieja archeological site (Madrid, Spain); **b** experimental replication

technotypes that specifically embody previous errors (Turq 1989, 2003). The presence of such types indicates high technical/technological skills. And not only is the solution a marker of high skill but so is the type of solution adopted in the same accident. There are simple and other more complex solution technotypes. For a complete analysis of the presence of skills in the lithic production, we consider relevant the definition not only of technical error technotypes (steps, crushing, cascades) but also the inclusion of technical and technological solution types identified by the capture or the working clean of previous fails. One example is the study of a bifacial piece of the Villiers-Louis site in the town of La Feuchelle (France). This piece shows both an extraction reflected in the last phase of configuration and the solution adopted by the knapper to reduce their error, which allowed them to finish the piece and to demonstrate their wide repertoire of technical knowledge (Soriano 2019).

In contrast, the inexpert knappers do not solve their mistakes and repeatedly make their failures without changing their behavior, generating an accumulation of effects

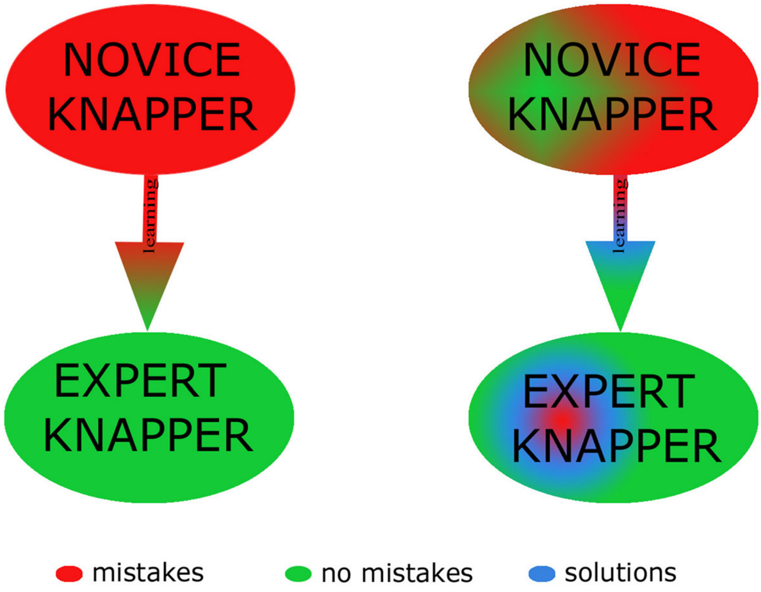

Fig. 6 Left: classic scheme of differentiation between novice and expert knappers. Right: an alternative dynamic scheme that characterizes novice and expert knappers

(crushing, cascades, dulling) on the pieces. In these cases, we can detect an accumulation of wrong decisions along the sequence: taking a very small or excessively twisted or cracked blank, constantly changing the working area, choosing an inadequate hammerstone or selecting an erroneous contact area on it (Cuartero 2014; Lamas et al. 2016) are just a few examples that characterize a process from a novice knapper.

The second case of an error made by expert knappers is one that is not decisive for future stages of the knapping sequence and can be considered as a controlled mistake. This is an example of the importance of controlling the produced errors in the moment of the sequence at which they occur (Fig. 7). In our experimental approach, we observed that occasionally expert knappers configure handaxes from blanks that present multiple crushing problems in one of their areas (Fig. 8). A simplistic correlation not considering the real sequence of events would lead the investigator to think that those pieces correspond to novices. However, if we analyze at what stage the crushing occurred, we could objectively conclude that if the errors (crushing and/or large percussion cones) have been made in the phase of extraction of the large flakes that does not indicate low dexterity. It is an acceptable error by the expert knapper in that phase of the reduction sequence.

Likewise and surprisingly, some error technotypes can become a solution during the knapping process. As mentioned before, analyzed in a simplistic and isolated way (as being an error equal to a novice's skill level), an investigator would conclude that these are types that indicate a low technical skill in the knapper. However, they are types that

