Flakes, Feelings, and Finesse: Experiential Studies of Skill Acquisition in Novice Knappers

KUMAR AKHILESH
Sharma Centre for Heritage Education, No.4, School Street, Sholinganallore, Chennai 600119, Tamil Nadu, INDIA; akhilarchaeo@gmail.com

PRACHI JOSHI
Sharma Centre for Heritage Education, No.4, School Street, Sholinganallore, Chennai 600119, Tamil Nadu, INDIA; prachinjo@gmail.com

SUTONUKA BHATTACHARYA
Sharma Centre for Heritage Education, No.4, School Street, Sholinganallore, Chennai 600119, Tamil Nadu, INDIA; and, Institute of Archaeology, The Hebrew University of Jerusalem, Mount Scopus, Jerusalem 9190501, ISRAEL; sutonuka.bhattachary@mail.huji.ac.il

YESHASWINI RAJAGOPALAN
The Archaeology Department, Durham University, The Palatine Centre, Stockton Road, Durham, DH1 3LE, UNITED KINGDOM; yeshas.raja98@gmail.com

SHALAISH BAISLA
Department of Quaternary and Prehistory, University Rovira i Virgili (URV), Tarragona 35, 43002 SPAIN; shaileshbaisla@gmail.com

ANKITA DEY
600 G.T.Road Siristala, Serampore, Hooghly, West Bengal,, INDIA; ankitadey1717@gmail.com

SURENDRA GHASKADBI
Developmental Biology Group, MACS-Agharkar Research Institute, GG Agarkar Road, Pune 411004, Maharashtra, INDIA; ghaskadbi@gmail.com

BALASUBRAMANIAN KARTHICK
Biodiversity and Paleobiology Group, MACS-Agharkar Research Institute, GG Agarkar Road, Pune 411004, Maharashtra, INDIA; karthickbala@aripune.org

MRUDULA MANE
Centre for Heritage Conservation, Research and Development Foundation, CEPT University, Ahmedabad, Gujarat, INDIA; mrudulmane@gmail.com

AKASH PANDEY
Department of Archaeology and Ancient History, The Maharaja Sayajirao University of Baroda, Gujarat, INDIA; akashpandey8936@gmail.com

SRINATH PERUR
52 Serpentine Road, KPW, Bengaluru 560020, Karnataka, INDIA; psrinath@gmail.com

CHANDNI ROY
Anita Tower, Block C, 4th Floor, Flat No. E4, 52/4 Ramkrishnagarh Road, Kolkata 700079, West Bengal, INDIA; chand16prehistoricrealm@gmail.com

ALOK SHARMA
Amity Institute of Anthropology, Amity University, Noida, Uttar Pradesh, INDIA; alok2153@gmail.com

AMMEL SHARON
Centre for Studies in Social Sciences, Calcutta, West Bengal, INDIA; ammel.sharon@gmail.com

CHINTAN THAKAR
Mahadev Ji Ki Ghati, Chavni Gate, Imli Bazar, Nathdwara, Rajsamand, Rajasthan; INDIA; chintanarchaeo@gmail.com

SWATI VERMA
Department of Archaeology and Ancient History, The Maharaja Sayajirao University of Baroda, Gujarat, INDIA; swativerma0284@gmail.com

AKANKSHA S. KASHIKAR
Department of Statistics, Savitribai Phule, Pune University, Pune, 411007, Maharashtra, INDIA; akanksha.kashikar@gmail.com

***PaleoAnthropology* 2025:1: xxx–xxx.** **https://doi.org/10.48738/2025.iss1.xxx** OPEN ACCESS **ISSN 1545-0031**
Paleoanthropology Society & European Society for the study of Human Evolution.
Early View available online 3 December 2024

SHANTI PAPPU*
Sharma Centre for Heritage Education, No.4, School Street, Sholinganallore, Chennai 600119, Tamil Nadu; and, Humanities and Social Sciences, Krea University, Andhra Pradesh, INDIA; pappu.shanti@gmail.com

*corresponding author: Shanti Pappu; *pappu.shanti@gmail.com*

submitted: 2 October 2023; revised: 13 April 2024; revised: 30 July 2024; accepted: 3 September 2024

Handling Editor in Chief: Karen Ruebens

ABSTRACT

Here, we present preliminary results from research investigating the influence of different pedagogical methods on skill acquisition among novice knappers, with implications for interpreting the Paleolithic and devising pedagogical methods in classrooms. We addressed questions related to knowledge acquisition among novice knappers in issues such as raw material selection and technological strategies comprising bipolar knapping, flaking cobbles, and handaxe *façonnage*. Experiments were set in a highly social and experiential framework and focused on investigating skill acquisition based on observation, mimicry, and direct or indirect intervention of an expert knapper. Variables included self-assessed emotional states of novice knappers before and after each experiment and analysis of selected attributes of the lithics (n=1835 artifacts in 10 experiments). We generated indices for variables related to skill acquisition that are significant for interpreting individual tools, assemblages, and evolutionary trends. Results suggest variability in skill acquisition in different technological processes through time and the effects of differing teaching methods. Large databases of lithic assemblages generated from novice knapping would facilitate global comparative studies investigating learning processes in lithic knapping, thereby enhancing an understanding of the archaeological record.

INTRODUCTION

The cognitive and evolutionary implications of stone tool manufacture arising from experimental studies have led to varied interpretations related to the transmission and acquisition of knowledge and skill sets among early hominins (Morgan et al. 2015; Silva-Gago et al. 2022; Stout et al. 2019). The origins of teaching and skill acquisition in the field of lithic knapping are much debated, comprising issues related to *connaissance and savoir faire*, proceduralization, declarative and procedural memory, cognitive and perceptual motor skills, styles, intra-individual variability, socialization, language, cooperation, and cognitive abilities among other perspectives (Bamforth and Finlay 2008; Lohse 2011; Pelegrin 1990; Muller et al. 2022, 2023; Pargeter et al. 2020; Snyder et al. 2022; Stout et al. 2019; Wynn and Coolidge 2004). In addition, studies of learning processes, be they among novice knappers or juvenile primates, deal with topics related to skill acquisition within holistic social environments where observation, mimicry, and guided aid are critical factors in learning tasks and traditions (Pelegrin 1990; Roux 1990; Tehrani and Reide 2008). One of the key themes in these studies is skill acquisition, where varied interpretations of what constitutes 'skills' are seen as encompassing expertise, elaboration of knapping activities, standardization and fluidity in artifact morphologies, and their technological, functional or aesthetic dimensions (Bamforth and Finlay 2008; Bleed 2008; Pelegrin 1990). Skill acquisition involves concepts of knowledge, applications, and standards (Bleed 2008) that draw on cognitive and motor activities that require learning and practicing (Roux 1990) and can range from ordinary production to elaborate knapping (Pelegrin 1990). Skill acquisition is closely associated with teaching and the social context of specific activities in diverse functional spaces within the purview of aspects of demonstration and direct intervention (Tehrani and Reide 2008). Associated issues involve debates on the cultural transmission of traditions (Boyd and Richerson 1996; Shennan 2002), degrees of stability of these 'traditions' in populations across space and time, and social learning through imitation, emulation, with/without language with structured methods or within environments that facilitate learning amidst novices (Csibra and Gergely 2006; Putt et al. 2014; Tehrani and Riede 2008).

Despite variability in inferences drawn from ethnographic evidence of craft traditions involving differing ways of observation, play, and mentorship, most argue for the need for adult guidance through pathways of procedural knowledge (Pelegrin 1990; Tehrani and Riede 2008). In such cases, "scaffolding" or integrating novices into the work of experts with or without extensive communication may be seen (Csibra and Gergely 2006; Greenfield 1984; Muller et al. 2017; Stout 2002; Stout et al. 2019). Discussions also include questions about innate abilities and the practice of reaching high skill levels (Olausson 2008).

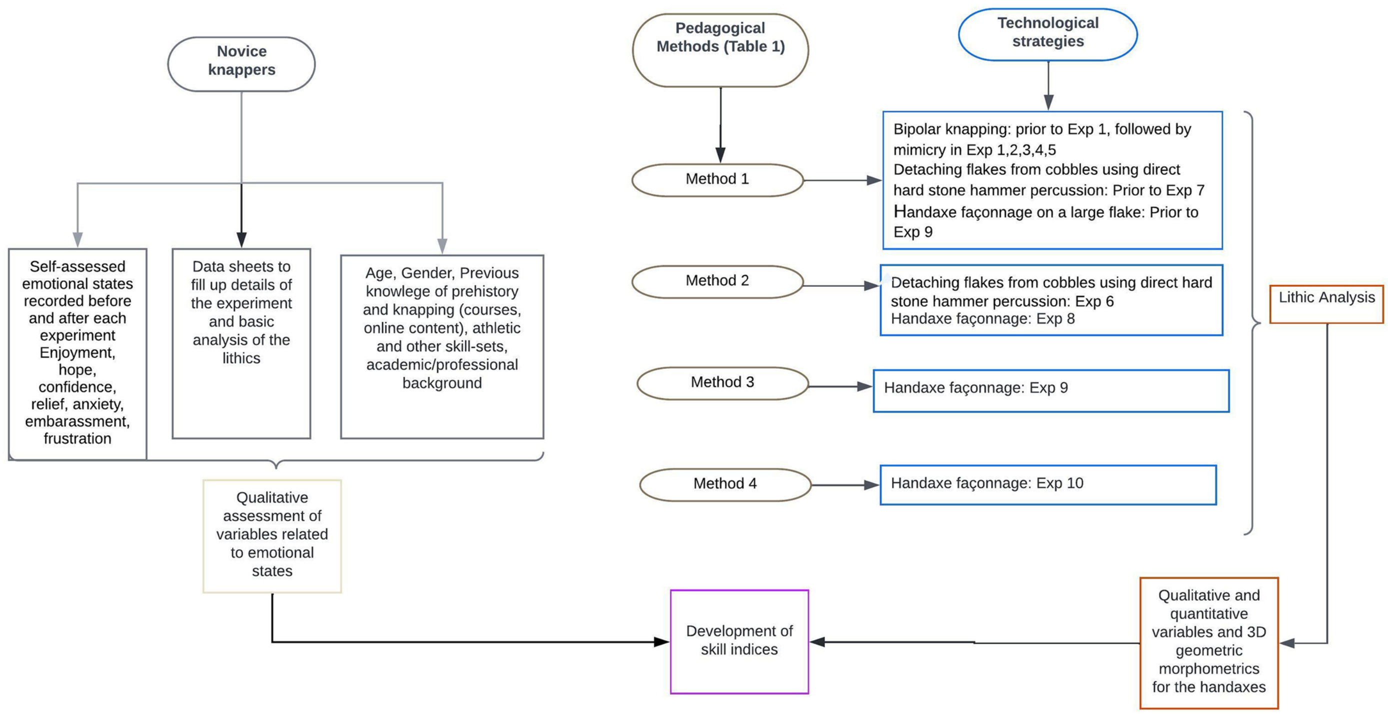


Figure 1. Schematic representation of the structure of the experiments.

These issues, as structured through experimental knapping, have been a vital aspect of the discussion in Lower Paleolithic research, despite an acknowledgment of differences in hominin species and in varied skill sets and professional/academic backgrounds that influence novice knappers (Assaf 2021; Badger and MacDonald 2007; Boyette and Hewlett 2018; Goren-Inbar 2011; Hewlett and Roulette 2016; Hewlett et al. 2011; Katsuhiko et al. 1997; Metin et al. 2016, 2020; Morgan et al. 2015; Musgrave et al. 2016, 2020; Nowell and White 2012; Petraglia et al. 2005; Putt 2015; Putt and Wijeakumar 2018; Stout and Khreisheh 2015; Stout et al. 2005). Different variables are used to identify novices in the archeological record with varied estimates of the duration to acquire expertise during which conceptual and motor skills are interwoven into practical manifestations that vary across social contexts (Earl and Bonnichsen 1984; Morgan et al. 2015). In this context, studies of India's long craft traditions highlight the immersion of the pupil in diverse dimensions of the master's life (Coomaraswamy 1909; Kramrisch 1958).

> "After the hand and eye and memory have been trained...", the pupil gains experience in practical work there being ".. nothing dilettante about the young craftsman's education. It begins early and is exceedingly thorough" (Coomaraswamy 1909: 89).

Compared with global studies, Indian prehistory has witnessed relatively sparse structured lithic knapping experiments despite a rich prehistoric record dating back to around 1 to 1.7 Ma (Pappu et al. 2011). The few studies concern themes on hominin cognition, building around raw materials, specific technological strategies and tool types, as well as modes of pedagogy (Akhilesh and Pappu 2015, 2023; Shipton and Nielson 2018; Shipton et al. 2009; 2018; Sinha 1999; Pal 2002; Polley 2010).

Here, we focus on three different technological strategies associated with Lower Paleolithic hominins (bipolar knapping, detaching flakes from cobble cores, and handaxe *façonnage*) to investigate the effects of specific teaching methods and modes of skill acquisition by novice knappers, as well as variability arising from individual efforts (Figure 1, Table 1). We seek to complement existing studies on knowledge acquisition (Lombao et al. 2017; Pargeter et al. 2020; Shipton and Clarkson 2015; Shipton and Nielsen 2018; Wilson et al. 2023; Zaidner 2013). Studies of the associated lithic assemblages generated as a result of these diverse methods are significant for assessing alternate modes of skill acquisition for interpreting the Paleolithic record and serve as guidelines for devising integrated pedagogical strategies for teaching lithic knapping in the modern classroom (Akhilesh and Pappu 2023). Here, we discuss experimental and experiential approaches toward examining ways of teaching and learning stone tool knapping, acknowledging diverse ways in which novices acquire skills in traditional societies within highly social settings (Boyd and Richerson, 1993; Herzlinger et al. 2017).

METHODOLOGY

PARTICIPANTS

A total of 13 participants were involved in the experiment (co-authors Yeshaswini Rajagopalan, Shalaish Baisla, Ankita Dey, Surendra Ghaskadbi, Balasubramanian Karthick,

TABLE 1. DESCRIPTION OF PEDAGOGICAL METHODOLOGIES IN ALL EXPERIMENTS (see Figure 1).

Methods of Pedagogy	Aim	Description	Experiments
Method 1	Assessing the level of skill acquisition based on observation and mimicry of a master knapper.	Demonstration of a specific technique by the 'teacher;' observation by novices, followed by mimicry.	• Bipolar knapping: prior to Exp 1, followed by mimicry in Exp 1, 2, 3 ,4, 5 • Detaching flakes from cobbles using direct hard stone hammer percussion: Prior to Exp 7 • Handaxe *façonnage* on a large flake: Prior to Exp 9
Method 2	Assessing to what extent novices can replicate technological strategies based solely on the observation of an artifact without any inputs from the master knapper.	'Reverse engineering': observation of archeological or experimental artifacts followed by attempts by the novices to replicate the same technology.	• Detaching flakes from cobbles using direct hard stone hammer percussion: Exp 6 • Handaxe *façonnage*: Exp 8
Method 3	Assessment of whether novice knappers can derive ideas to resolve knapping errors merely by observation of how the master knapper approaches various problems that arise during knapping.	Observation of the 'teacher' resolving common errors arising in knapping on the artifact he was shaping, following which participants could either copy the same strategies or adopt new solutions on their own artifacts.	• Handaxe *façonnage*: during Exp 9
Method 4	To assess when novices desire the master knapper to directly intervene on their partially completed artifacts to resolve problems. To investigate whether this communication and interaction improves their learning skills.	Direct intervention by the 'teacher' to resolve problems encountered by novices, working on the tools that they were knapping. The novice knappers approached the 'teacher' only if they had specific problems that they were unable to resolve themselves.	• Handaxe *façonnage*: during Exp 10

Mrudula Mane, Akash Pandey, Srinath Perur, Chandni Roy, Alok Sharma, Ammel Sharon, Chintan Thakar, Swati Verma); their names are replaced by code numbers (Supplementary Table S1). Novices were informed of the experiment's goals and signed participation consent forms before the project's initiation. They also signed data confidentiality and informed consent forms, agreeing to be co-authors for this publication. They granted permission to use photographic and other materials recorded in the experiments for academic purposes. The experimental workshop was held from May 30 to June 5, 2022**.**

Almost all participants had some knowledge of lithic knapping, primarily through online videos or lectures (see Supplementary Table S1). Only four participants (F2, F3, F5, M3) had experienced a knapping workshop yet possessed skills limited to a novice level, as indicated by knapping results (discussed in this paper) and their self-acknowledgment. The selection of a mix of archaeologists and those from other professions/academic fields was based on the premise that traditional communities would necessarily include novices with varied knowledge and skill levels, observing and imitating experts and being introduced to craft traditions using diverse methods. Rarely would there be complete ignorance of tool manufacture and use (Kramrisch 1958; see Metin 2016 regarding blind tests). Further, the prevalence of content related to prehistory on widely accessible social media and other online portals leads to a situation where complete ignorance of the subject matter may be rare. We situate the experiments in a social and experiential context, acknowledging that this would lead to variables over which one may not have complete control, and yet providing a rich wealth of information ranging from attitudes to lithic attributes (Hewlett et al. 2011; Naveh 2016; Terashima and Hewlett 2016).

EXPERIMENTS AND PEDAGOGICAL STRATEGIES

Experiments included Lower Paleolithic technological strategies comprising bipolar knapping of cobbles, direct hard-hammer percussion to detach flakes from cobble cores, and handaxe *façonnage* on large flakes. The sequence of these technological strategies marks a gradual increase in complexity and skill. The pedagogies implemented in our experiments are summarized in Table 1. Method 1 was based on the principle of observation and mimicry in pedagogy. 'Reverse engineering' or Method 2 comprised observation of tools followed by attempts to replicate them. In Method 3, the expert knapper ('teacher') knapped a handaxe, intentionally generating and rectifying common errors. Novices could observe the rectification process and copy that; alternately, they could resolve problems they faced with other solutions. In Method 4, the teacher directly intervened, resolving errors on the novices' handaxes if and when they desired. Each experiment had distinct aims related to modes of skill acquisition and implications for interpreting aspects of Paleolithic assemblages (see Table 1, Figure 1). Results presented here are organized based on the different technological strategies (bipolar knapping, detaching flakes from cores, handaxe *façonnage*) wherein diverse pedagogical methods were employed. Thus, although Method 1 was utilized in bipolar knapping (Exp 1–5) and hard stone hammer percussion (Exp 7), the variability in the technological skills involved in each set of knapping strategies led to different learning outcomes visible in the cores, waste products, and tools generated.