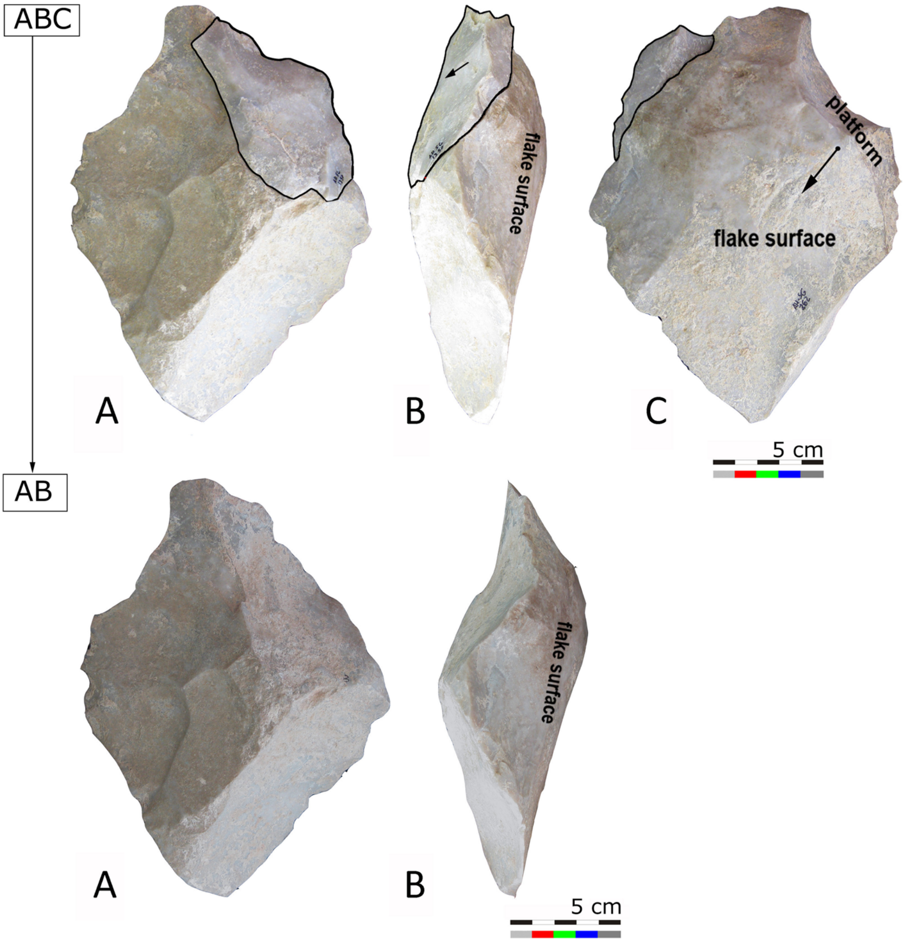

Fig. 7 Bifacial preform from Charco Hondo 2 archeological site (Madrid, Spain) with a refitted flake that shows a controlled error (small distal hinge) in initial phases

solve a bigger problem. Examples of this are intentional overpass flakes during the bifacial configuration process to eliminate aggregation of percussion cones produced in initial phases (large flake production in giant cores). Although there is no agreement about this interpretation, some studies consider that those apparently excessive strikes in bifacial reductions are resources used by the most skilled knappers for a quick thinning of the blank (Almeida 2005; Lohse et al. 2014). This possibility confirms that expertise can be detected simply as a matter of economy of effort. For experts, if you can do it in just one single blow, why do it in many? Another example of this circumstance is the overpass flakes obtained to create Tabelbala-type cleavers in the North African Acheulian (Tixier 1956; Inizan et al. 1995; Sharon 2009, p. 349) (Fig. 9).

The third type of error associated with expert knappers can be discerned, as we have already mentioned, by the low repetition and infrequent overlap of errors. Generally, the expert, when he fails during the process, changes some technical behaviors (the knapping tool, the gesture, the strength, the trajectory) or reaches for technological