All participants had to strictly abide safety norms by wearing protective goggles, gloves, and shoes during knapping. Kumar Akhilesh (henceforth KA) functioned as the expert 'teacher', owing to his long experience in lithic experimental studies and teaching knapping to children, university students, faculty, and the interested public for over a decade (Akhilesh and Pappu 2015, 2023). Prachi Joshi (PJ) and Shanti Pappu (SP) (prehistorians) recorded observations. Raw materials selected were quartz, quartzites, quartzitic sandstones, chert, dolerite, and granite. In each experiment, controls were maintained over the nature of raw materials (properties, size, shape) to eliminate variability and to be able to estimate degrees of reduction uniformly. Cobbles, pebbles, and flakes suitable for use as cores, blanks, and hammerstones were organized in a yard and divided into sections for each experiment (Figure 2A, B). Participants were permitted to exercise their judgment in the selection processes and assess the difficulty level in making these choices (Figure 2C, D, E).

The organization of each experiment involved a circular seating arrangement to facilitate interaction and recording. Participants could choose their place and change it as they wished. They could also converse among themselves. Seating places and the extent of the conversation were recorded (Figure 3A, B, C)**.** Documentation of knapping postures aided in understanding whether novices mimicked the teacher or were based on individual comfort levels (Figure 3D).

Skill levels were assessed based on the results of the lithics produced, culminating in the generation of indices to evaluate questions of interest (see Table 1). After the experiments, although some analysis was done during the workshop by the participants, all artifacts were re-analyzed by KA, PJ, SP, and Yeshaswini Rajagopalan (YR) (for attributes selected, refer to Supplementary Table S2). Each experiment was judged to be completed once the task given to the participants was achieved, e.g., the completion of the bipolar knapping of pebbles. 3D geometric morphometric studies of handaxe shapes and symmetry were undertaken following established protocols (Herzlinger and Goren-Inbar 2020; Herzlinger and Grosman 2018; Herzlinger et al. 2017; 2021). In addition, we conducted a Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) ranking as described below.

TOPSIS is a widely used multi-criteria decision-making method that can be applied to various fields. The TOPSIS method was first introduced and discussed by Hwang and Yoon (1981), and it enables users to effectively handle complex decision-making problems by considering multiple criteria simultaneously. Here, differing variables related to the lithics (cores, flakes, and tools) were selected to

Figure 2. The raw material yard showing: A) organization of rock samples for the different experiments; B) participants being introduced to the organization of the raw material yard; C) selection of hammerstones by participants; D) selection of raw material by participants for Exp 6, 7; E) participants selecting large flakes for Exp 8–10; F) choice of a thin triangular shaped large flake by one participant.

assess skill levels (Bradley and Khreisheh 2015, Cattabriga and Peresani 2024; Foulds 2013; Muller et al. 2022; Proffitt et al. 2022; Stout and Semaw 2006). The TOPSIS method was adopted to obtain a single score for each participant by factoring in these diverse variables. Thus, the objective of the TOPSIS method here is to rank the participants by considering various criteria from the three sets of experiments. Details of the TOPSIS decision-making process and variables are discussed in the Supplementary Information.

In addition to lithic attributes, we encouraged participants to record their emotional states before and after each experiment, grading them on a scale of 0–5 in ascending order of influence (Figures 4, 5, and Supplementary Figure S1). These qualitative observations are useful for experts teaching lithic knapping in classroom situations.

RESULTS OF THE KNAPPING EXPERIMENTS

Here, we discuss the results obtained from each set of experiments dealing with differing technological strategies in terms of the structure of the experiment, the nature of the lithics generated, and the self-assessed emotional states of the participants. We also discuss the pedagogical strategies adopted for each set of experiments (see Table 1).

BIPOLAR KNAPPING (EXPERIMENTS 1 TO 5)

Globally, one observes considerable variability in bipolar

Figure 3. An example of seating arrangements during handaxe façonnage experiments showing: A) circular organization of seating in Exp 8; B) i. position of the expert knapper KA and a participant sitting adjacent to him during Exp 9 to observe demonstration of rectification of knapping errors, ii. seating arrangements in Exp 9; and, iii. participant observing how expert knapper KA resolves errors while working on his handaxe; C) i–iii seating arrangements in Exp 10. Note the change in participants' seating arrangements. The arrows indicate conversation between individual participants, with yellow arrows marking greater interaction; (D) seating postures of participants during knapping showing: i–v. specific postures adopted during bipolar knapping. Note that these often differed from the kneeling posture demonstrated by KA (i); E) knapping postures for Exp 6 and 7 (hard hammer flaking of cobble cores). [The alphanumeric codes represent participants (M, black=male; F, blue=female) with positions of expert knapper (KA) and recorders (SP, PJ)].

- Enjoyment: to learn new skills
- Hope: to master the said skills
- Confidence: in the capability to do so
- Relief: in achieving desired goals
- Anxiety: to be able to complete the given task
- Embarrassment: in comparison to other participants' success
- Frustration: in lack of achievement of desired goals
- Learning mode: ability to achieve the task without intervention
- Learning curve: degree of skill enhancement

Figure 4. Emotional states were self-assessed by participants and ranked on a scale of 1–5 (lowest to highest) before and after each experiment.

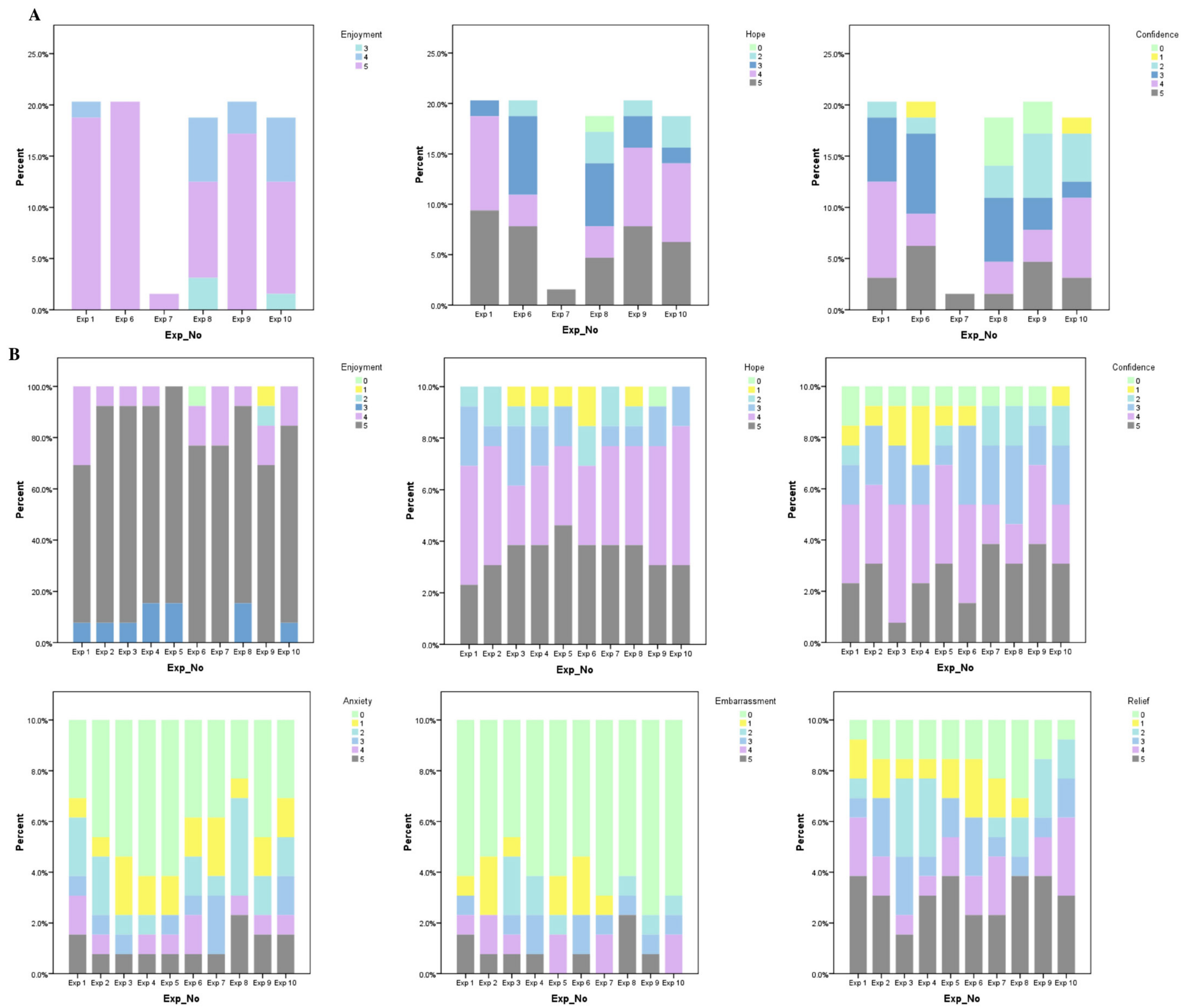


Figure 5. Self-assessed emotional states ranked on a scale of 1 to 5, showing: A) variability in emotional states before each experiment; and, B) variability in emotional stages after each experiment.

knapping strategies (Diez-Martín et al. 2011; Duke and Pargeter 2015); here, we chose to replicate only one method, i.e., slicing a pebble on an anvil. This method was selected owing to the ability to judge skills in splitting the pebble, achieving symmetry in obtaining two segments and assessing hand-eye coordination. The goal was to determine skill acquisition based on observation of techniques and mimicry of an expert knapper (KA) (Method 1) (see Table 1). We organized thirteen sets of five pebbles in the raw material yard. Participants were allowed to choose any set, along with a dolerite hammerstone (rounded and elongated cobble) and an anvil (cobble with two flat faces) (Figure 6A). Participants observed KA demonstrating bipolar knapping of pebbles and then mimicked this in five experiments.

RESULTS OF BIPOLAR KNAPPING EXPERIMENTS

Success Rates, Number of Blows, and Segments Obtained

From Exp 1 onwards, most participants grasped the concept and could split the pebble (Figure 7A). However, the ability to repeatedly split the pebble into two symmetrical segments was inconsistent (Figure 7B). Further, there was no reduction in the number of blows required to split the pebble throughout the experiments (Figure 7C). On average, the pebbles were split into two segments after 1–5 blows (see Figure 6E, G; Figure 7D). Participants could not split the pebble in several instances despite repeated blows, resulting in shatter and percussion marks (Figure 6H). Throughout Exp 1 to 5, we noted errors such as a failure to initiate breakage, shattering of the pebble, and a varied number of blows to split the pebble (Figures 6B, C, D, H; Figure 7). Participants expressed difficulty in choosing suitable pebbles, hammerstones, and anvils in the raw material yard (Figure 7E). Pitting marks were noted on anvils and percussion marks on hammerstones at the end of all experiments (Figure 6F). Only one hammerstone broke.

Metrical Dimensions

The mean dimensions (length, breadth, thickness, and weight) of artifacts used are as follows: anvils (114.23 x 85.92 x 45.12mm, 803.62gm), hammerstones (103.54 x 73.69 x 48.09mm, 649.77gm) and pebbles (42.31 x 32.09 x 19.08mm, 54.20gm). Standardization of sizes was ensured before the experiments. We noted minimal variability in the dimensions of the segments obtained after bipolar knapping (Figure 8A). However, compared to Exp 1, greater control was noted in Exp 5 with detachment of longer and thinner segments (Figure 8B). Thus, skill enhancement is not seen in terms of splitting the pebble into two symmetrical halves. Instead, it occurs in the ability to maintain some degree of control when splitting the pebble.

Self-Assessed Emotional States Before Beginning the Experiments

Participants displayed high anticipated enjoyment and hope in achieving their goals. Confidence levels varied. Anxiety levels were overall low. However, high anxiety levels were not related to the intensity of other emotional stages (see Supplementary Figure S1).

Self-Assessed Emotional States After Completion of Each experiment

Enjoyment levels are uniformly high in all experiments, irrespective of success and failure; this is primarily owing to the exhilaration of the ability to break the stone (see Figure 5). Confidence levels were high regardless of success or failure or achievement of symmetrical slicing of cobbles, dropping in cases where numerous blows were required. Levels of relief followed the degree of success in completing the task rather than perfection levels, with a few participants displaying lower levels when a higher number of blows was required to split the pebble (see Figure 5). Anxiety levels generally decreased from Exp 1 to Exp 5, with a change occurring in Exp 3. However, in several instances, we noted consistently high levels of anxiety (see Figure 5). Embarrassment levels reflected perceptions of their ability compared to others and varied as per individuals, irrespective of success rates (see Figure 5). Frustration was based on success in splitting the pebble and the number of blows required, but it varied according to individual personalities.

Problems faced by all participants included trouble in achieving the following: 1) the correct angle and force to split the pebble, 2) balancing the pebble on the anvil, 3) hand-eye coordination, and 4) disconformity in choosing a suitable sitting posture. Except for one participant, all felt the demonstration was sufficient to mimic. Almost all novices succeeded in opening the pebbles regardless of whether they could slice these perfectly into two segments or not, with variability in success rates through the experiment sequence.

DETACHMENT OF FLAKES FROM COBBLE CORES BY FREEHAND STONE HAMMER PERCUSSION (EXPERIMENTS 6 AND 7)

In this set of experiments, the goal was to investigate skill acquisition in detaching flakes from cobble cores based on 'reverse engineering' and observation and mimicry of a master knapper (KA) (Methods 1 and 2) (see Table 1; Tables 2, 3, Figures 9, 10, 11). The goal was to reduce the core as far as possible within a fixed duration of 30 minutes per experiment and to generate flakes with suitable cutting edges. Participants were free to select suitable cobbles (n=2 for Exp 6 and 7, quartzite/quartzitic sandstone), hammerstones (n=1, dolerite), and anvil (n=1, dolerite) from the section demarcation in the raw material yard (Figure 9B). The dimensions and morphology of cobbles laid out in Exp 7 were intentionally different from those in Exp 6, which increased the task's difficulty levels. Owing to the initial standardization of raw materials and cobble morphologies, the success or failure of novice knappers was a reflection of skill rather than faults in the rocks selected.

Before Exp 6, participants had observed cores and flakes in the lab; subsequently, they proceeded to detach as many flakes as possible from the selected cobble (Method

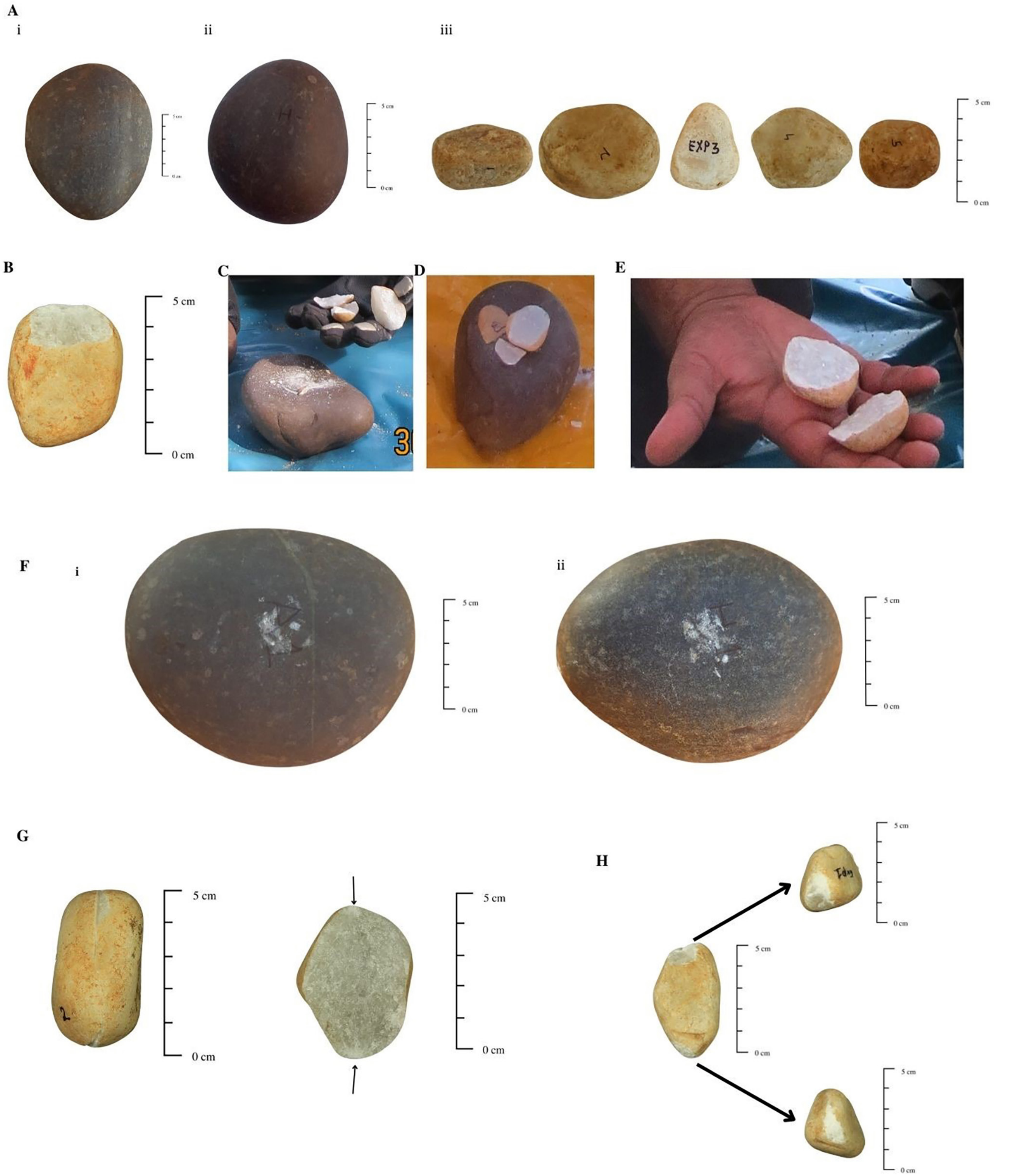


Figure 6. Bipolar knapping showing: A) examples of i. anvil, ii. hammerstone, iii. five pebbles used in Exp 1–5; B) intact pebble with percussion marks arising from an inability to split the same; C) shattered pebble; D) pebble shattered into more than two segments; E) pebble split into two segments; F) pitting and percussion marks on i. anvil, ii. hammerstone; G) percussion marks on a pebble where the participant successfully sliced the pebble into two segments; H) percussion marks on an unsuccessful attempt to split the pebble.