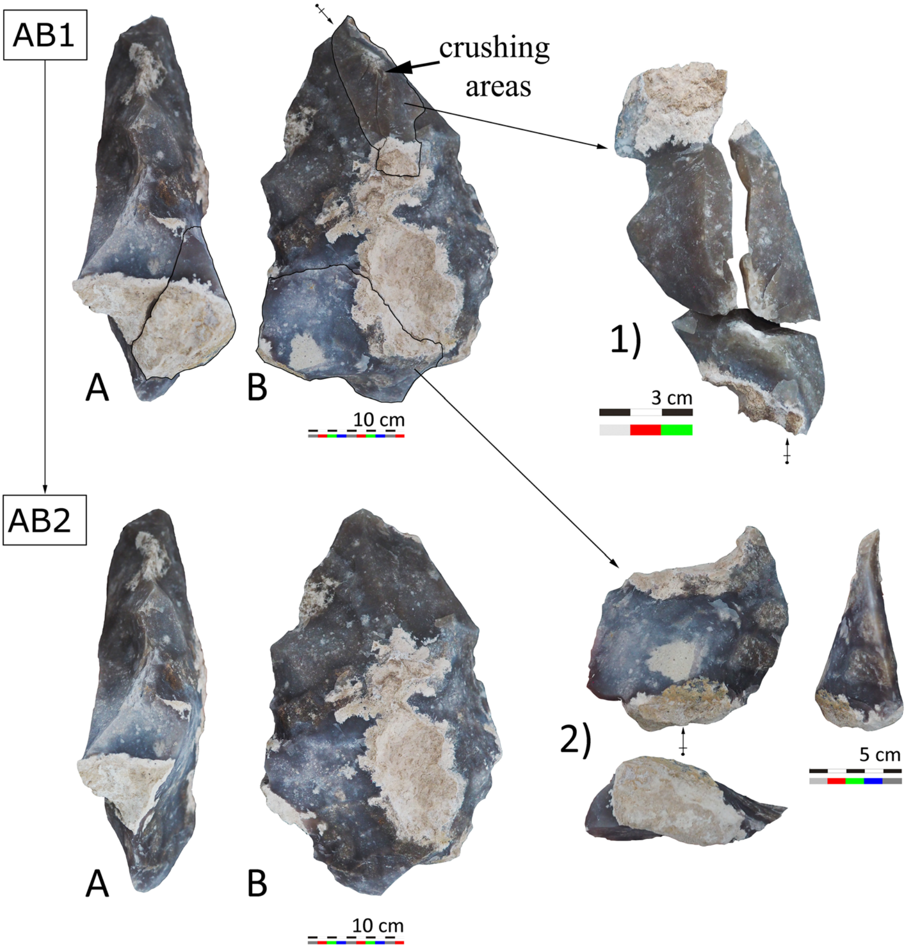

Fig. 8 Bifacial experimental preform with two expert knapper technotypes in which crushing areas (1) and irregular volumes (2) generated during the large flake production phase are solved

solutions (lateralizes the following series, widens the depth in the strike, carries out cleaning by means of overpass flakes, reinforces the platform using cascades) (Fig. 10). Experimentally, it is usual to document the technical changes made by the expert knapper against the new knappers. The latter insist on hitting the same area where they initially failed and produce an accumulation of errors (Fig. 11).

The fourth type of error observed in expert knappers is the one that, although terminating in a fatal situation (at a technical level), analyzed as a whole allows us to appreciate a high technological skill level until the end. This type of error is especially recognizable in the blanks. Thus, it is common to find preforms, final bifaces, or leaf-points that have mesial or diametral fractures that do not allow reconfiguration processes and are abandoned (Fig. 5). The Solutrean materials of Les Maîtreaux (France) include a large number of fractured preforms abandoned during processing. They are errors that made it impossible to continue with the process and have to do with the appearance of insurmountable problems related to the heterogeneity of the raw material or the assumption of a high level of risk in the knapping process (Almeida 2005; Aubry et al. 2008). This last case is very frequent in the Acheulian bifacial materials in the configuration of the distal part. It also occurs in Levallois reductions with the production of lateralizations or overpass flakes caused by tiny errors in preparation of the percussion platforms. However, the detailed analysis of the piece at a technical and technological level indicates a high level of global technical and technological skills until the production of the irreversible error.

Occasionally, change in the raw material conditions (fissures, alterations in the quality, flaws) could be the reason for rejection in different phases of the knapping sequence (Fig. 12). For this reason, experts are differentiated by their expert selection of blank morphologies, raw material qualities, and block or spall homogeneity.

The various technologies in lithic industries show that particular individuals had advanced cognitive abilities, since the morphology of their pieces surmounts the constraints of the raw piece (Pelegrin 1990; Stringer and Andrews 2011, p. 209). For Pelegrin (2005), ahead of a morphological imposition, planning is essential and the ability of the knapper to form mental templates will be a determining factor in achieving the production of a specific tool (for example, a biface). Decisions are constantly made along the reduction sequence and a bad choice can determine the future evolution of the process. It is not a matter exclusively of technical ability but of the acquisition of a background knowledge that guides the knapper to good decisions along the reduction route.

The control of the morphology and volume equilibrium is an important aspect from the initial phases of configuration (Fig. 13) and will be decisive in the last moments when the knapper seeks a regularization of the edge and balance between the surfaces (Newcomer 1971; Baena 1998).

The analysis of archeological and experimental material indicates that in bifacial reduction projects, inexperienced knappers generate trifacial pieces instead of the symmetrical bifacials produced by experts. In addition, the edges of those trifacial products possess a poor level of effectiveness (Fig. 14). These differences are due to the poorly controlled or uncontrolled delineation of the edges and the repartition of volumes on each face throughout the entire knapping process. In our opinion, the organization of each series of extractions depends on the morphology that was previously acquired, and that volume/morphology conditions the final shape of the core/tool.

The knapping process involves a constant dialogue between knowledge, skill, and raw material in which the expert knapper adapts or varies their behavior depending on the result produced at each moment. However, low-skilled apprentices and novices either possess an inability to recognize the problems that arise (in particular those knappers without any experience) or, even if they are aware of the problems (those with some experience), lack the ability to continuously adapt knapping behaviors to arrive at the solution. Therefore, profile deviations (Figs. 13 and 15) or convex differences in the bifacial section are common (Baena 1998). It is interesting to note that when novices had finished the tool, they could not judge whether it was well or poorly done until an expert replica was shown to them.