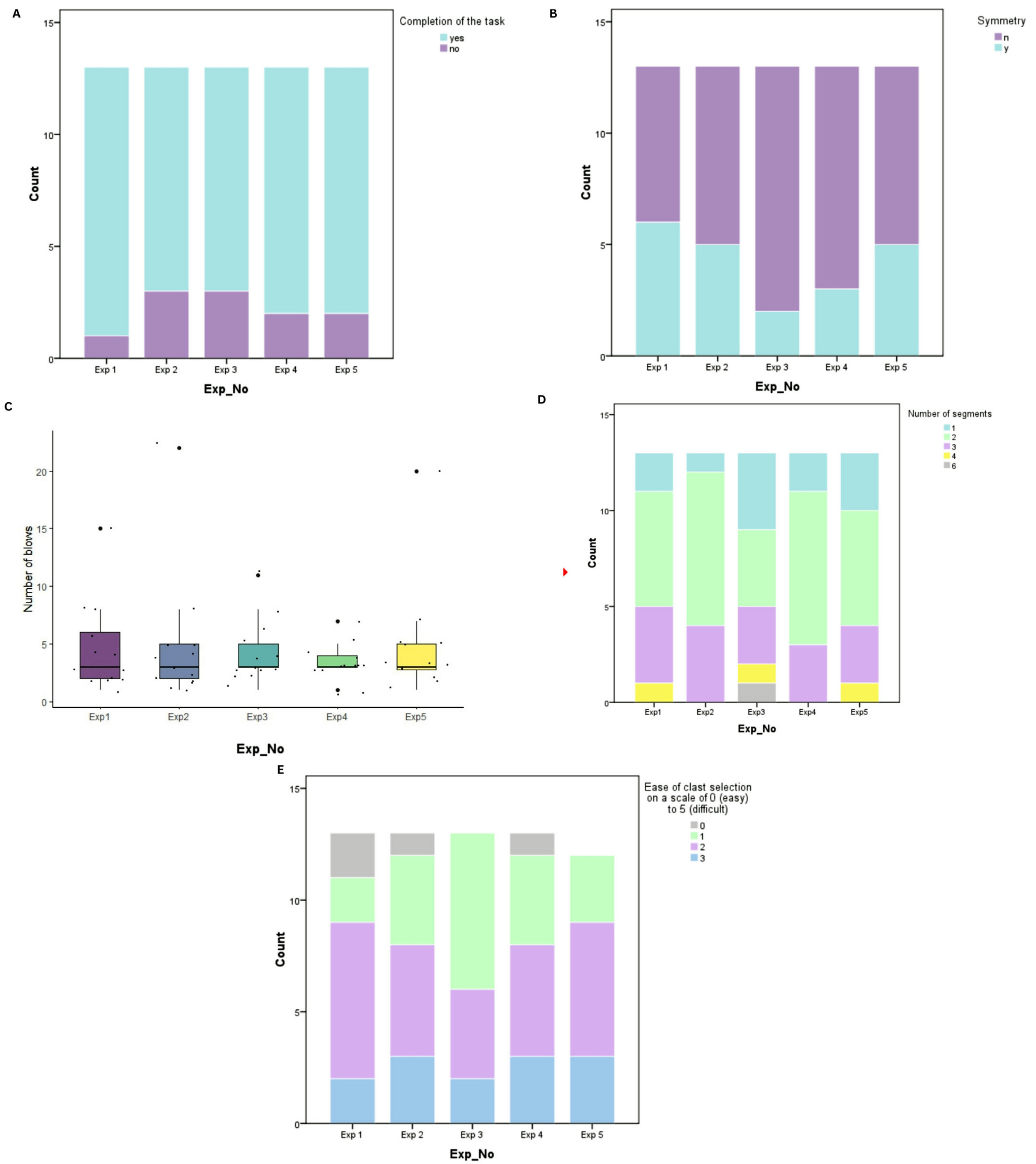


Figure 7. Results of splitting pebbles using bipolar knapping (Exp 1 to Exp 5) showing: A) rates of success and failure rates in the experiments; B) rates for achieving success in slicing the pebble into two symmetrical segments; (y=yes, n=no); C) number of blows employed to achieve desired results; D) number of segments obtained from knapping each pebble; E) Scale of difficulty in selecting suitable pebbles (on a scale of 0 to 5, with 0 being the easiest and 5 implying the highest level of difficulty).

A

B

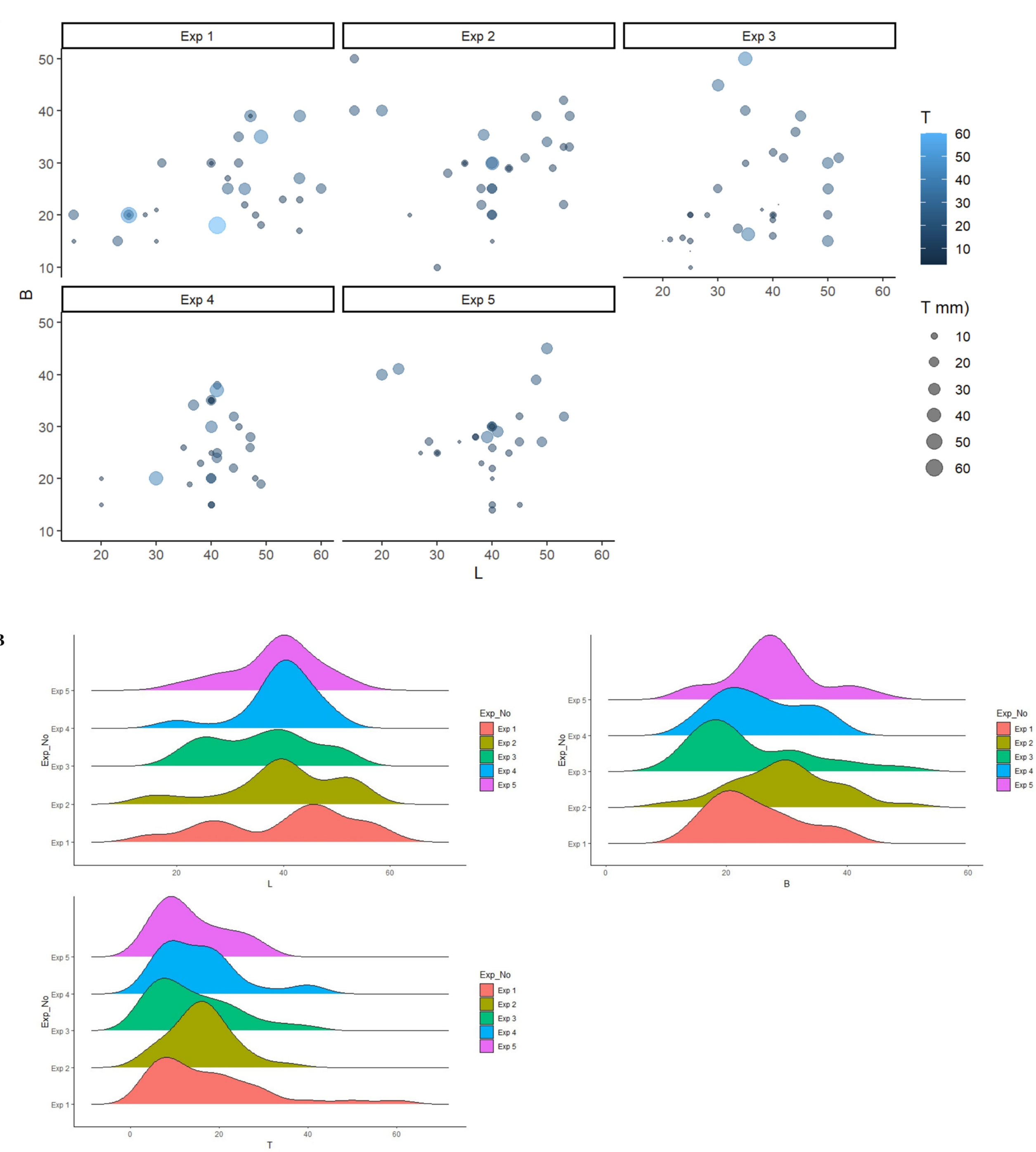


Figure 8. Results of splitting pebbles using bipolar knapping (Exp 1 to Exp 5) showing: A) dimensions of segments in Exp 1 to Exp 5; B) ridge plots of segments showing individual dimensions of segments in each experiment (dimensions are in mm).

2). Before Exp 7, KA demonstrated the detachment of flakes from a cobble using direct hard hammer percussion (Method 1), following which participants proceeded to mimic the same. One participant broke two hammerstones (H1: 114 x 73 x 38mm, 495gm, H2: 124 x 104 x 54mm, 1059gm) before the final one was used. A deconstruction of flaking patterns is provided in Supplementary Table S3.

RESULTS OF KNAPPING COBBLES TO DETACH FLAKES USING HARD HAMMER PERCUSSION

Qualitative Observations Based on Participant Feedback

All participants found it easy to select suitable clasts (difficulty was ≤2 to 3 on a scale of increasing difficulty (0 to

TABLE 2. DEGREE OF REDUCTION IN CORES IN EXP 6 AND 7.

A-Cortex percentage retained on the cores

	Exp 6		Exp 7	
Percentage of cortex coverage	**Count**	**Table N %**	**Count**	**Table N %**
0–25	1	3.8	1	3.8
25–50	0	0	1	3.8
50	1	3.8	0	0
50–75	3	11.5	5	19.2
75–100	5	19.2	5	19.2
100	3	11.5	0	0
na (broken)	0	0	1	3.8
Total	**13**	**50.0**	**13**	**50.0**

B-Organization of flake scar removals on cores

	Exp 6		Exp 7	
organization of flake scars	**Count**	**Table N %**	**Count**	**Table N %**
bidirectional	3	11.50	3	11.50
bifacial	1	3.80	3	11.50
centripetal	1	3.80	0	0
multidirectional	1	3.80	1	3.80
peripheral multifacial	0	0	1	3.80
undirectional	4	15.30	4	15.40
not applicable	3	11.50	1	3.80
Total	**13**	**50.0**	**13**	**50.0**

C-Comparison of number of flakes versus number of flake scars on the cores

	Exp 6		Exp 7	
Number of visible flake scars on the core	**Count**	**Table N %**	**Count**	**Table N %**
0	3	11.5	1	3.8
1	2	7.7	0	0
2	1	3.8	3	11.5
3	2	7.7	1	3.8
4	1	3.8	1	3.8
5	0	0	1	3.8
6	1	3.8	1	3.8
7	1	3.8	1	3.8
8	1	3.8	0	0
9	0	0	2	7.7
11	0	0	1	3.8
13	1	3.8	0	0
15	0	0	1	3.8
Total	**13**	**50.0**	**13**	**50.0**
The actual number of flakes generated	**64**	**36.20**	**113**	**63.80**

Early View available online 3 December 2024

TABLE 3. WASTE PRODUCTS ARISING FROM FLAKING COBBLES WITH HARD STONE HAMMER PERCUSSION IN EXP 6 and EXP 7 (L=length, B=breadth, T=thickness, Wt=weight).

A-Dimensions

Exp. No.	Waste products		L (mm)	B (mm)	T (mm)	Wt (gms)
Exp 6	Angular/blocky piece	N	4	4	4	4
		Mean	33.76	39.61	15.52	20.75
		Minimum	29.70	16.50	9.60	12.00
		Maximum	42.30	52.04	20.05	28.00
		Std. Deviation	5.86	15.79	4.39	7.54
	Flake	N	60	60	60	60
		Mean	38.57	40.27	12.62	32.65
		Minimum	14.62	14.64	3.65	1.00
		Maximum	76.00	86.00	76.70	199.00
		Std. Deviation	16.35	17.85	11.11	47.37
Exp 7	Angular/blocky piece	N	16	16	16	16
		Mean	65.71	40.36	23.14	161.56
		Minimum	29.80	21.00	5.00	11.00
		Maximum	144.28	77.30	75.85	1016.00
		Std. Deviation	29.53	17.58	20.42	283.14
	Flake	N	97	97	97	97
		Mean	45.59	50.26	15.57	53.61
		Minimum	16.00	7.91	1.00	3.00
		Maximum	99.20	121.39	74.60	294.00
		Std. Deviation	17.28	22.54	10.99	62.96

B-Dimensions of flakes (organized following Toth [1987])

Flakes as defined by Toth (1987)	Exp. No.		L (mm)	B (mm)	T (mm)	Wt (gms)
Flake type I: Cortical platform, cortical dorsal surface	Exp 6	N	10	10	10	10
		Mean	45.62	54.46	16.59	68.40
		Minimum	23.96	24.80	8.80	8.00
		Maximum	71.50	86.00	27.70	199.00
		Std. Deviation	18.00	18.00	7.24	68.85
	Exp 7	N	12	12	12	12
		Mean	46.26	67.98	16.31	72.17
		Minimum	20.00	30.06	5.00	5.00
		Maximum	90.93	121.39	26.32	169.00
		Std. Deviation	18.85	28.95	7.11	60.79

5). A participant who could not open the cobble in successive attempts in Exp 7 recorded great difficulty in selecting cobbles. The difficulty levels recorded by participants were unrelated to their success or failure in the experiments. Anticipated enjoyment levels were high before the experiment commenced, touching a scale of 5. Almost all participants except one expressed high hopes and confidence, the exceptions being those who performed poorly in the preceding experiment. Anxiety levels varied (see Supplementary Figure S1).

TABLE 3. WASTE PRODUCTS ARISING FROM FLAKING COBBLES WITH HARD STONE HAMMER PERCUSSION IN EXP 6 and EXP 7 (L=length, B=breadth, T=thickness, Wt=weight). (continued)

B-Dimensions of flakes (organized following Toth [1987])

Flakes as defined by Toth (1987)	Exp. No.		L (mm)	B (mm)	T (mm)	Wt (gms)
Flake type II: Cortical platform, partially cortical dorsal surface	Exp 6	N	14	14	14	14
		Mean	44.66	47.56	19.79	52.86
		Minimum	20.70	17.10	4.36	3.00
		Maximum	76.00	85.00	76.70	188.00
		Std. Deviation	18.07	21.06	19.32	61.52
	Exp 7	N	27	27	27	27
		Mean	51.74	58.52	21.39	81.15
		Minimum	26.00	28.00	8.00	9.00
		Maximum	99.20	93.00	74.60	294.00
		Std. Deviation	18.65	16.53	14.09	79.62
Flake type III: Cortical platform, noncortical dorsal surface	Exp 6	N	7	7	7	7
		Mean	35.46	31.10	8.49	10.14
		Minimum	17.91	15.01	6.10	5.00
		Maximum	49.50	57.87	14.16	27.00
		Std. Deviation	9.53	13.41	3.06	7.97
	Exp 7	N	15	15	15	15
		Mean	37.24	36.03	9.56	20.60
		Minimum	28.00	7.91	5.00	4.00
		Maximum	59.17	76.90	19.46	93.00
		Std. Deviation	11.28	19.30	3.68	25.24
Flake type IV: Noncortical platform, cortical dorsal surface	Exp 6	N	3	3	3	3
		Mean	42.12	38.12	12.40	22.00
		Minimum	34.45	32.50	10.16	15.00
		Maximum	46.46	42.15	14.41	36.00
		Std. Deviation	6.66	5.02	2.13	12.12
	Exp 7	N	3	3	3	3
		Mean	41.27	45.20	15.48	48.00
		Minimum	30.00	28.00	8.00	11.00
		Maximum	58.80	59.60	26.45	111.00
		Std. Deviation	15.39	15.98	9.71	54.84
Flake type V: Noncortical platform, partially cortical dorsal surface	Exp 6	N	14	14	14	14
		Mean	41.33	39.64	10.68	24.71
		Minimum	19.65	20.00	5.00	4.00
		Maximum	76.00	60.00	18.00	86.00
		Std. Deviation	15.07	14.55	3.88	22.73
	Exp 7	N	26	26	26	26
		Mean	46.56	46.62	13.26	43.73
		Minimum	18.00	13.00	1.00	3.00
		Maximum	86.40	95.08	32.00	177.00
		Std. Deviation	17.61	22.59	6.88	47.90

Early View available online 3 December 2024

TABLE 3. WASTE PRODUCTS ARISING FROM FLAKING COBBLES WITH HARD STONE HAMMER PERCUSSION IN EXP 6 and EXP 7 (L=length, B=breadth, T=thickness, Wt=weight). (continued)

B-Dimensions of flakes (organized following Toth [1987])

Flakes as defined by Toth (1987)	Exp. No.		L (mm)	B (mm)	T (mm)	Wt (gms)
Flake type VI: Noncortical platform, noncortical dorsal surface	Exp 6	N	3	3	3	3
		Mean	24.45	29.00	5.91	4.33
		Minimum	22.32	26.00	4.43	3.00
		Maximum	28.02	32.50	8.30	7.00
		Std. Deviation	3.11	3.28	2.09	2.31
	Exp 7	N	12	12	12	12
		Mean	40.78	37.52	13.88	32.08
		Minimum	16.00	21.00	3.00	3.00
		Maximum	72.70	61.40	59.35	225.00
		Std. Deviation	15.84	12.38	15.04	61.56

C-Flake terminations

	Exp 6		Exp 7	
Flake Terminations	**Count**	**Column N %**	**Count**	**Column N %**
feather	37	61.7	68	70.1
broken	13	21.7	20	20.6
step	5	8.3	4	4.1
abrupt	1	1.7	5	5.2
unclear	4	6.7	0	0
Total	**60**	**100.0**	**97**	**100.0**

D-Striking platforms

	Exp 6		Exp 7	
Striking Platform	**Count**	**Column N %**	**Count**	**Column N %**
cortical	32	53.3	53	54.6
plain	20	33.3	37	38.1
facetted	0	0	2	2.1
partly cortical partly plain	0	0	3	3.1
broken	2	3.3	1	1.0
unclear	6	10.0	1	1.0
Total	**60**	**100.0**	**97**	**100.0**

After the experiments, we noted that participants expressed high levels of enjoyment, save for one who failed in Exp 6. Hope levels were based mainly on success rates; anxiety was generally low, except for a few who displayed consistently high levels throughout the experiments. There is a decrease in frustration rates from Exp 6 to 7 and an increase in their perceptions of having a positive learning curve; however, this was not necessarily supported by the lithics generated from knapping (see Supplementary Figure S1).