Based on experimental reproductions, Shelley (1990) has already identified that the apprentices made bifaces with triangular cross sections, and Winton (2005) considers the relationship between length/width in bifaces as a relevant aspect at a technological level. In his experiment, he identified that novices make bifaces smaller and thicker

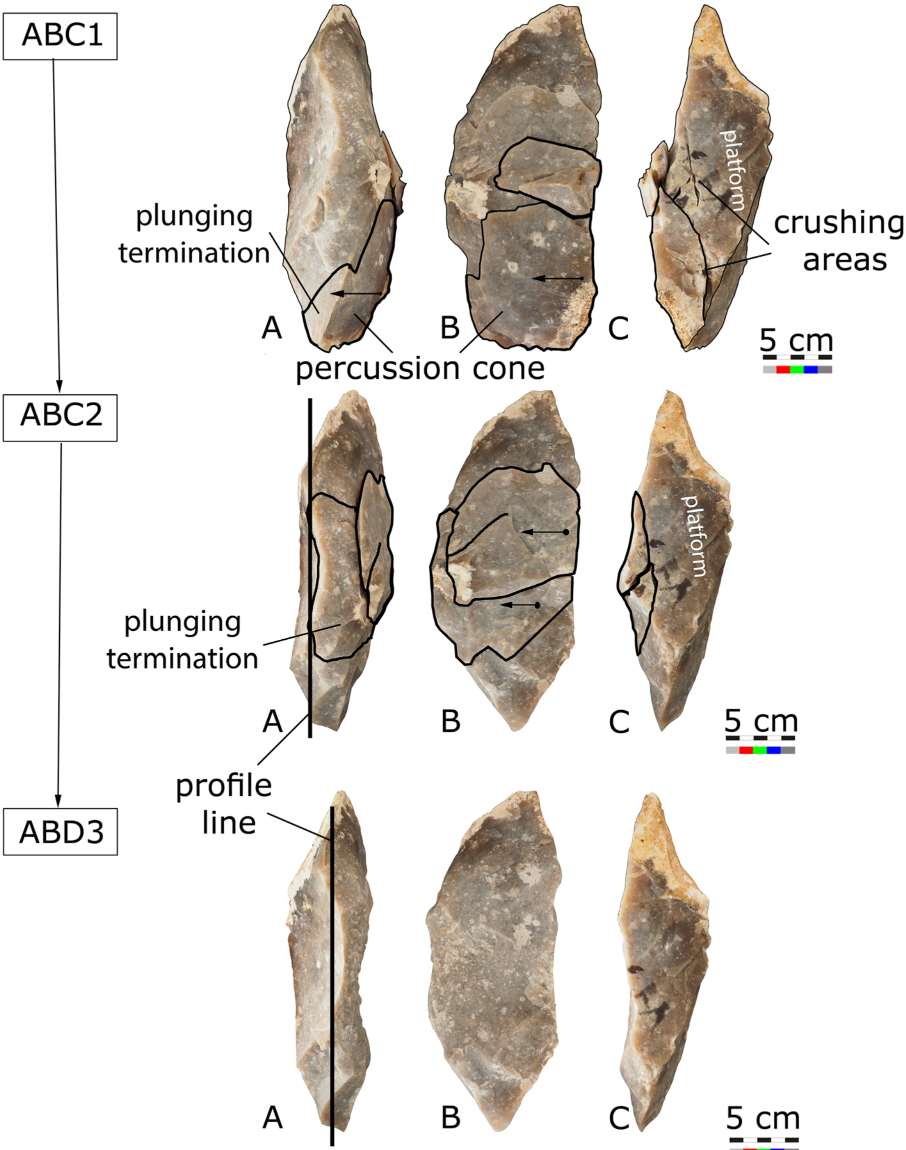

Fig. 9 An experimental example of an overshot flake in bifacial reductions (initial stages). The expert knapper strikes from the opposite side and removes the percussion cone located on a natural surface of the blank (ABC1) and at the same time corrects the asymmetry in the profile of the preform (ABD3)

than those of experts, with asymmetric profiles, conservation of cortex, and short sequences.

These variations are crucial aspects when we evaluate the presence of experts and novices in the archeological record. Selection of blanks (both morphology and raw material quality) conditions the development of the future result. In this respect, sites such as Charco Hondo 2 or Area 3 (Madrid, Spain) from the Lower and Middle Paleolithic (Ortiz and Baena 2017; Baena Preysler et al. 2018) indicate that experts apply efficiency criteria in the blank selection (dimension thickness and quality) in order to assure the best result. In our case, there are some elements that help us in our approach to the identification of different skill levels and in the recognition of the remains of "experts" in such context. Due to the character of quarrying areas, there is a readily available supply of a relatively homogeneous raw material, both in knappable quality and in blank formats. Moreover, there is mainly one functional purpose for the human activity in those areas—that is, lithics sourcing—as well as a relative synchronicity in the whole assemblage. Those circumstances suggest that variations in the reduction intensity are a function of individual intentions and capacities. At the same time, these factors are extremely important in their influence upon the study of different temporal sets. In those cases, attributes are obviously not directly units of an inherited cultural evolutionary process (Lycett et al. 2016). We work with discrete intervals of confidence and we are assuming that in such contexts, many different skill levels are at work. In order to distinguish them, we assume that even experts can produce mistakes, and we try to describe and analyze them in a qualitative way.

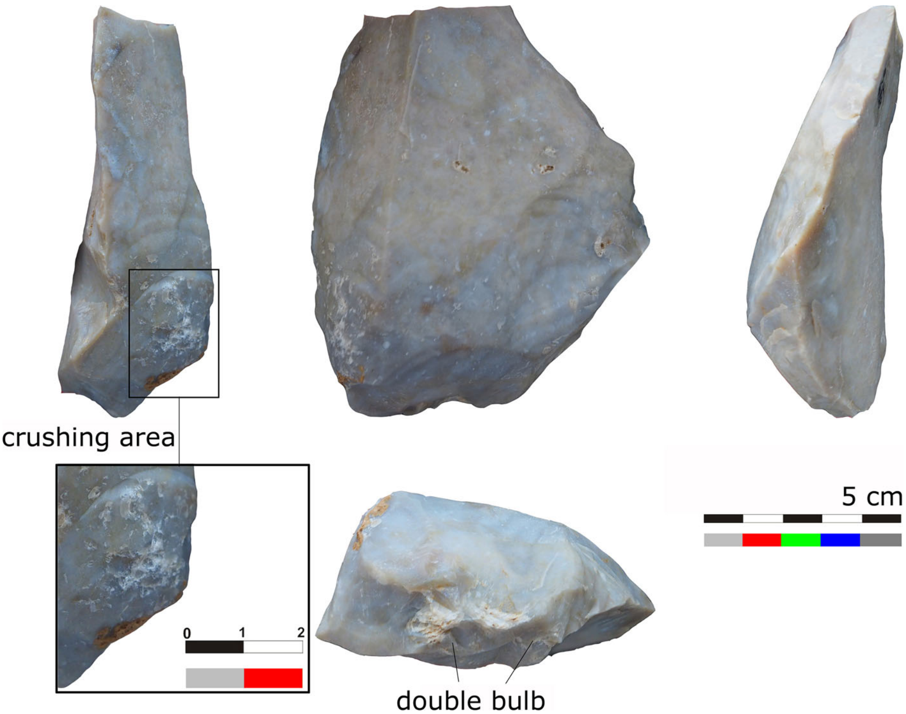

Fig. 10 Solution of crushing areas during an initial shaping of a bifacial flake from Charco Hondo 2 archeological site (Madrid, Spain)