Observations Based on Metrical Analysis of the Lithic Assemblages

As noted earlier, cobble sizes varied between Exp 6 and 7, with the latter representing larger size ranges (Figure 10A). However, it is significant that in Exp 7, despite the use of

TABLE 3. WASTE PRODUCTS ARISING FROM FLAKING COBBLES WITH HARD STONE HAMMER PERCUSSION IN EXP 6 and EXP 7 (L=length, B=breadth, T=thickness, Wt=weight). (continued)

E-Number of dorsal flake scars

Number of dorsal flake scars	Exp 6		Exp 7	
	Count	Column N %	Count	Column N %
0	25	41.7	19	19.6
1	25	41.7	40	41.2
2	7	11.7	31	32.0
3	3	5.0	5	5.2
5	0	0	1	1.0
unclear	0	0	1	1.0

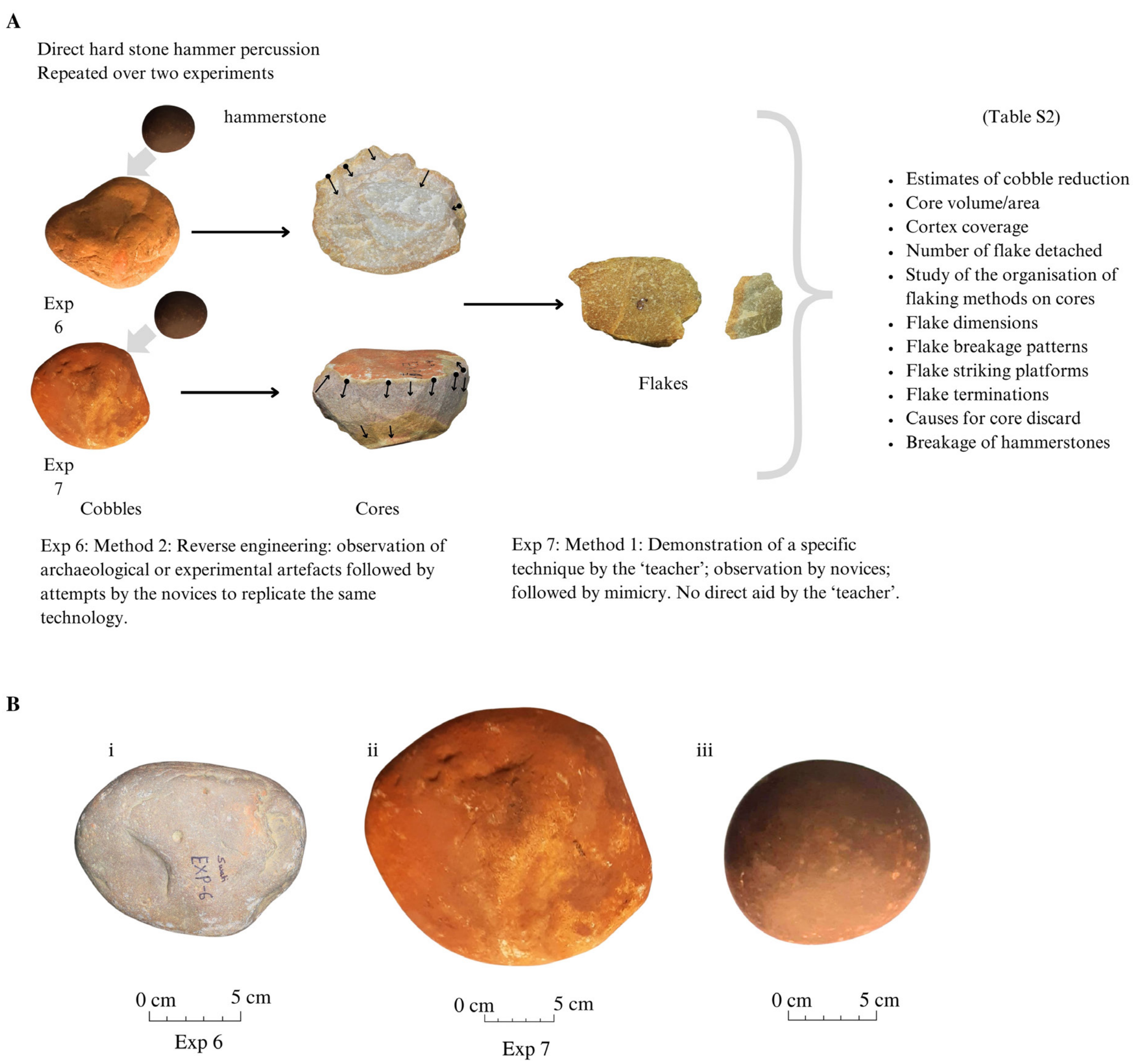


Figure 9. Freehand hard stone hammer flaking of cobbles (Experiments 6 and 7) showing: A) schematic diagram with methodology adopted; B) choice of cobbles for i. Exp 6 ii. Exp 7, and iii. Hammerstones were used in both experiments.

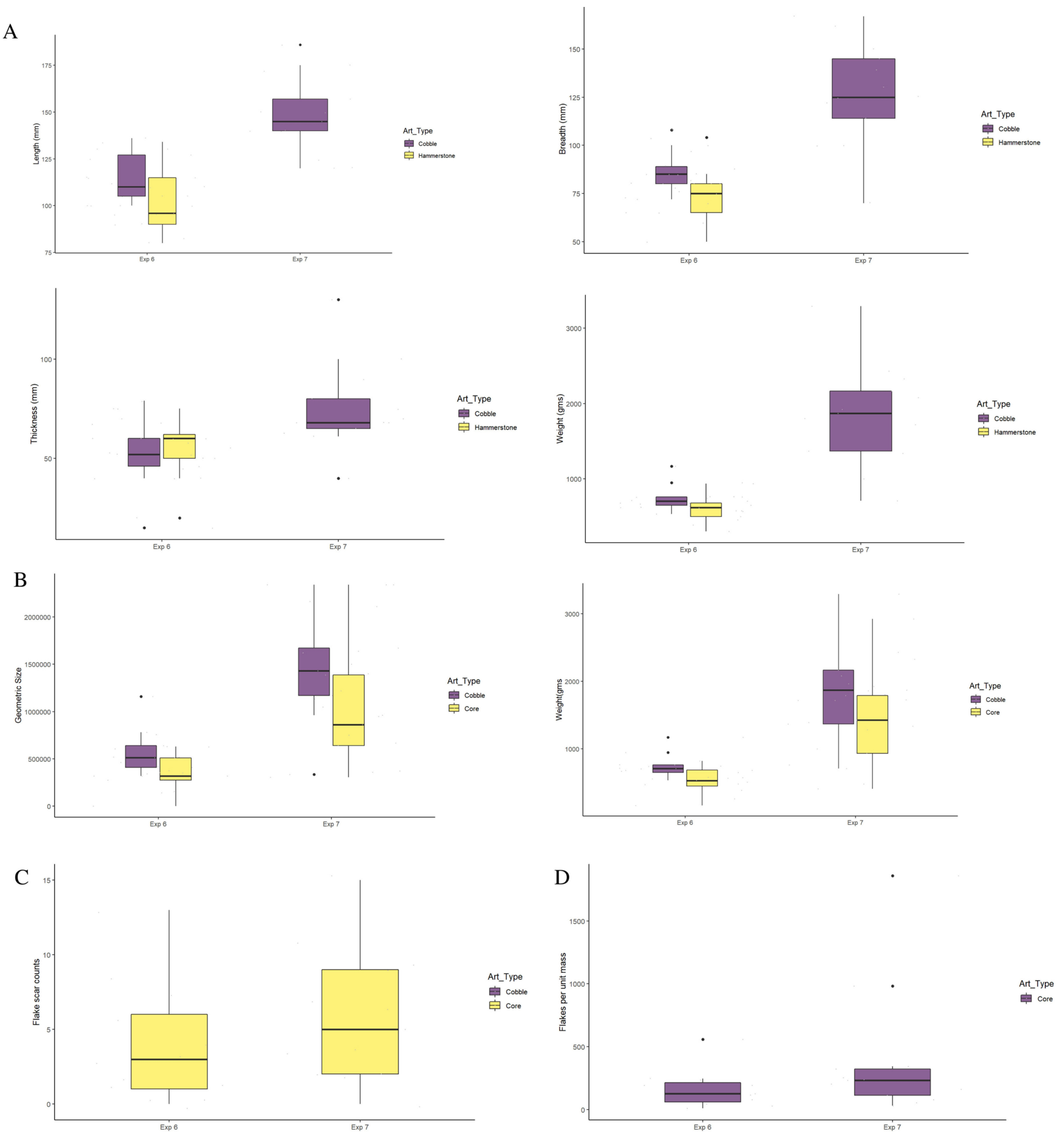


Figure 10. Experiments Exp 6 and Exp 7 showing: A) metrical dimensions of cobbles and hammerstones used in Exp 6 and Exp 7; B) geometric size (Length x Breadth x Thickness) and weights of cores and cobbles; C) number of flake scars noted on cores; D) proportion of flakes per unit mass of the cores for each experiment.

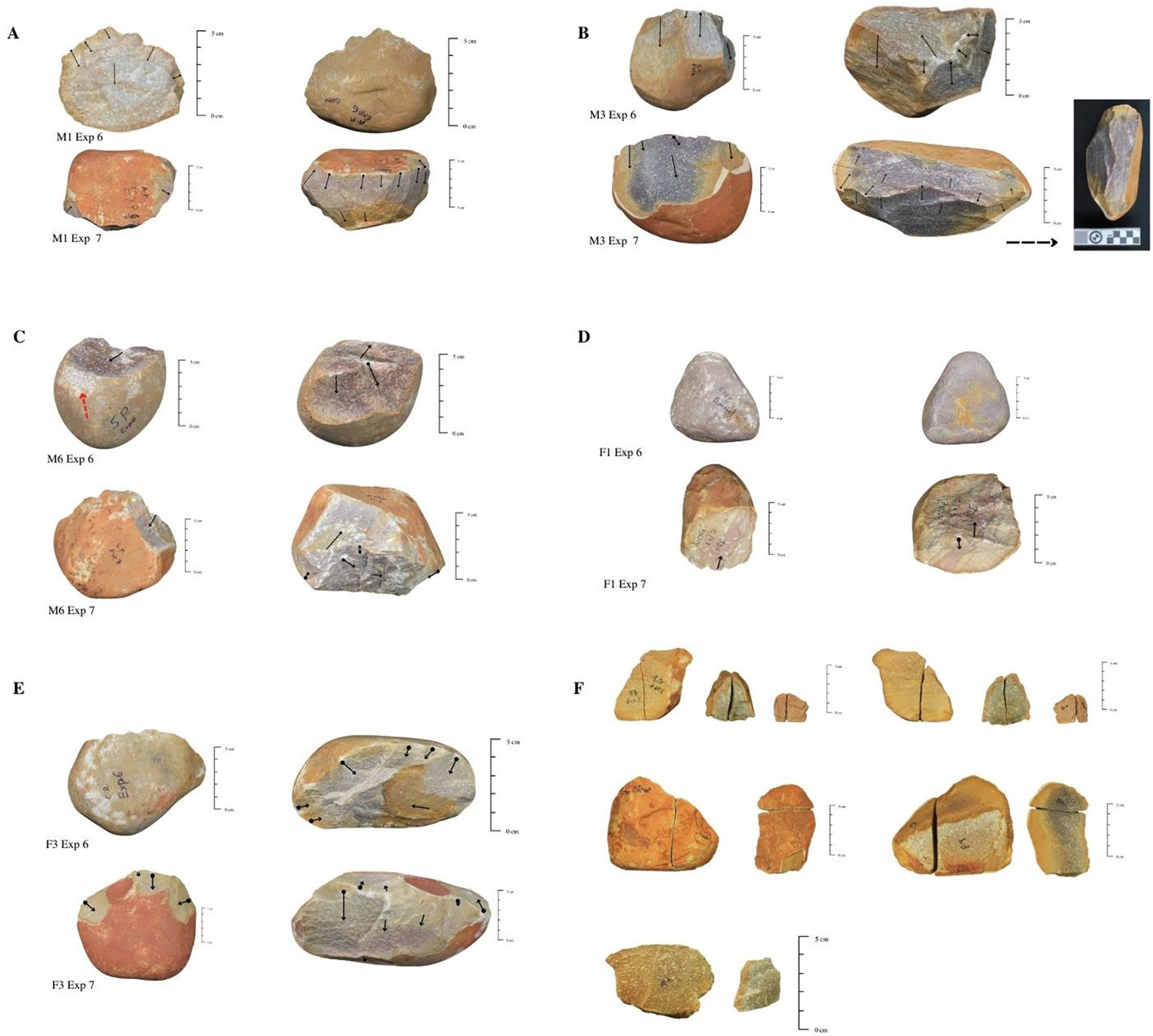


Figure 11. Cores and flakes arising from knapping cobbles in Exp 6 and Exp 7 showing: A-E) different patterns of core reduction strategies employed and shape variability resulting from the same. Note cores unintentionally resembling uni/bifacial choppers (B); F) nature of flakes detached from cores showing types of breakage patterns.

longer, wider, thicker, and heavier cobbles as compared to that of Exp 6, there was no significant reduction in the core (either in terms of geometric size or mass) (Figure 10B, C, D). A simple core reduction formula was selected based on estimates of flake density per unit mass (weight in grams, closely correlated with geometric size, i.e., length x breadth x thickness) (Caruana et al. 2014). The percentage of cortex coverage and number of flakes detached also support this observation. Several participants could not initiate flaking in Exp 6 and achieved this in Exp 7 (Table 2A).

Similar flaking strategies were employed in both Exp 6 and Exp 7, with increased bifacial flaking and peripheral multifacial strategy in the latter case (Table 2B). We note a slightly higher number of flake scars in Exp 7 than Exp 6 as estimated per unit area or mass (Table 2C; see Figure 10; Supplementary Figure S2A, B**).** Most participants struck the cores at angles of ~90°; some adopted the same angle as practiced in bipolar knapping. Some failed to initiate flaking and changed the cobbles. Two participants opened the cobbles by placing them on the ground and attempted to strike using direct percussion. Despite three attempts, one participant was unable to initiate flaking.

An interesting result is that several novice knappers unintentionally achieved a core morphology resembling that of a uni- or bifacial chopper arising from the exploitation of suitable striking platforms along the core-periphery, thereby unintentionally creating a working edge (Figure 11B). Percussion marks elsewhere on the core indicated unsuccessful attempts to initiate flaking elsewhere. This has implications for typological nomenclatures and global debates on the gradation or differentiation between cores and chopper/chopping tools (Ashton et al. 1994).

Analysis of Flakes Detached in Exp 6 and Exp 7

A total of 177 flakes and angular/blocky pieces were detached from both experiments in addition to a large quantity of shatter, with a higher number of flakes in Exp 7 (see Supplementary Figure S2A, B; see Table 3). Flake dimensions increase from Exp 6 to Exp 7. We note an increase in noncortical flakes (flake Type VI; Toth 1987), with more flaking in Exp 7, indicative of a larger original core mass (Table 3B).

Broken flakes occur in both experiments; these slightly exceed complete ones in Exp 6 (broken: 35, 22.3%; complete: 25, 15.9%), while in Exp 7, complete flakes are comparatively higher (broken: 40, 25.5%; complete: 57, 36.3%) (Table 3C, D, E). Few siret breaks occur (n=9 flake halves) (Figure 11F). Broken flake terminations are sparse, decreasing from Exp 6 to Exp 7, with an increase in feather terminations (see Table 3C). In both experiments, striking platforms remained predominantly cortical or plain (see Table 3D). In Exp 7, more flakes have a greater number of dorsal flake scars than those in Exp 6, suggestive of more intensive flaking (see Table 3E). To summarize, there is an increase in controlled flaking in Exp 7 based on dimensions of flake removals, degree of completeness, and the intensity of flaking in terms of core reduction.

HANDAXE *FAÇONNAGE* (EXP 8, 9, 10)

Three pedagogical strategies were adopted here (see Table 1; Figures 12, 13, 14, 15). The first method (Exp 8, Method 2) involved knapping following observation of handaxes displayed in the lithics laboratory without demonstrating bifacial knapping (see Figure 12). In Exp 9 (see Table 1, Method 1), KA demonstrated knapping of a handaxe, with participant observation and subsequent mimicry based on the memory of what was observed. KA added another component to the experiment by continuing to work on his handaxe, intentionally creating and rectifying errors that commonly arise during novice knapping. Participants could approach KA and observe the manner he adopted to solve issues and then mimic the same or use different strategies (see Table 1, Method 3). Care was taken to enable the participants to sit adjacent to KA rather than face him to allow precision in mimicry rather than having to cope with different observation angles in a non-verbal instructive environment. In Exp 10, the strategy shifted, and KA rectified problems through direct intervention using extensive communication (see Table 1, Method 4; see Figures 3, 12).

Before the commencement of Exp 8, despite previous knapping problems, all participants expressed high levels of anticipated enjoyment and confidence, few had low levels of hope; all were anxious (see Figure 5; see Supplementary Figure S1).

Flake blanks were organized into three progressively increasing size categories for each experiment. Most participants (n=10) selected large and thick flakes, expecting that these would be easier to knap; two selected medium flakes, and one selected a small, thin, and roughly pointed flake (see Figure 2F). Failure was attributed to the choice of wrong flakes or a lack of suitable mass; some were unable to pinpoint the correct reason.

All complete handaxes and flakes were analyzed (Tables 4, 5). The increase in handaxe dimensions reflects the initial flake blank sizes (see Table 4). Overall, flake scar counts increased on both faces over time, albeit subject to individual skill variability (Table 4C). Similarly, participants could progressively detach more biface reduction flakes from Exp 8 to Exp 10 (Exp 8=168, Exp 9=409, Exp 10=640). The maximum range in variability in the relative number of flakes per unit weight (volume) of the tool is seen in Exp 9, with an increase in the intensity of flaking through time (see Table 10 below). Details of the surface areas from which flakes were detached also increase progressively (see Table 10 below).

Regarding the reduction intensity, the maximum reduction (weight) is seen in Exp 10 (see Table 4). On completion of the experiments, except for two participants, all others maintained a high enjoyment level. Two participants who were disappointed with their results had failed all experiments (n=1) or had broken the handaxe during knapping (n=1). Anxiety levels relate to either breakage or inability to achieve what was perceived as an ideal handaxe morphology (see Figure 13; see Supplementary Figure S1).

State of Completion

Out of 39 handaxes, 34 were complete, the remaining broken or discarded. Breakage patterns were as follows (Figure 14A):

1. <u>Breakage in the initial stages of handaxe façonnage</u>: This is seen in one participant in Exp 8 and Exp 9. In Exp 8, bifacial flaking could not be achieved, and the flake broke along one edge. If found in the archaeological record, this broken, minimally retouched large flake would have little evidence to show that it was to be shaped into a handaxe. In Exp 9, the participant achieved a degree of bifacial flaking along one lateral edge. Subsequently, both areas designated to shape the apex and butt broke, with the final form having a roughly pointed morphology. It was abandoned, although an experienced knapper could have rectified the mistake and continued flaking. If found in the archeological record, it would be called an unfinished handaxe with a broken lateral edge.
2. <u>Breakage mid-way through handaxe façonnage</u>: In one case (Exp 8), attempts were made to shape the flake through large invasive scars. Following intensive percussion at a wrong angle, the preform broke and was abandoned despite the presence of sufficient mass to continue flaking. The break lay in an area intended to form the apex. An internal fault in the raw material also accentuated this break. In another

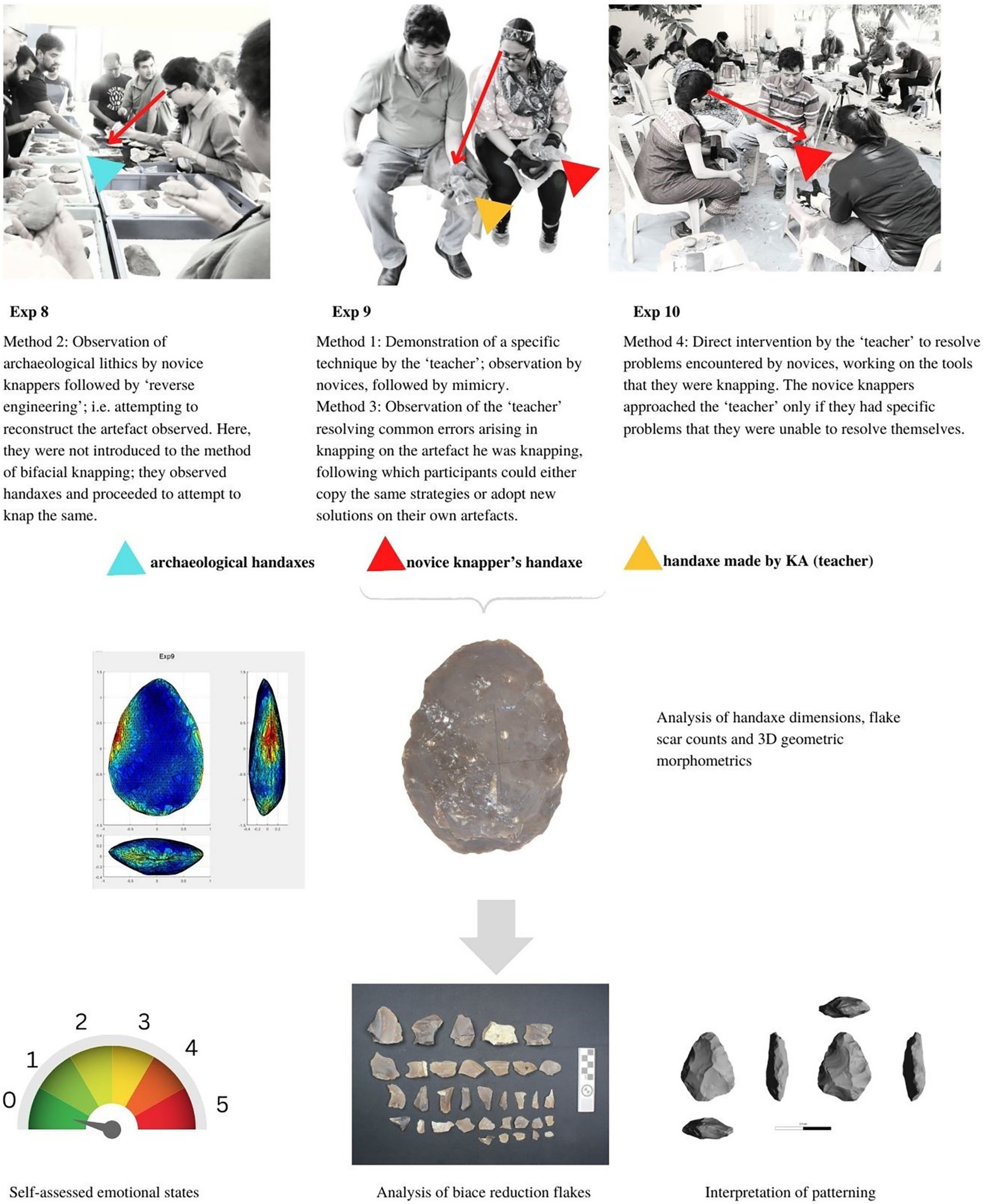


Figure 12. Schematic diagram for handaxe façonnage *experiments showing pedagogical methods adopted.*

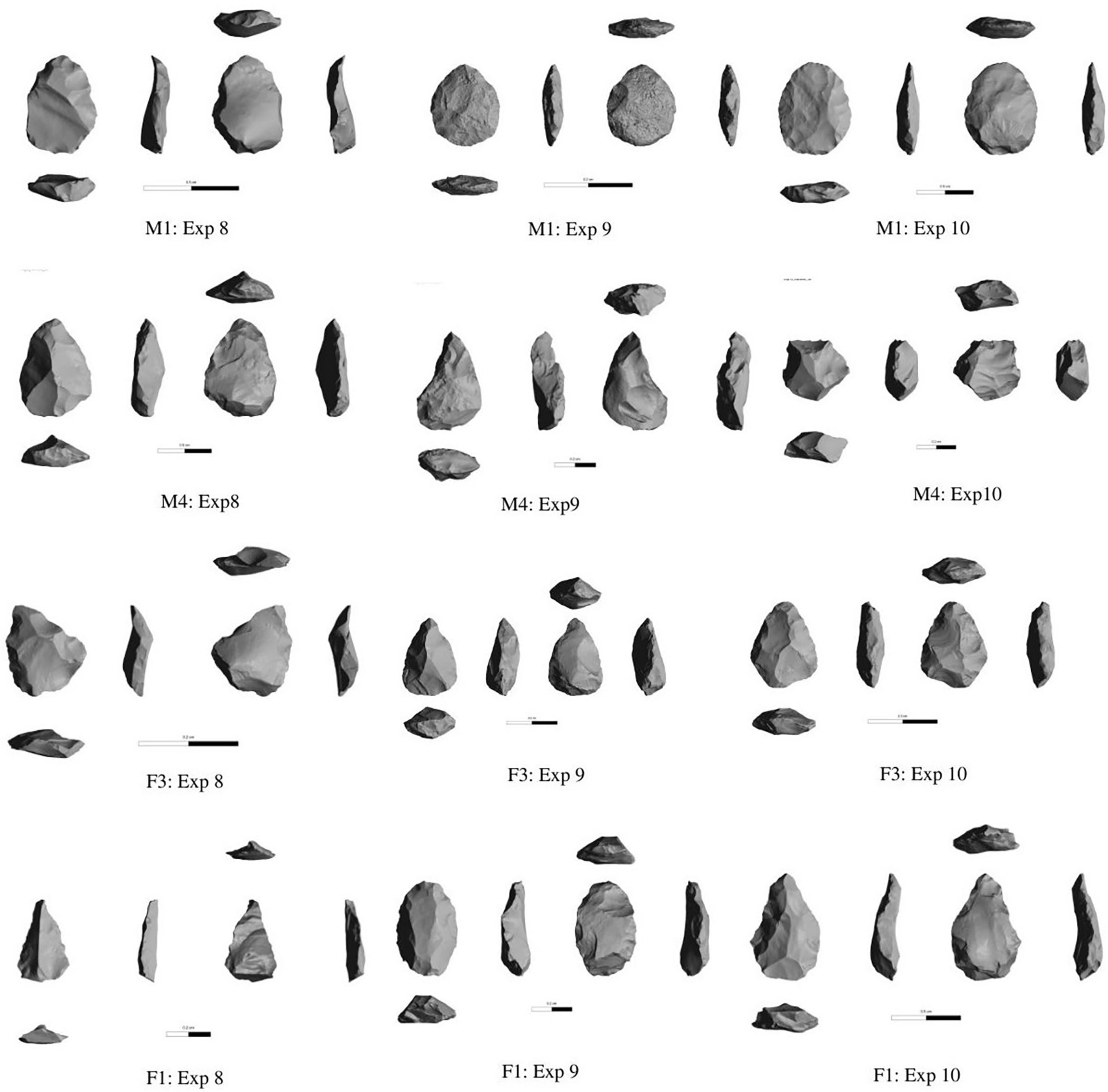


Figure 13. Examples of 3D solid models of handaxes knapped (images generated using Artifact Geomorph Toolbox 3D (AGMT3-D) (Herzlinger et al. 2018) (M=Male, F=Female).

example, in Exp 8, breakage mid-way resulted in the discard of the unfinished tool.

3. Breakage in the final stage of handaxe thinning**:** The tool split in half in Exp 10 when the participant attempted to refine it after achieving the handaxe morphology.
4. Other types of breakage**:** In one case in Exp 8, large invasive flakes reduced the tool's mass and size. A final blow led to a situation where the participant could not continue flaking and abandoned the tool.

Biface Reduction Flakes

A small proportion of broken flakes occur in all experiments, with decreasing proportions in Exp 10. Bulbs are primarily prominent, while striking platforms are predominantly plain or have pseudo-facets arising from bifacial knapping along lateral edges (Tables 6, 7)**.** There is a decrease in the number of step terminations from Exp 8 to 10.

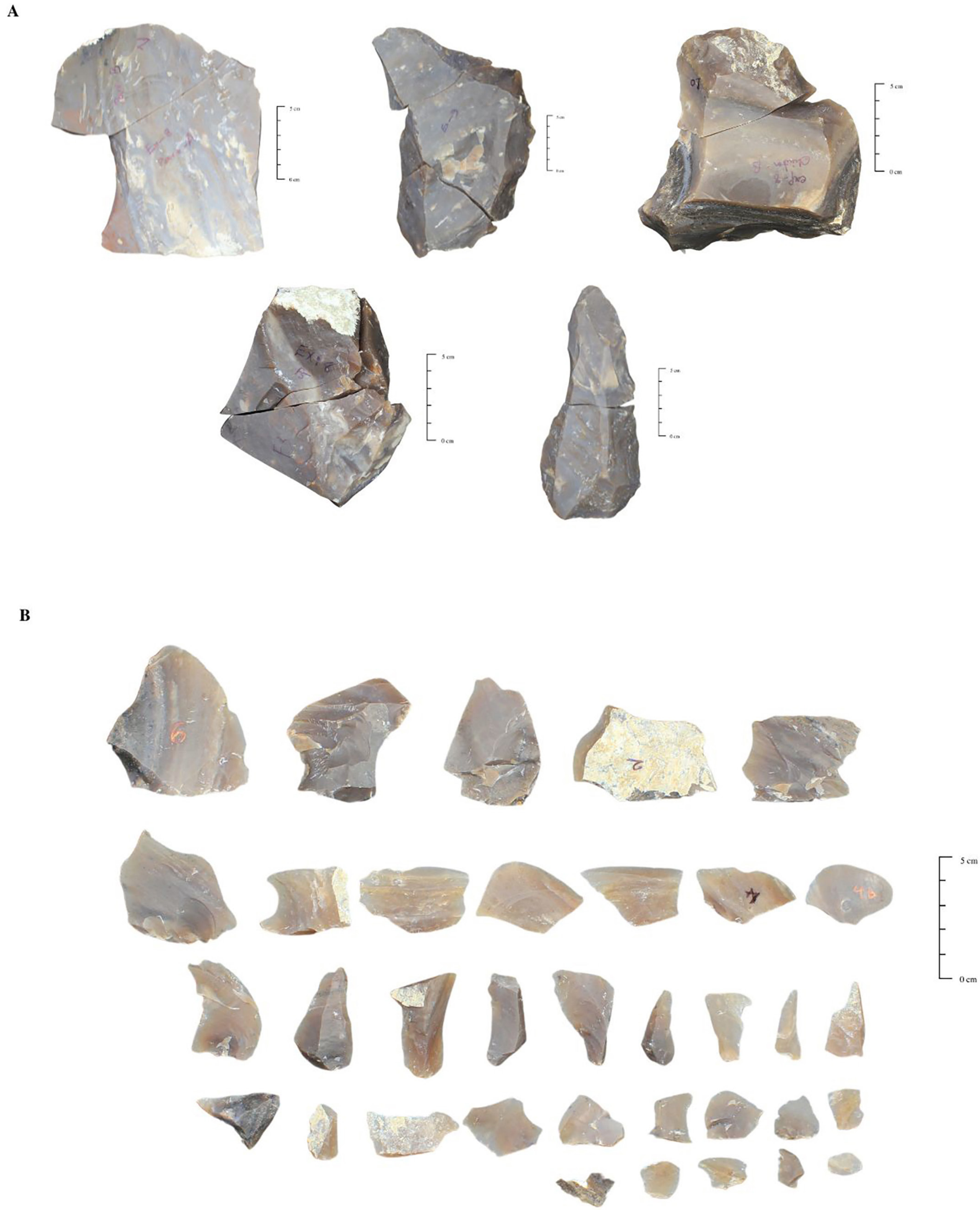
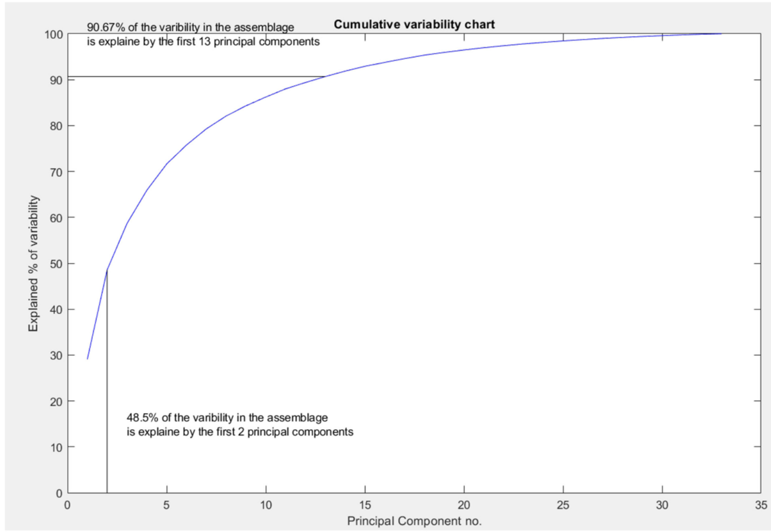


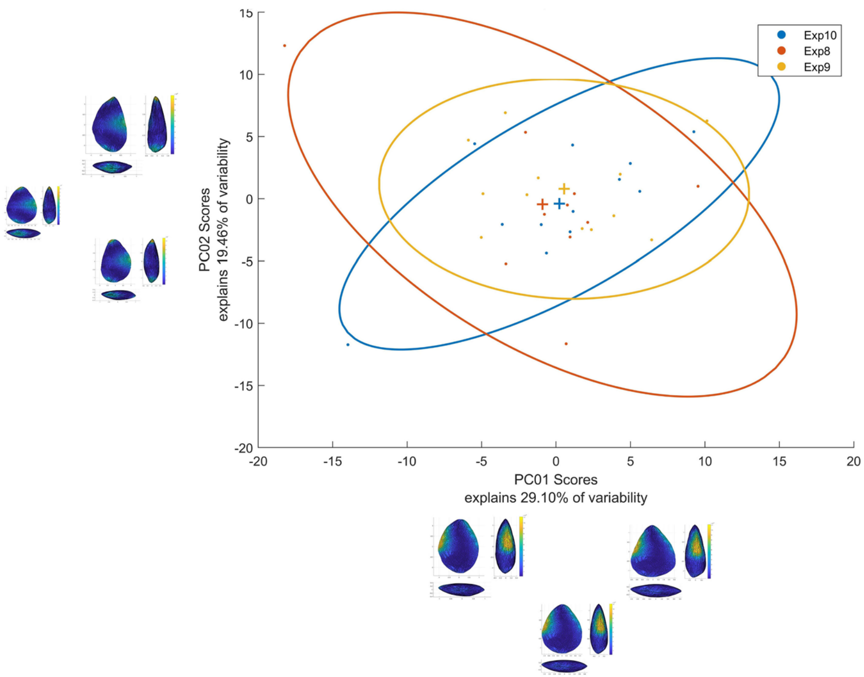
Figure 14. Handaxe façonnage *experiments Exp 8, 9, 10 showing: A) breakage patterns during experiments; and, B) waste flakes arising during handaxe manufacture.*

Early View available online 3 December 2024

A



B



C

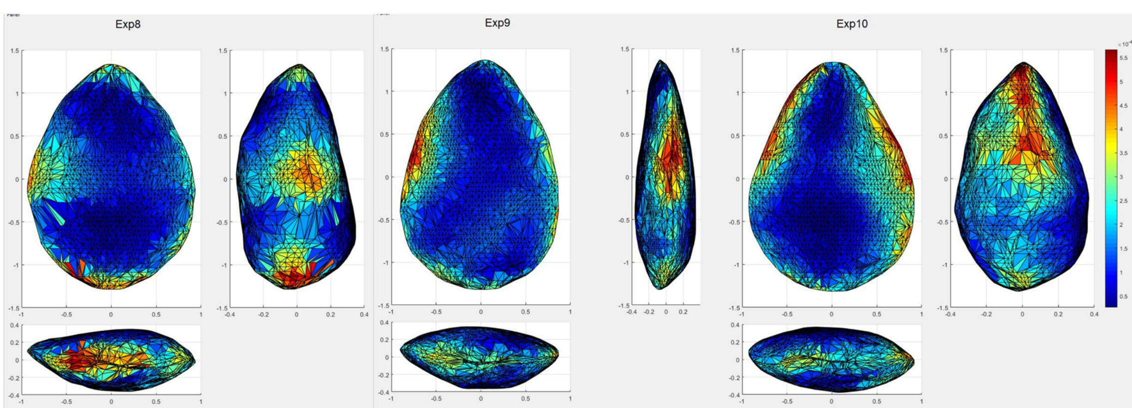


Figure 15. Geometric morphometric analysis of handaxes showing: A) cumulative PC variability chart; B) scatterplot of the item scores on the first two PCs (after Herzlinger et al. 2018, Figure 7: 12); C) the groups' means comparison panel mean shapes of handaxes in each experiment (after Herzlinger et al. 2018, Figure 6: 10).