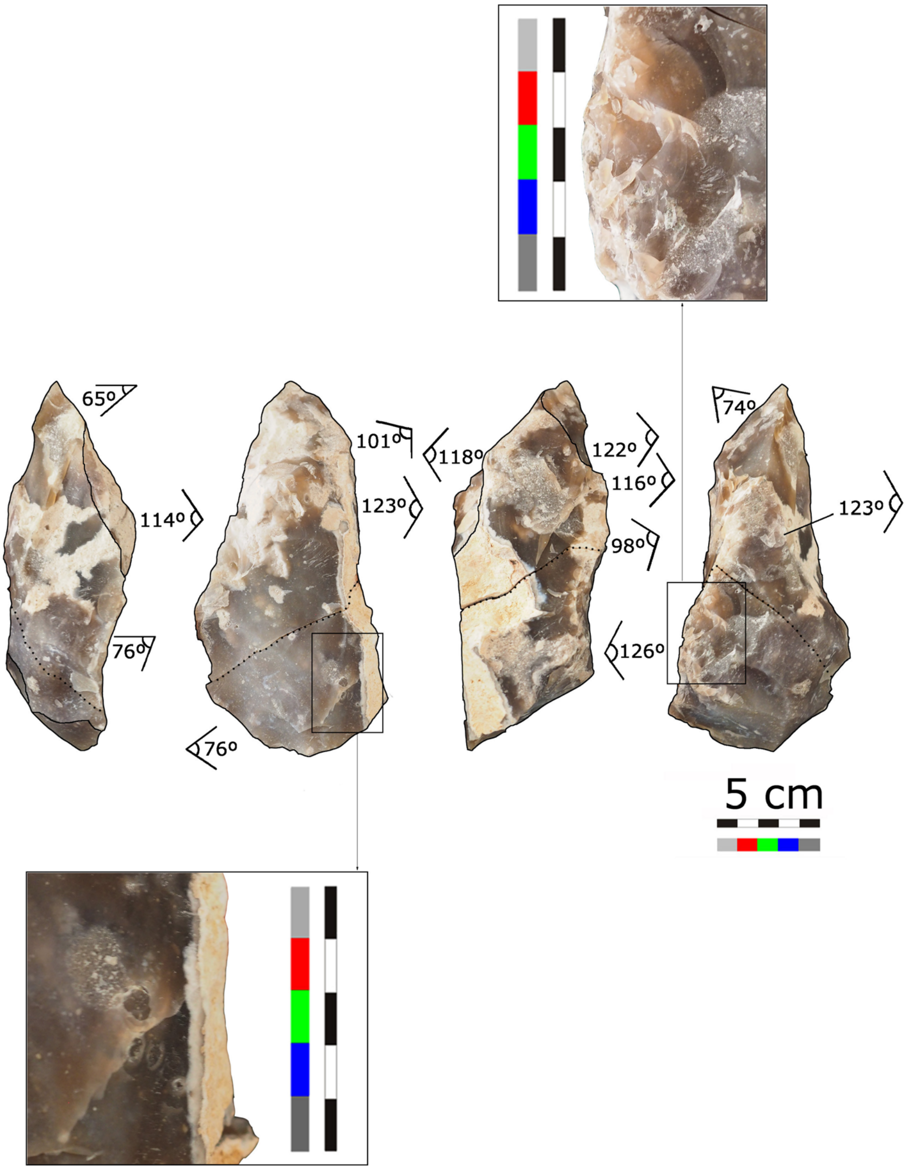

Fig. 11 Experimental bifacial reduction performed by a novice knapper with detail of the crushed areas and cascades generated using striking angles greater than 90°

Discussion and Conclusions

Although this work is only a preliminary theoretical approach to the study of skill levels and learning processes during Paleolithic periods, we expect it to have a methodological impact by its combination of the experimental perspective, the diacritical analysis of individual pieces and refit clusters, and the definition and comparison of skill types

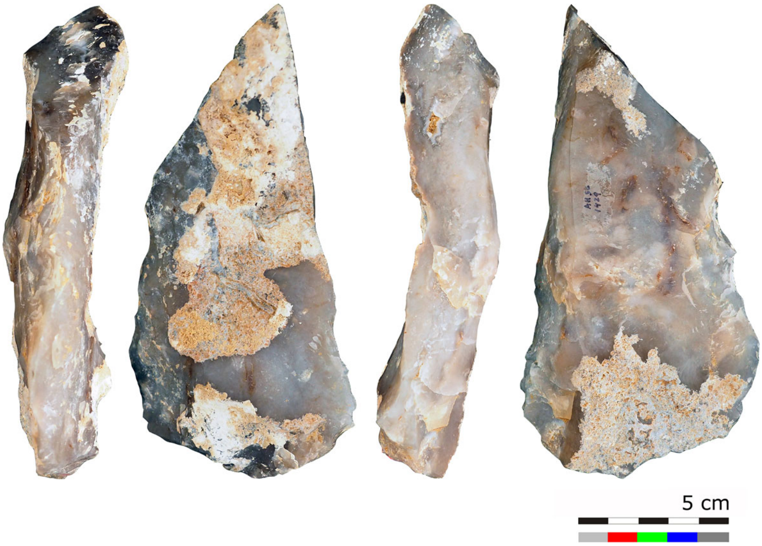

Fig. 12 Initial bifacial preform with a diagonal breakage produced by the poor raw material quality, from Charco Hondo 2 archeological site (Madrid, Spain)

produced along the sequence. All these methodologies contributed to the determination of the presence of different skills in each of the reduction phases.

In this contribution, the unclear line that separates the expert knappers from the novices and apprentices is claimed to be delineated.

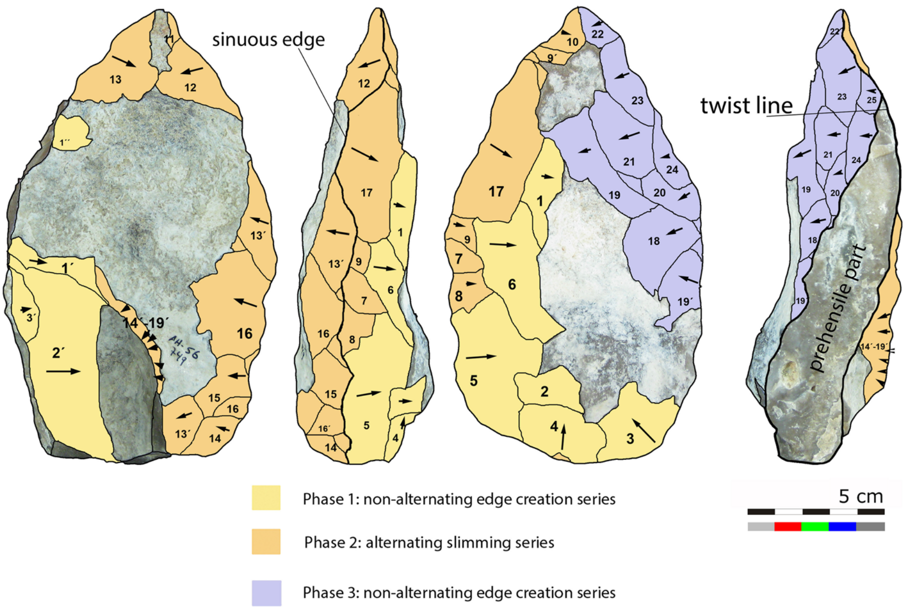

Fig. 13 Diacritical analysis of biface no. 749 from Charco Hondo 2 archeological site (Madrid, Spain). The piece presents asymmetry in profile and residual cortex at the edges as indicators of technical experience but limited technological skill