TABLE 4. ATTRIBUTES RELATED TO LARGE FLAKES, HAMMERSTONES, WASTE PRODUCTS, AND HANDAXES IN EXP 8, 9, 10 (L=length, B=breadth, T=thickness, Wt=weight).

A-Dimensions of artifacts

Artifact	Exp. No.		L (mm)	B (mm)	T (mm)	Wt (gms)
Original Flake	Exp8	N	13	13	13	13
		Mean	159.00	119.62	48.54	752.77
		Minimum	105.00	12.50	28.00	410.00
		Maximum	181.00	160.00	80.00	1046.00
		Std Deviation	21.91	39.05	17.78	199.61
	Exp9	N	13	13	13	13
		Mean	209.00	146.65	57.92	1291.92
		Minimum	150.00	110.00	38.00	865.00
		Maximum	260.00	180.00	110.00	2198.00
		Std Deviation	30.71	25.12	17.39	365.54
	Exp10	Count	13	13	13	13
		Mean	243.85	198.85	71.77	2690.08
		Minimum	215.00	150.00	50.00	1587.00
		Maximum	290.00	270.00	165.00	3812.00
		Std Deviation	22.84	28.66	32.18	573.21
Handaxe	Exp8	N	10	10	10	10
		Mean	132.50	97.50	38.90	491.20
		Minimum	90.00	79.00	22.00	195.00
		Maximum	170.00	120.00	58.00	840.00
		Std Deviation	26.00	13.70	10.44	192.79
	Exp9	N	12	12	12	12
		Mean	150.25	96.58	40.58	628.17
		Minimum	113.00	53.00	22.00	296.00
		Maximum	255.00	130.00	54.00	1212.00
		Std Deviation	36.58	22.74	10.85	281.91
	Exp10	N	12	12	12	12
		Mean	159.58	116.92	45.92	851.58
		Minimum	99.00	85.00	28.00	360.00
		Maximum	195.00	145.00	60.00	1125.00
		Std Deviation	27.14	20.04	9.25	229.67
Hammerstone	Exp8/9/10	N	14	14	14	14
		Mean	88.64	78.86	47	523
		Minimum	70.00	58.00	30	104
		Maximum	115.00	110.00	75	963
		Std Deviation	13.18	16.45	12	204
Biface reduction flakes	Exp8	N	168	168	168	168
		Mean	37.07	37.77	10.75	14.95
		Minimum	12.29	5.46	1.77	1.00
		Maximum	227.79	219.15	181.33	144.00
		Std Deviation	20.88	22.98	15.35	21.96

Early View available online 3 December 2024

TABLE 4. ATTRIBUTES RELATED TO LARGE FLAKES, HAMMERSTONES, WASTE PRODUCTS, AND HANDAXES IN EXP 8, 9, 10 (L=length, B=breadth, T=thickness, Wt=weight) (continued).

A-Dimensions of artifacts

Artifact	Exp. No.		L (mm)	B (mm)	T (mm)	Wt (gms)
Biface reduction flakes	Exp9	N	409	409	409	409
		Mean	35.14	38.64	7.89	11.59
		Minimum	10.33	6.24	1.26	1.00
		Maximum	93.75	670.00	27.62	146.00
		Std Deviation	14.52	35.30	4.04	16.23
	Exp10	N	640	640	640	640
		Mean	43.43	44.55	10.33	25.84
		Minimum	9.98	2.02	1.00	1.00
		Maximum	139.19	144.88	56.53	406.00
		Std Deviation	18.57	22.35	6.84	41.43
Angular/blocky piece	Exp8	N	11	11	11	11
		Mean	57.24	50.37	20.00	68.09
		Minimum	21.71	20.03	12.36	9.00
		Maximum	133.45	75.48	33.00	174.00
		Std Deviation	33.44	20.60	6.82	69.58
	Exp9	N	14	14	14	14
		Mean	50.31	39.35	20.62	54.57
		Minimum	20.22	15.74	6.81	3.00
		Maximum	99.08	64.09	34.66	208.00
		Std Deviation	20.38	18.32	8.96	61.23
	Exp10	N	17	17	17	17
		Mean	68.79	47.85	25.92	91.41
		Minimum	34.52	21.08	11.22	8.00
		Maximum	142.45	79.75	57.00	423.00
		Std Deviation	28.12	19.10	13.03	113.28
Biface apex	Exp9	N	1	1	1	1
		Mean	19.93	97.05	28	195
		Minimum	19.93	97.05	28	195
		Maximum	19.93	97.05	28	195
		Std Deviation	.	.	.	.
Broken handaxe segment	Exp8	N	3	3	3	3
		Mean	93.12	60.59	34.72	209.67
		Minimum	59.00	47.97	31.05	86.00
		Maximum	112.59	69.64	40.82	285.00
		Std Deviation	29.64	11.27	5.32	107.95
	Exp10	N	2	2	2	2
		Mean	87.50	65.00	41.00	229.50
		Minimum	85.00	50.00	40.00	168.00
		Maximum	90.00	80.00	42.00	291.00
		Std Deviation	3.54	21.21	1.41	86.97

TABLE 4. ATTRIBUTES RELATED TO LARGE FLAKES, HAMMERSTONES, WASTE PRODUCTS, AND HANDAXES IN EXP 8, 9, 10 (L=length, B=breadth, T=thickness, Wt=weight) (continued).

A-Dimensions of artifacts

Artifact	Exp. No.		L (mm)	B (mm)	T (mm)	Wt (gms)
Broken Roughout segment	Exp8	N	4	4	4	4
		Mean	103.75	121.50	38.75	393.25
		Minimum	65.00	67.00	23.00	160.00
		Maximum	136.00	170.00	63.00	640.00
		Std Deviation	34.74	43.05	17.17	261.31
	Exp9	N	3	3	3	3
		Mean	111.33	105.00	38.33	416.33
		Minimum	73.00	75.00	28.00	197.00
		Maximum	150.00	145.00	45.00	843.00
		Std Deviation	38.50	36.06	9.07	369.55

B-Reduction in weight from the original flake blanks to the final handaxes

	Exp8 Wt (gms) Mean	Exp9 Wt (gms) Mean	Exp10 Wt (gms) Mean
Original Flake	753	1292	2690
Handaxe	491	628	852
Loss in weight	**262**	**664**	**1838**
Percentage of reduction	**35%**	**51.39%**	**68.32%**

C-Total number of dorsal and ventral flake scars

Exp. No.		Face 1: Number of scars	Face 2: Number of scars
Exp8	Count	10	10
	Mean	8.10	6.00
	Minimum	4.00	2.00
	Maximum	13.00	10.00
	Standard Deviation	3.07	2.91
Exp9	Count	12	12
	Mean	11.33	7.83
	Minimum	6.00	2.00
	Maximum	19.00	15.00
	Standard Deviation	3.52	4.04
Exp10	Count	12	12
	Mean	13.17	11.50
	Minimum	6.00	4.00
	Maximum	22.00	17.00
	Standard Deviation	5.69	3.97

TABLE 5. DIMENSIONS OF A) HANDAXES (complete and broken); B) COMPLETE HANDAXES, AND C) COMPLETE FLAKES ARISING FROM BIFACE REDUCTION (n=973) (excluding angular/blocky pieces and shatter) (Exp 8, Exp 9, Exp 10).

A: Case Summaries

Exp No.		L (mm)	B (mm)	T (mm)
Exp 8	N	13	13	13
	Mean	125.62	103.6154	39.38
	Minimum	65	65.00	22
	Maximum	170	170.00	63
	Std. Deviation	30.872	28.54102	12.400
Exp 9	N	13	13	13
	Mean	141.00	95.3077	40.92
	Minimum	73	53.00	22
	Maximum	255	145.00	54
	Std. Deviation	41.845	24.80385	10.836
Exp 10	N	12	12	12
	Mean	146.50	109.6667	44.25
	Minimum	85	50.00	28
	Maximum	195	145.00	60
	Std. Deviation	37.970	29.35777	8.709

B: Case Summaries

Exp No.		L (mm)	B (mm)	T (mm)
Exp 8	N	8	8	8
	Mean	138.50	99.5000	39.63
	Minimum	90	80.00	22
	Maximum	170	120.00	58
	Std. Deviation	24.877	13.66957	11.698
Exp 9	N	9	9	9
	Mean	149.89	93.7778	40.78
	Minimum	113	53.00	22
	Maximum	255	130.00	54
	Std. Deviation	42.742	23.03681	11.945
Exp 10	N	10	10	10
	Mean	158.30	118.6000	44.90
	Minimum	99	85.00	28
	Maximum	195	145.00	60
	Std. Deviation	28.852	21.71124	9.469

C

	L (mm)	B (mm)	T (mm)	Wt (gms)
Mean	41.09	42.78	10.01	21.07
Minimum	11.05	5.46	1.00	1.00
Maximum	227.79	670.00	181.33	356.00
Std. Deviation	18.46	29.19	8.55	33.81

TABLE 6. BREAKAGE PATTERNS OF BIFACE REDUCTION FLAKES (Exp 8, Exp 9, Exp 10).

Exp. No.	State	Count	Table N %
Exp8	broken	43	3.5
	complete	125	10.3
	Total	168	13.8
Exp9	broken	93	7.6
	complete	316	26.0
	Total	409	33.6
Exp10	broken	108	8.9
	complete	532	43.7
	Total	640	52.6
Total	**broken**	**244**	**20.0**
	complete	**973**	**80.0**
	Total	**1217**	**100.0**

Geometric Morphometrics of Handaxe Shapes

A pilot study of shape trends was conducted for the handaxes knapped in Exp 8, 9, and 10. Shape trends suggest that more than 90% of the variability in the assemblage is explained by the first 13 principal components (Figure 15A-C). The scores represent the relative expression of each shape trend in each artifact (n=34). Accordingly, the first two principal components, which are accountable for approximately half of the shape variability (48.5% of the variability), were plotted alongside the hypothetical shapes on their extremities. When examining the centroids for all three experiments, we note that Exp 8 is positioned slightly towards the negative side of both PC1 and PC2. Exp 9 is positive on both axes, and Exp 10 is positive for PC1 and negative for PC2, although they are clustered close together (Figure 15B).

The first principal component represents a shape trend that changes from a rounded thick, globular shape to one that is thinner and elongated on positive values and to a wider and thicker elongated shape on negative values (at + and -5). The second principal component gathered variation from a shape trend that changes from a rounded, thick, globular shape to a pointed tip in a thinner shape on positive ends and a wider tip in a thicker shape on negative ends. In both PC1 and PC2, a thick cross-section on both lateral sides and butt ends is noted (see Figure 15B).

There is an overlap in the general shape of artifacts made by novice knappers across the experiments and us-

TABLE 7. NATURE OF STRIKING PLATFORMS FOR BIFACE REDUCTION FLAKES (Exp 8, Exp 9, Exp 10).

	Exp8		Exp9		Exp10		Total	
Types of platform	**Count**	**Table N %**	**Count**	**Table N %**	**Count**	**Table N %**	**Count**	**Table N %**
plain	72	5.9	193	15.9	302	24.8	567	46.6
pseudo-facetted	91	7.5	211	17.3	320	26.3	622	51.1
cortical	1	0.1	0	0	5	0.4	6	0.5
partially cortical	1	0.1	0	0	0	0	1	0.1
pointed	0	0	0	0	1	0.1	1	0.1
broken	0	0	2	0.2	2	0.2	4	0.3
absent	0	0	0	0	4	0.3	4	0.3
unclear	3	0.2	3	0.2	6	0.5	12	1.0
Total	**168**	**13.8**	**409**	**33.6**	**640**	**52.6**	**1217**	**100.0**

TABLE 8. DIMENSIONAL DISTRIBUTION OF SHAPE VARIABILITY (across the X, Y and Z dimensions) OF EACH GROUP.

	N	Shape variability	% caused by X	% caused by Y	% caused by Z
Exp 8	10	11.39	57.19	7.52	35.28
Exp 9	12	9.28	51.47	2.91	45.62
Exp 10	12	9.37	55.84	6.54	37.62

ing different teaching methods. This accounts for almost half of the shape variability in the sample (see Figure 15A). Interestingly, shape variability within the group in Exp 8 is greater than in other experiments. Exp 9 has a more circular ellipse than Exp 10, represented by a much narrower ellipse (Table 8, see Figure 15B).

The two morphological outliers observed in Exp 8 and Exp 10 are a result of breakage of handaxes during flaking; while this should technically have been omitted, the novice knappers were insistent that these were indeed functional handaxes desired by them (see Figure 13, M4 Exp 10; see Figure 15B). The tools made in Exp 9 are primarily homogeneous, while Exp 8 and Exp 10 present substantially higher shape variability. The Euclidean distance matrix between the three groups shows that distances between Exp 9 and 10 are the lowest, and Exp 8 and Exp 9 are the highest (Table 9). When we consider variability between Exp 8, 9, and 10 in terms of Euclidean distance from the mean shapes of each group, we note that the most variable is that in Exp 8, differing from the next highest value (Exp 10), while Exp 9 and 10 are almost similar to each other (see Table 8).

In Exp 8, higher relative shape variability is observed (see Table 8). All three experiments show a reasonably similar pattern in which less than 50% of the variability originates from the Z dimensions, corresponding to relative thickness, and a little over 50% stems from differences in the X dimension, corresponding to relative width. In the case of the Y dimension, significant differences are observed for Exp 9 (only 3%) compared to Exp 8 and 10 (~7%) (see Table 8). Differences are also observed in the spatial distribution of shape variability between the experiments (see Figure 15C). Much of the variability in all the experiments comes from differences in the tools' lateral, proximal, and distal peripheral areas.

Other morphometric indices were documented (Table 10). In general, there are sparse significant differences between experiments. Regarding volume, the artifacts from Exp 10 are the largest, with a mean volume value almost double that of Exp 8, suggesting that extensive reduction was not achieved irrespective of the original flake blank sizes (see Table 4).

Examining deviation from perfect symmetry (bilateral and bifacial), Exp 8 and Exp 10 have similarly high values, suggesting they are not as symmetrical as handaxes in Exp 9 (see Table 10). When we look at the edge curvature, the left and right edge indices in Exp 8 and Exp 9 show a relatively similar pattern and have higher values than Exp 10. This suggests some degree of increased control in bifacial flaking in Exp 10. Edge planform irregularity is minimal between experiments (see Table 10).

Interpersonal Discussions and Comments

In Exp 8, where participants had to assess modes of bifacial knapping based on observation alone (Method 2), there was a high error rate, as noted in the finished products and debitage. Here, participants' confidence and judgment of their ability did not match the evidence of skill levels as judged from the lithics. In Exp 9, following a demonstration (Methods 1, 3) and an explanation of principles, some variability is seen in how often a novice approached KA. The most common problem was deciding where to initiate knapping. Irrespective of skill levels, those who systematically followed the principle of bifacial knapping achieved some degree of success. In Exp 10, all participants were keen to involve KA in direct intervention to resolve problems.

TABLE 9. DISTANCE MATRIX OF MULTIDIMENTIONAL MATRIX EUCLIDEAN DISTANCES BETWEEN EXP 8, EXP 9, AND EXP 10 MEAN SHAPES OF HANDAXES (AGMT3-D) (after Herzlinger et al. 2018).

	Exp 8	Exp 9	Exp 10
Exp 8	0	3.52	3.05
Exp 9	3.52	0	2.98
Exp 10	3.05	2.98	0

TABLE 10. SUMMARY STATISTICS FOR MAIN MORPHOLOGICAL ATTRIBUTES FOR EACH EXPERIMENT.

Morphological Attributes		Exp 8 N=10	Exp 9 N=12	Exp 10 N=12
Volume	Max	66.69	148.26	148.91
	Median	14.53	9.68	26.29
	Min	0.54	0.6	7.14
	Mean	19.36	24.4	38.93
	Std Dev	20.12	41.36	41.67
Surface area	Max	44.46	93.72	86.81
	Median	14.45	12.69	22.51
	Min	1.97	2.16	7.72
	Mean	17.01	19.96	28.76
	Std Dev	12.54	24.99	22.05
Deviation from perfect 3D bilateral symmetry	Max	1.33	0.56	0.83
	Median	0.36	0.28	0.36
	Min	0.2	0.05	0.23
	Mean	0.46	0.29	0.40
	Std Dev	0.32	0.17	0.16
Deviation from perfect 3D bifacial symmetry	Max	0.65	0.63	0.51
	Median	0.34	0.29	0.3
	Min	0.1	0.04	0.17
	Mean	0.37	0.29	0.32
	Std Dev	0.17	0.17	0.12
Left edge curvature	Max	71.71	70.55	31.97
	Median	17.08	17.12	12.72
	Min	8.01	6.45	6.57
	Mean	23.39	23.52	15.24
	Std Dev	18.56	18.96	8.25
Right edge curvature	Max	123.25	71.54	55.93
	Median	19.38	18.09	14.21
	Min	10.4	5.74	5.15
	Mean	28.31	21.96	16.63
	Std Dev	33.7	17.9	13.39
Left edge planform irregularity	Max	7.7	9.09	11.35
	Median	4.96	4.42	6.01
	Min	1.21	0.85	1.5
	Mean	4.77	4.53	6
	Std Dev	1.99	2.59	2.64
Right edge planform irregularity	Max	11.89	9.95	12.14
	Median	4.31	4.71	5.25
	Min	2.52	1.29	2.8
	Mean	5.78	4.6	6.68
	Std Dev	3.27	2.61	3.38

Early View available online 3 December 2024

TABLE 10. SUMMARY STATISTICS FOR MAIN MORPHOLOGICAL ATTRIBUTES FOR EACH EXPERIMENT (continued).

Morphological Attributes		Exp 8 N=10	Exp 9 N=12	Exp 10 N=12
Left edge section irregularity	Max	15.98	12.66	18.07
	Median	6.12	6.92	6.3
	Min	2.02	1.03	3.94
	Mean	7.21	6.64	8.23
	Std Dev	4.76	3.77	4.32
Right edge section irregularity	Max	12.96	12.09	14.91
	Median	6.56	5.82	6.95
	Min	2.44	1.97	2.49
	Mean	6.74	6.65	7.27
	Std Dev	3.67	3.47	3.28

DISCUSSION AND CONCLUSION

The process of knowledge acquisition among novice knappers is complex and relies on numerous variables being the subject of considerable research and debate (Duke and Pargeter 2015; Geribàs et al. 2010; Lombao et al. 2017; Pargeter et al. 2019; 2020; Silva-Gago et al. 2022; Stout 2002; Stout and Kreisheh 2015). This research project constituted a preliminary study exploring skill acquisition among novice knappers and generating databases of information on the artifacts generated, with implications for interpreting the Paleolithic record and for designing pedagogical approaches in teaching students lithic knapping (Akhilesh and Pappu 2023). The range of experiments, from bipolar knapping to handaxe *façonnage*, facilitated observations on diverse strategies adopted by novice knappers under differing pedagogical methods or levels of technological complexity.

The boxplots of TOPSIS scores (Figure 16) show that the scores in the first set of experiments (Exp 1 to Exp 5, bipolar knapping) are slightly negatively skewed, with no outliers. This suggests that most participants performed moderately well in all experiments. Thus, pedagogical Method 1 (observation and mimicry) was enough for novices to grasp and implement the concept with a degree of overall success. Participants did a self-assessment of their learning curves (Figure 17), the results of which, although subjective, suggested that in the case of bipolar knapping (Exp 1–5), most were confident of having grasped the concept and the necessary hand-eye coordination skills solely based on observation of the demonstration by KA. Similarly, the self-assessed learning curve increased from Exp 1 to Exp 5. However, participants' belief in their increasing learning trajectory is not always corroborated in the analysis of their knapped lithic products (see Figures 7, 17). Although the concept of slicing the pebble was grasped immediately and mimicked, achieving perfection in obtaining two symmetrical segments varied; this could take more practice. However, we note an increasing ability to maintain control over the dimensions of segments as the experiment progressed. In these experiments, the original size and shape of the pebble (quartz) were standardized and controlled. However, in archeological examples, raw material types and morphologies would play a role in influencing consistency in knapping results. The archeological record would also be expected to comprise split or battered pebbles with marks of percussion reflecting varied levels of skill and success.

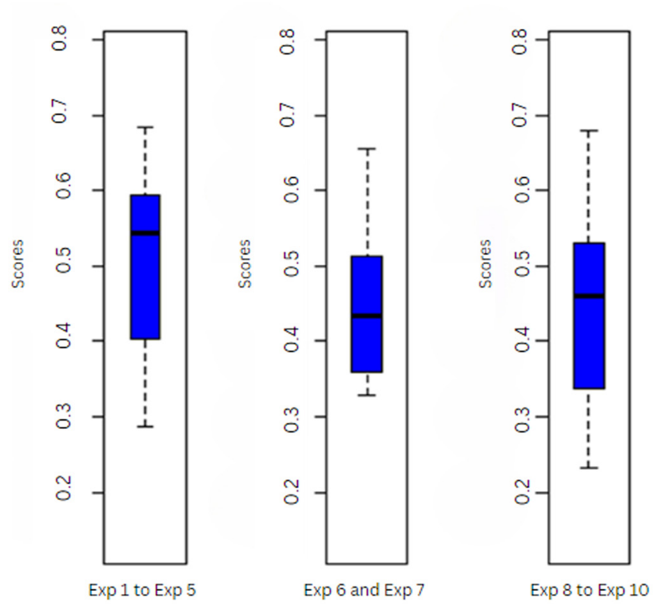


Figure 16. Comparison of TOPSIS scores for all experiments (boxplots).

The TOPSIS scores in the second set of experiments (Exp 6 and 7, direct stone hard hammer percussion detach-

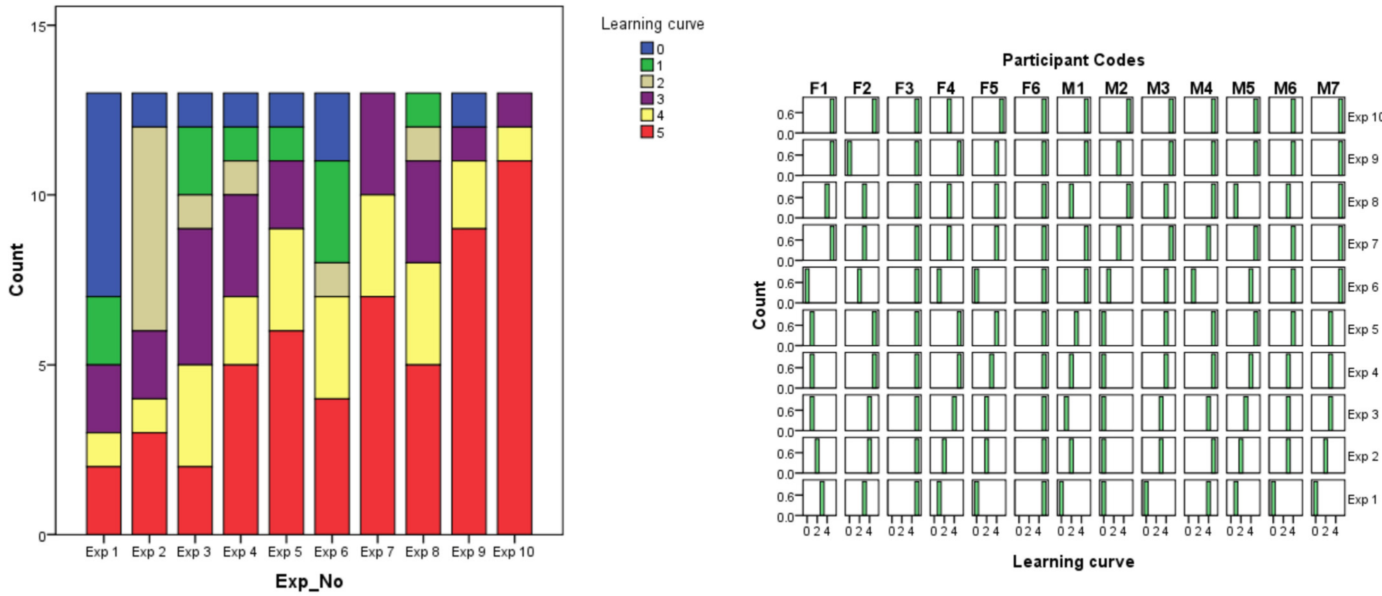


Figure 17. Self-assessed learning curves. Novice knappers ranked themselves on scales of 0–5 (see Figure 4) in perceptions of their own learning curves.

ing flakes from cobbles) are highly positively skewed, with no outliers, suggesting that very few participants could enhance skill levels in a significant manner within the duration of the experimental program (see Figure 16). Here, two pedagogical methods (Method 2 for Exp 6, i.e., 'reverse engineering') followed by observation of knapping by the teacher and mimicry (Method 1, Exp 7) were employed. Despite the overall lower degree of skill enhancement, we note the adoption of new flaking strategies in Exp 7 with greater core exploitation after initial decortication, higher counts of flakes detached, and increased flake size with more dorsal scars (see Tables 2, 3). Analysis of the lithics suggests that <50–75% of the core was reduced in most cases. Irrespective of the size of the original cobble selected, erroneous knapping strategies resulted in the loss of suitable flaking angles, breakage of cores, and inability to initiate flaking or complete or partial exhaustion of the core, leading to their discard. Battering marks on cobbles were also indicators of unsuccessful attempts to initiate flaking. These could be distinguished from percussion marks on hammerstones as they are randomly distributed across the core's surface and are larger in size. In some instances, there is an unintentional development of a bifacial chopper-like morphology, which has implications for archeological debates on cores versus bifacial chopper/chopping tool nomenclatures.

In the handaxe *façonnage* experiments (Exp 8–10), variability in skill levels was noted (see Figure 16). 3D geometric morphometrics of the handaxes revealed minor differences between Exp 8, 9, and 10. However, Exp 9 stands out (Method 3), where participants rectified errors while observing the expert implement similar strategies on his handaxe. In Exp 8 (Method 1), they attempted to achieve the shape following observations of archeological handaxes, leading to knapping errors and morphological variability. In Exp 10 (Method 4), they approached the expert (KA) only when they faced a situation they could not resolve, whereby accumulation of errors led to significant issues in the final tool. Breakage patterns have implications for the classification of 'unfinished handaxes' in the archeological record, with participants having differing views on what they believed to be a completed tool. This also reflected, in some instances, the novice knapper's inability to realize the potential for rectification of errors through continued flaking. We ranked novice knappers as per their combined score across all the experiments based on TOPSIS scores (Table 11). The scores for each set of experiments are color-coded on the Green–White–Red scale. Thus, the dark green cell color indicates the best performance, whereas the dark red color indicates the worst performance, suggesting a gradual increase in performance levels in Exp 8–10 for most participants.

To examine if all participants showed similar progression, we carried out a k-means cluster analysis over the scores corresponding to the three sets of experiments. This analysis categorized participants into three categories. F6, M1, M3, M6 belong to cluster 1 and consistently perform well. F5, M4, M5, and M7 belong to cluster 2, and their performance is almost similar to the first cluster for the first set of experiments. Their performance is moderate in the second set of experiments and very poor in the third (see Table 11). The remaining participants improved considerably in the last set of experiments (Figure 18).

Experimental protocols preferred a social setting with the cultural transmission of knowledge occurring among novice knappers (see Snyder et al. 2022 for alternate views). Despite opportunities for conversation, this was minimal

TABLE 11. INDIVIDUAL TOPSIS SCORES FOR EACH SET OF EXPERIMENTS.*

Novice Knapper	Exp 1 to 5	Exp 6 to 7	Exp 8 to 10	Average Score
M1	0.58	0.66	0.58	0.61
F6	0.58	0.51	0.68	0.59
M6	0.68	0.49	0.53	0.57
M5	0.66	0.52	0.32	0.50
M3	0.54	0.43	0.52	0.50
F5	0.59	0.36	0.46	0.47
F3	0.47	0.36	0.55	0.46
M4	0.63	0.38	0.33	0.45
F1	0.40	0.47	0.44	0.44
M7	0.46	0.56	0.23	0.41
F2	0.40	0.33	0.49	0.41
M2	0.39	0.37	0.44	0.40
F4	0.29	0.35	0.34	0.33

*The scores for each set of experiments are color-coded on the Green–White–Red scale. Dark green cell colors indicate the best performance; the dark red colors indicate the worst performance.

and had no impact on learning skills, as noted in the lithics produced. Similarly, prior knowledge of knapping did not impact the learning outcomes, as indicated by the experiments in handaxe *façonnage* (Exp 8, 9, 10) (Table 12; Supplementary Figure S3).

Observation and mimicry did appear to benefit novices in Exp 6 and 7 and Exp 8 to 9, with novices gaining confidence through observation of both knapping methods (Method 1) and how errors could be rectified (Method 3). In contrast, direct intervention through rectification of errors on handaxes by an expert (Method 4) did not achieve good results, as novices called for expert help only when the errors accumulated to a point beyond rectification. The social environment and emotional states of knappers played some role in attitudes of learning acquisition, although not necessarily in the final products generated; this knowledge is beneficial for designing multiple ways in which lithic knapping can be taught in modern classroom contexts. With the increasing complexity of the technological strategies adopted (from bipolar to bifacial knapping), expert

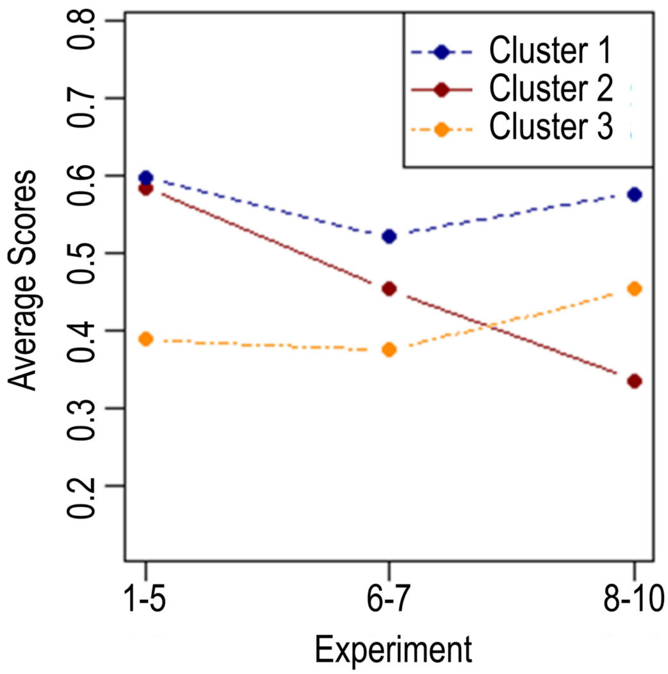


Figure 18. Average scores for each cluster for each set of experiments.

'teachers' would be required to supplement mimicry with more diverse intervention levels. Lithic attributes generated from experimental studies arising from novice knapping can aid in establishing databases that may be compared with archeological assemblages and experimental lithics produced by expert knappers. Studies on novice knapping in the archeological and contemporary context are new in South Asian archeology, and this pilot study constitutes a significant step in generating data for testing hypotheses in well-excavated Paleolithic assemblages.

ACKNOWLEDGMENTS

We thank the Sharma Centre for Heritage Education (SCHE) for supporting this project. The article arises from a workshop on lithic knapping conducted as part of the SCHE Down Ancient Trails course 'Introduction to South Asian Prehistory' (31 May–6 June 2022). We thank the editors and reviewers for their advice and suggestions. P.J. thanks to the Homi Bhabha Fellowships Council. We are grateful to the TVS Foundation for their support.

DISCLOSURE STATEMENT

The authors report there are no competing interests to declare.

AUTHOR CONTRIBUTIONS

The study was conceived by Kumar Akhilesh (KA), Shanti Pappu (SP), Prachi Joshi (PJ), and Sutonuka Bhattacharya (SB). The knapping expert was Kumar Akhilesh. All other authors served as participants in the experimental program. Lithic analysis was conducted by KA, SP, PJ, and Yeshaswini Rajagopal. Statistics for skill assessment were done by Akanksha Kashikar. The manuscript was written by KA, SP, PJ, and SB.

DATA AVAILABILITY

Relevant data is presented within the manuscript and its supporting Online Resources. Experimental artifacts are curated at the Sharma Centre for Heritage Education, Chennai, India.

GEOLOCATION INFORMATION

Chennai, Tamil Nadu, India.

TABLE 12. VARIABLES IN EXP 8 TO 10 (handaxe *façonnage*) IN PARTICIPANTS WTH MINIMAL EXPERIENCE IN KNAPPING AND THOSE WITH NO PRIOR EXPERIENCE.

Morphological Attributes	Participant with prior minimal knapping experience	Participant with no knapping experience
Deviation from bilateral symmetry	0.31	0.41
Deviation from bifacial symmetry	0.27	0.35
Left edge curvature	21.24	20.62
Right edge curvature	33.04	17.78
Left edge planform irregularity	4.06	5.61
Right edge planform irregularity	5.09	5.97
Volume	28.30	26.25
Surface area	22.26	21.12

Early View available online 3 December 2024

REFERENCES

Akhilesh, K., Pappu, S., 2015. Bits and pieces: lithic waste products as indicators of Acheulean behaviour at Attirampakkam, India. J. Archaeol. Sci. Rep. 4, 226–241. https://doi.org/10.1016/j.jasrep.2015.08.045

Akhilesh, K., Pappu, S., 2023. Let's knap: experiences in teaching lithic studies in South Asia. Lithic Technol. 48(3), 278–290. https://doi.org/10.1080/01977261.2022.2142386

Ashton, N., McNabb, J., Irving, B., Lewis, S., Parfitt, S., 1994. Contemporaneity of Clactonian and Acheulian flint industries at Barnham, Suffolk. Antiquity 68(260), 585–589. https://doi.org/10.1017/S0003598X00047074

Assaf, E., 2021. Dawn of a new day: the role of children in the assimilation of new technologies throughout the Lower Paleolithic. L'Anthropologie 125(1), 102836. https://doi.org/10.1016/j.anthro.2021.102836

Badger, R., MacDonald, M.N., 2007. Culture, language, pedagogy: the place of culture in language teacher education. Pedagogy, Culture and Society 15(2), 215–227. https://doi.org/10.1080/14681360701403722

Bamforth, D.B., Finlay, N., 2008. Introduction: archaeological approaches to lithic production skill and craft learning. J. Archaeol. Method Theory 15, 1–27. https://doi.org/10.1007/s10816-007-9043-3

Bleed, P., 2008. Skill matters. J. Archaeol. Method Theory 15, 154–166. https:doi.org/10.1007/s10816-007-9046-0

Boyd, R., Richerson P.J., 1996. Why culture is common, but cultural evolution is rare. Proc. British Acad. 88, 77–93.

Boyette, A.H., Hewlett, B.S., 2018. Teaching in hunter-gatherers. Rev. Phil. Psych. 9, 771–797. https://doi.org/10.1007/s13164-017-0347-2

Bradley, B.A, Khreisheh, N. 2015. Knapping skill assessment. Persistent identifier. EXARC J. 2015/3. https://exarc.net/ark:/88735/10202

Caruana, M.V., Carvalho, S, Braun, D.R., Presnyakova, D., Haslam, M., Archer, W., Bobe, R., Harris, J.W.K., 2014. Quantifying traces of tool use: a novel morphometric analysis of damage patterns on percussive tools. PLoS One 9(11), e113856. https://doi.org/10.1371/journal.pone.0113856

Cattabriga, G., Peresani, M. 2024. Criteria for identifying knapping skill level through the analysis of lithic cores: an example from Val Lastari, Late Palaeolithic, Italy. Lithic Technol. 49(4), 416–431. https://doi.org/10.1080/01977261.2024.2303230

Coomaraswamy, A.K., 1909. The Indian Craftsman. Probsthain, London.

Csibra, G., Gergely, G., 2006. Social learning and social cognition: the case for pedagogy. In: Munakata, Y., Johnson, M.H. (Eds.), Processes of Change in Brain and Cognitive Development. Attention and Performance, XXI. Oxford University Press, Oxford, pp. 249–274.

Diez-Martín, F., Yustos, P.S., Domínguez-Rodrigo, M., Prendergast, M.E., 2011. An experimental study of bipolar and freehand knapping of Naibor Soit quartz from Olduvai Gorge (Tanzania). Am. Antiq. 76(4), 690–708. https://doi.org/10.7183/0002-7316.76.4.690

Duke, H., Pargeter, J., 2015. Weaving simple solutions to complex problems: an experimental study of skill in bipolar cobble-splitting. Lithic Technol. 40 (4), 349–365. https://doi.org/10.1179/2051618515Y.0000000016

Earl, Y.D., Bonnichsen, R., 1984. Understanding stone tools: a cognitive approach. Center for the Study of Early Man, University of Maine, Orono.