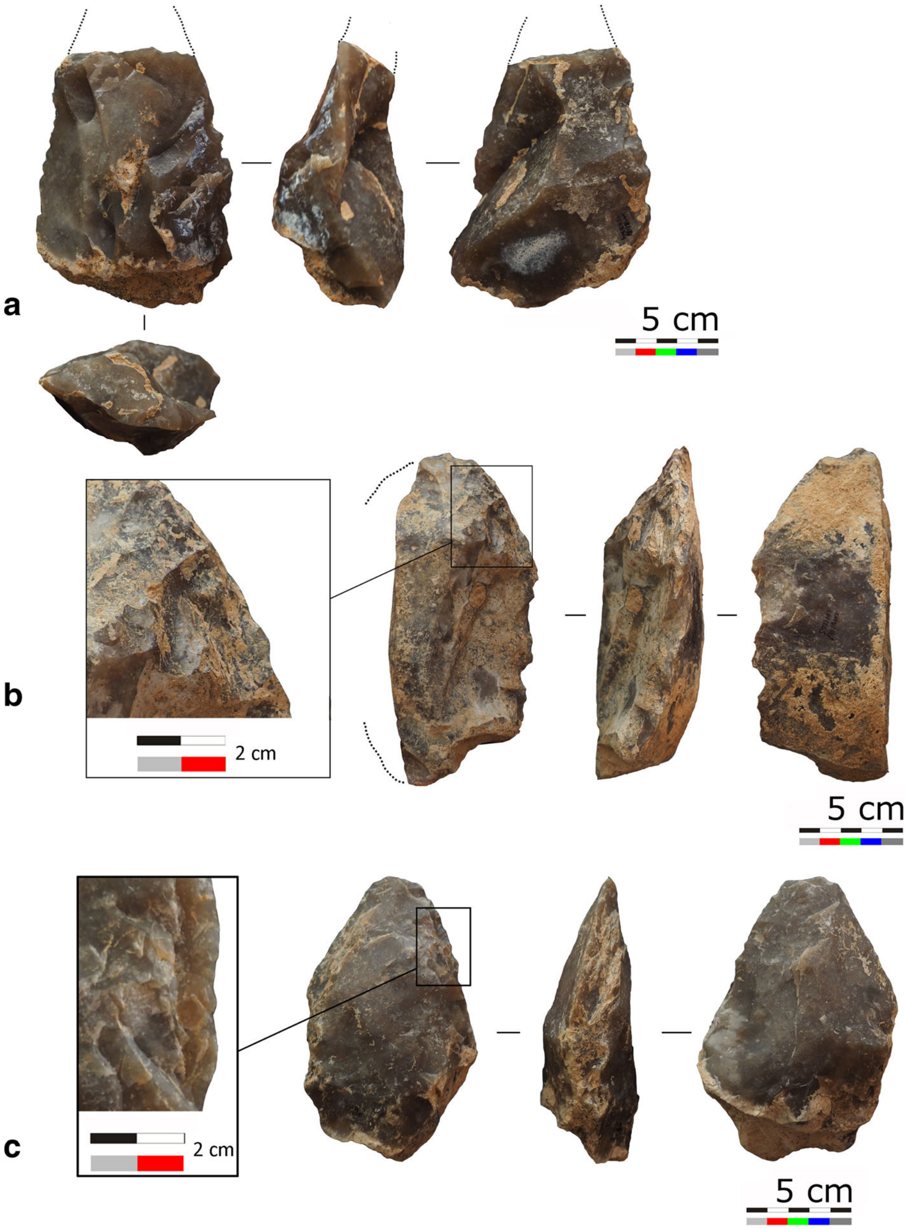

Fig. 14 Preforms and bifaces with errors from Cantera Vieja archeological site (Madrid, Spain). **a** Erroneous selection of the raw material opens up internal flaws during the reduction process; **b** trifacial piece recycled from a fractured biface; **c** accumulation of steps in an asymmetric biface

In different ways and to different degrees, both knappers fail in some technical aspects; experts also produce mistakes, but the mental schemes behind such mistakes are clearly different. The determination of the types of errors and solutions along the

Fig. 15 Experimental example of a knapper with technical skills but with technological limitations that produced torsion in the biface profile

time scale of the knapping process allows us to more reliably interpret the diversity of a register that generates a diversity of knappers. Nobody is saying that it will be easy to read and define the technological and skill-based elements that compose an industry, but this process of identification has to get under way in order to reach real comprehension of who the author of particular productions was and of those communities that organize the production of tools.

The range of factors that introduce variability in the lithic record, and thus in our ability to recognize the existence of different skill levels in a particular context, is very broad (Eren et al. 2011a). Factors such as time constraints, intensity in configuration, raw material quality, or an activity's intended outcome deeply affect the potential recognition of authorship. But, in the study of the Acheulian lithic quarries from Central Iberia, the abundance and homogeneity of lithic raw material, along with the singular functionality of the sites, provide an excellent laboratory for its study and recognition.

Traditional approaches to analysis of the learning processes and skill levels in lithic technology are based on unidirectional correlations between accidents and errors at the low-skill knapping levels. Several years of lithic experiments at the Laboratory of Experimental Archaeology (LAEX) at the Autonomous University of Madrid, along with the study of different Lower and Middle Paleolithic quarries from Iberia, suggest a more complex reality in the skill-level composition of the lithic knappers. Quarries are an excellent backdrop for the study of the social relations inside the production and learning models due to the context of raw material abundance (Baena et al. 2015).

Perfection is rarely attainable and only in particular situations is it recognized in the archeological record. Criteria of three-dimensional symmetry in the products are usually interpreted as synonymous with high dexterity without evaluating aspects such as specific functional needs, tool conception (Boëda 2013), adequate accessibility to raw material and tools (Gopher and Barkai 2014), individual idiosyncrasy (Soressi and Dibble 2003), temporary needs (Moncel et al. 2014), and even the symbolic value of specific tools (Le Tensorer 2006; Bleed 2008; Zutovski and Barkai 2016).

Experimental protocols have used "expert knappers" as principal agents to produce comparative materials for skill studies. However, the definition of what is and what is not an "expert" is essential if we are planning to use comparative products from them. Expertise is not only the result of the time expended in knapping, nor just the ability to create nice final pieces. The perfect knowledge of what is going to be reproduced or studied is fundamental. Of course, the ability to reproduce the process with adequate techniques and methods is required, but it is also essential to align those techniques and methods to the material to be analyzed. For this reason, the use of no genuine experts as experimenters seriously places in question the relevance of the conclusions.

In any case, the recognition of expertise in lithic knapping has to be studied from a dynamic perspective in which there are not only good and bad knappers but a wide variety of skills. And this aspect is of particular importance if we pretend to know which type of learning processes have occurred in particular human groups. Particular distributions of skills levels inside a group (recorded by the variability of described types and final products) could reveal differences in the learning models (Cuthbertson 2015), although several circumstances could affect its manifestation.

We purport to provide a new perspective for future studies by enriching the recognition of technotypes related to dexterity levels. In summary, the existence of skill limitations is defined by a gradual scale of skills and expressed in several ways. Technical limitations are frequently related to unselected blanks or erroneous decisions in their selection, uncontrolled morphologies, and volumes, reiteration of "classic" errors, and the absence of solutions during the reduction sequence. By contrast, experts make an adequate selection of blocks and have enough experience in the evaluation of raw material quality (by external attributes), have the ability to fit the final design on the blank, have the capacity to adapt the techniques during the reduction process and to solve minor problems, and stop the process when it has no future or the danger of causing fatal errors is high.

What is important is to make a constant distinction between the technical and technological types in the archeological materials and in the experimental results, and vice versa, in order to successfully identify the potential existence of different skill levels in the lithic transformation. We need to not just identify the presence of such skills but also to understand the existence of particular social structures in the *chaîne opératoire*. This recognition can be essential to an understanding of cultural evolutionary models (Creanza et al. 2017).

The basic attribution of errors to technical limitations and thus to inexpert individuals is therefore simplistic. For example, the lithic production of modern-day knapping experts changes along their life timeline. This is the case if expert knappers encounter health problems. Loss of vision or nerve problems, for example, could dramatically affect their lithic production. In this case, the experience of the knappers is recorded by the trial of solutions after producing mistakes, and for our approach it does not matter whether with or without success. Such easy attributions do not work with humans.

Nobody denies that successes, failures, and mistakes are obviously present in the archeological record. Our ancestors have some or all of the abilities and limitations of our own nature. If approaches to skills set out to demonstrate merely the presence of expertise and learning in the past, it will be not worthwhile, and we should not waste our time. From our point of view, the study of the presence of learning activities and skill levels in the record must be part of a general interpretation of the cultural transmission processes, of the identification of the social contribution to the production, and of the organization and functionality of the social group, and must be an inherent part of our understanding of the cultural evolution between species.

We cannot be conformist, and we need a continuous and active generation of new resources and ideas for the study of learning and expertise, applied from a synchronic and diachronic perspective, attending to circumstantial events, and considering the relevance of group and individual conclusions (Julien et al. 2014). Such a mind-set is necessary, not just to confirm the humanity of our ancestors, but to understand real historical and social changes in the cultural evolutionary process.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standard.

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