Foulds, F.W.F., 2013. The enigmatic handaxe: in search of idiosyncrasies in bifacial technology through three-dimensional form. In: Foulds, F.W.F. (Ed.) Experimental Archaeology and Theory. Recent Approaches to Archaeological Hypotheses. Oxbow Books, Oxford, pp.101–129.

Geribàs, N., Mosquera, M., Vergès, J.M., 2010. What novice knappers have to learn to become expert stone toolmakers. J. Archaeol. Sci. 37(11), 2857–2870. https://doi.org/10.1016/j.jas.2010.06.026

Goren-Inbar N., 2011. Culture and cognition in the Acheulian industry: a case study from Gesher Benot Ya'aqov. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 12, 366(1567), 1038–1049.https://doi.org/10.1098/rstb.2010.0365 PMID: 21357226; PMCID: PMC3049101

Greenfield, P.M., 1984. A theory of the teacher in the learning activities of everyday life. In: Rogoff, B., Lave, J. (Eds.), Everyday Cognition: Its Development in Social Context. Harvard University Press, Cambridge, MA, pp. 117–138.

Herzlinger, G., Grosman, L., 2018. AGMT3-D: a software for 3-D landmarks-based geometric morphometric shape analysis of archaeological artifacts. PLoS One 13(11), e0207890. https://doi.org/10.1371/journal.pone.0207890

Herzlinger, G., Goren-Inbar, N., 2020. Beyond a cutting edge: a morpho-technological analysis of Acheulian handaxes and cleavers from Gesher Benot Ya'aqov, Israel. J. Paleolit. Archaeol. 3, 33–58. https://doi.org/10.1007/s41982-019-00033-5

Herzlinger, G., Goren-Inbar, N., Grosman, L., 2017. A new method for 3D geometric morphometric shape analysis: the case study of handaxe knapping skill. J. Archaeol. Sci. Rep. 14, 163–173. https://doi.org/10.1016/j.jasrep.2017.05.013

Herzlinger, G., Varanda, A., Deschamps, M., Brenet, M., Lopez-Tascon, C., Goren-Inbar, N., 2021. Reevaluation of the classification scheme of the Acheulian in the Levant–50 years later: a morpho-technological analysis of handaxe variability. PaleoAnthropology 2021:1, 23–84.

Hewlett, B.S., Roulette, C.J., 2016. Teaching in hunter–gatherer infancy. R. Soc. Open Sci. 3, 150403. https://doi.org/10.1098/rsos.150403

Hewlett, B.S., Fouts, H.N., Boyette, A.H., Hewlett, B.L., 2011. Social learning among Congo Basin hunter–gatherers. Phil. Trans. R. Soc. B 366, 1168–1178. https://doi.org/10.1098/rstb.2010.0373

Hwang, C.L., Yoon, K., 1981. Methods for Multiple Attribute Decision Making. In: Multiple Attribute Decision Making. Lecture Notes in Economics and Mathematical Systems 186. Springer, Berlin, pp. 58–191. https://doi.org/10.1007/978-3-642-48318-9_3

Katsuhiko, O., Aoki, K., Akazawa, T., 1997. Transmission of tool-making through verbal and non-verbal communication: preliminary experiments in Levallois flake production. Anthropol. Sci. 105(3), 159–168.

Kramrisch, S., 1958. Traditions of the Indian craftsman. J. Am. Folk. 71281, 224–230. https://doi.org/10.2307/538558

Lohse, J., 2011. Step by step. Lithic Technol. 36(2), 97–108. https://doi.org/10.1179/lit.2011.36.2.97

Lombao, D., Guardiola, M., Mosquera, M., 2017. Teaching to make stone tools: new experimental evidence supporting a technological hypothesis for the origins of language. Sci. Rep. 7, 14394. https://doi.org/10.1038/s41598-017-14322-y

Eren, M.I., Lycett, S.J., Patten, R.J., Buchanan, B., Pargeter, J., O'Brien, M.J., 2016. Test, model, and method validation: the role of experimental stone artifact replication in hypothesis-driven archaeology. Ethnoarchaeology 8(2), 103–136. https://doi.org/10.1080/19442890.2016.1213972

Eren, M.I., Lycett, S.J., Tomonaga, M., 2020. Underestimating Kanzi? Exploring Kanzi-Oldowan comparisons in light of recent human stone tool replication. Evol. Anthropol. 29, 310–316. https://doi.org/10.1002/evan.21858

Morgan, T.J., Uomini N.T., Rendell, L.E., Chouinard-Thuly, L., Street, S.E., Lewis, H.M., Cross, C.P., Evans, C., Kearney, R., de la Torre, I., Whiten, A., 2015. Experimental evidence for the co-evolution of hominin tool-making teaching and language. Nature Comm. 6, 6029. https://doi.org/10.1038/ncomms7029

Muller, A., Clarkson, C., Shipton, C., 2017. Measuring behavioural and cognitive complexity in lithic technology throughout human evolution. J. Anthropol. Archaeol. 48, 166–180. https://doi.org/10.1016/j.jaa.2017.07.006

Muller, A., Shipton, C., Clarkson, C., 2022. Stone toolmaking difficulty and the evolution of hominin technological skills. Nature Sci. Rep. 12, 5883. https://doi.org/10.1038/s41598-022-09914-2

Muller, A., Shipton, C., Clarkson, C. 2023. The proceduralization of hominin knapping skill: memorizing different lithic technologies. Cambr. Archaeol. J. 33(4), 655–672.

Musgrave, S., Morgan, D., Lonsdorf, E., Mundry, R., Sanz, C., 2016. Tool transfers are a form of teaching among chimpanzees. Nature Sci. Rep. 6, 34783. https://doi.org/10.1038/srep34783

Musgrave, S., Lonsdorf, E., Morgan, D., Prestipino, M., Bernstein-Kurtycz, L., Mundry, R., Sanz, C., 2020. Teaching varies with task complexity in wild chimpanzees. Proc. Natl. Acad. Sci. U.S.A. 117(2), 969–976. https://doi.org/10.1073/pnas.1907476116

Naveh, D., 2016. Social and epistemological dimensions of learning among Nayaka hunter-gatherers. In: Terashima, H., Hewlett, B.S. (Eds.), Social Learning and Innovation in Contemporary Hunter-Gatherers. Evolutionary and Ethnographic Perspectives. Springer, Tokyo, pp. 125–133.

Nowell, A., White, M., 2012. Growing up in the Middle Pleistocene: life history strategies and their relationship to Acheulian industries. In: Nowell, A., Davidson, I. (Eds.), Stone Tools and the Evolution of Human Cognition, University Press of Colorado, Denver, pp. 67–82.

Olausson, D.J., 2008. Does practice make perfect? Craft expertise as a factor in aggrandizer strategies. J. Archaeol. Method Theory 15, 28–50. https://doi.org/10.1007/s10816-007-9049-x

Pal, J.N., 2002. Subsistence activities among the Mesolithic people of North India as revealed by microwear studies of microliths. In: Misra, V.D., Pal, J.N. (Eds.), Mesolithic India. University of Allahabad, Department of Ancient History, Culture and Archaeology, Allahabad, pp. 313–326.

Pappu, S., Gunnell, Y., Akhilesh, K., Braucher, R., Taieb, M., Demory, F., Thouveny, N., 2011. Early Pleistocene presence of Acheulian hominins in south India. Science 331(6024), 1596–1599. https://doi.org/10.1126/science.1200183

Pargeter, J., Khreisheh, N., Stout, D., 2019. Understanding stone tool-making skill acquisition: experimental methods and evolutionary implications. J. Hum. Evol. 133, 146–166

Pargeter, J., Khreisheh, N., Shea, J.J., Stout, D., 2020. Knowledge vs. know-how? Dissecting the foundations of stone knapping skill. J. Hum. Evol. 145, 102807. https://doi.org/10.1016/j.jhevol.2020.102807

Pelegrin, J., 1990. Prehistoric lithic technology: some aspects of research. Archaeol. Rev. Cambr. 9, 116–125.

Petraglia, M.D., Shipton, C., Paddayya, K., 2005. Life and mind in the Acheulean. A case study from India. In: Gamble, C., Porr, M. (Eds.), The Hominid Individual in Context. Routledge, London, pp. 197–219.

Polley, K., 2010. Flint knapping experiment: an overview in Indian context. J. Indian Anthropol. Soc. 45, 307–314.

Proffitt, T., Bargalló, A., de la Torre, I., 2022. The effect of raw material on the identification of knapping skill: a case study from Olduvai Gorge, Tanzania. J. Archaeol. Method Theory 29, 50–82.

Putt, S.S., 2015. The origins of stone tool reduction and the transition to knapping: an experimental approach. J. Archaeol. Sci. Rep. 2, 51–60. https://doi.org/10.1016/j.jasrep.2015.01.004

Putt, S.S., Wijeakumar, S., 2018. Tracing the evolutionary trajectory of verbal working memory with neuro-archaeology. Interact. Stud. 19(1–2), 272–288. https://doi.org/10.1075/is.17042.put

Putt, S.S., Woods, A.D., Franciscus, R.G., 2014. The role of verbal interaction during experimental bifacial stone tool manufacture. Lithic Technol. 39(2), 96–112. https://doi.org/10.1179/0197726614Z.00000000036

Roux, V., 1990. The psychological analysis of technical activities: a contribution to the study of craft specialization. Archaeol. Rev. Cambr. 9(1), 142–153.

Shennan, S., 2002. Archaeology and evolutionary ecology. World Archaeol. 34(1), 1–5. https://doi.org/10.1080/00438240220134223

Shipton, C., Clarkson, C., 2015. Handaxe reduction and its influence on shape: an experimental test and archaeological case study. J. Archaeol. Sci. Rep. 3, 408–419. https://doi.org/10.1016/j.jasre[.2015.06.029

Shipton, C., Petraglia, M.D., Paddayya, K., 2009. Stone tool experiments and reduction methods at the Acheulean site of Isampur Quarry, India. Antiquity 83, 769–785.

Shipton, C., Nielsen, M., 2018. The acquisition of biface knapping skill in the Acheulean. In: Di Paolo, L.D., Di Vincenzo, F., De Petrillo, F. (Eds.), Evolution of Primate Social Cognition. Springer Verlag, Dordrecht, pp. 283–297.

Shipton, C., Clarkson, C., Cobden, R., 2018. Were Acheulean bifaces deliberately made symmetrical? Archaeological and experimental evidence. Cambr. Archaeol. J. 29, 1–15. https://doi.org/10.1017/S095977431800032X

Silva-Gago, M., Terradillos-Bernal, M., Hodgson, T., Bruner, E., 2022. The role of vision during Lower Palaeolithic tool-making. J. Paleolit. Archaeol. 5, 19. https://doi.org/10.1007/s41982-022-00129-5

Sinha, P., 1999. Prehistoric technology. In: Pande, G.C. (Ed.), The Dawn of Indian Civilization up to c. 600 BC. History of Science, Philosophy and Culture in Indian Civilization, D.P. Chattopadhyay (general Ed.), Project of History of Indian Science, Philosophy and Culture Centre for Studies in Civilizations, New Delhi, pp. 139–173.

Snyder, W.D., Reeves, J.S., Tennie, C., 2022. Early knapping techniques do not necessitate cultural transmission. Sci. Adv. 8(27): eabo2894. https://doi.org/10.1126/sciadv.abo2894

Stout, D., Quade, J., Semaw, S., Rogers, M.J., Levin, N.E., 2005. Raw material selectivity of the earliest stone toolmakers at Gona, Afar, Ethiopia. J. Hum. Evol. 48(4), 365–380. https://doi.org/10.1016/j.jhevol.2004.10.006

Stout, D., 2002. Skill and cognition in stone tool production: an ethnographic case study from Irian Jaya. Curr. Anthropol. 435, 693–722. https://doi.org/10.1086/342638

Stout, D., Khreisheh, N., 2015. Skill Learning and human brain evolution: an experimental approach. Cambr. Archaeol. J. 25(4), 867–875. https://doi.org/10.1017/S0959774315000359

Stout, D., Semaw, S., 2006. Knapping skill of the earliest stone toolmakers: insights from the study of modern human novices. In: Toth, N., Schick, K.D. (Eds.), The Oldowan: Case Studies into the Earliest Stone Age. Stone Age Institute Press, Gosport, IN, pp. 307–320.

Stout, D., Rogers, M.J., Jaeggi, A.V., Semaw, S., 2019. Archaeology and the origins of human cumulative culture: a case study from the earliest Oldowan at Gona, Ethiopia. Curr. Anthropol. 60(3), 309–340.

Tehrani, J.J., Riede, F., 2008. Towards an archaeology of pedagogy: learning, teaching and the generation of material culture traditions. World Archaeol. 40 (3), 316–331. https://doi.org/10.1080/00438240802261267

Silva-Gago, M., Fedato, A., Terradillos-Bernal, M., Alonso-Alcalde, R., Hodgson, T., Bruner, E., 2022. Does knowledge influence visual attention? A comparative analysis between archaeologists and naïve subjects during the exploration of Lower Palaeolithic tools. Archaeol. Anthropol. Sci. 14(6), 114.

Terashima, H., Hewlett, B.S. (Eds.), 2016. Social Learning and Innovation in Contemporary Hunter-Gatherers. Evolutionary and Ethnographic Perspectives. Springer, Tokyo.

Toth, N., 1987. Behavioral inferences from Early Stone artifact assemblages: an experimental model. J. Hum. Evol. 16, 763–787.

Wilson, E., Stout, P.D., Liu, C., Kilgore, M.C., Pargeter, J., 2023. Skill and core uniformity: an experiment with Oldowan-like flaking systems. Lithic Technol. 48(4), 333–346. https://doi.org/10.1080/01977261.2023.2178767

Zaidner, Y., 2013. Adaptive flexibility of Oldowan hominins: secondary use of flakes at Bizat Ruhama, Israel. PLoS One 8(6), e66851. https://doi.org/10.1371/journal.pone.0066851

Wynn, T., Coolidge, F.L., 2004. The expert Neandertal mind. J. Hum. Evol. 46(4), 467–487.

Supplement 1: Flakes, Feelings, and Finesse: Experiential Studies of Skill Acquisition in Novice Knappers

KUMAR AKHILESH
Sharma Centre for Heritage Education, No.4, School Street, Sholinganallore, Chennai 600119, Tamil Nadu, INDIA; akhilarchaeo@gmail.com

PRACHI JOSHI
Sharma Centre for Heritage Education, No.4, School Street, Sholinganallore, Chennai 600119, Tamil Nadu, INDIA; prachinjo@gmail.com

SUTONUKA BHATTACHARYA
Sharma Centre for Heritage Education, No.4, School Street, Sholinganallore, Chennai 600119, Tamil Nadu, INDIA; and, Institute of Archaeology, The Hebrew University of Jerusalem, Mount Scopus, Jerusalem 9190501, ISRAEL; sutonuka.bhattachary@mail.huji.ac.il

YESHASWINI RAJAGOPALAN
The Archaeology Department, Durham University, The Palatine Centre, Stockton Road, Durham, DH1 3LE, UNITED KINGDOM; yeshas.raja98@gmail.com

SHALAISH BAISLA
Department of Quaternary and Prehistory, University Rovira i Virgili (URV), Tarragona 35, 43002 SPAIN; shaileshbaisla@gmail.com

ANKITA DEY
600 G.T.Road Siristala, Serampore, Hooghly, West Bengal,, INDIA; ankitadey1717@gmail.com

SURENDRA GHASKADBI
Developmental Biology Group, MACS-Agharkar Research Institute, GG Agarkar Road, Pune 411004, Maharashtra, INDIA; ghaskadbi@gmail.com

BALASUBRAMANIAN KARTHICK
Biodiversity and Paleobiology Group, MACS-Agharkar Research Institute, GG Agarkar Road, Pune 411004, Maharashtra, INDIA; karthickbala@aripune.org

MRUDULA MANE
Centre for Heritage Conservation, Research and Development Foundation, CEPT University, Ahmedabad, Gujarat, INDIA; mrudulmane@gmail.com

AKASH PANDEY
Department of Archaeology and Ancient History, The Maharaja Sayajirao University of Baroda, Gujarat, INDIA; akashpandey8936@gmail.com

SRINATH PERUR
52 Serpentine Road, KPW, Bengaluru 560020, Karnataka, INDIA; psrinath@gmail.com

CHANDNI ROY
Anita Tower, Block C, 4th Floor, Flat No. E4, 52/4 Ramkrishnagarh Road, Kolkata 700079, West Bengal, INDIA; chand16prehistoricrealm@gmail.com

ALOK SHARMA
Amity Institute of Anthropology, Amity University, Noida, Uttar Pradesh, INDIA; alok2153@gmail.com

AMMEL SHARON
Centre for Studies in Social Sciences, Calcutta, West Bengal, INDIA; ammel.sharon@gmail.com

CHINTAN THAKAR
Mahadev Ji Ki Ghati, Chavni Gate, Imli Bazar, Nathdwara, Rajsamand, Rajasthan; INDIA; chintanarchaeo@gmail.com

SWATI VERMA
Department of Archaeology and Ancient History, The Maharaja Sayajirao University of Baroda, Gujarat, INDIA; swativerma0284@gmail.com

AKANKSHA S. KASHIKAR
Department of Statistics, Savitribai Phule, Pune University, Pune, 411007, Maharashtra, INDIA; akanksha.kashikar@gmail.com

***PaleoAnthropology* 2025:1** **Supplement to Akhilesh et al. 2025:1** OPEN ACCESS **ISSN 1545-0031**
Paleoanthropology Society & European Society for the study of Human Evolution.
Early View available online 3 December 2024

Early View available online 3 December 2024

• *PaleoAnthropology* 2025:1

SHANTI PAPPU
Sharma Centre for Heritage Education, No.4, School Street, Sholinganallore, Chennai 600119, Tamil Nadu; and, Humanities and Social Sciences, Krea University, Andhra Pradesh, INDIA; pappu.shanti@gmail.com

SUPPLEMENT 1

This supplementary material includes: Supplementary Text (Methodology), Supplementary Tables S1–S3, Supplementary Figures S1–S3, and References.

TOPSIS Methodology

In TOPSIS, the decision-making process involves the following key steps:

1. Identification of criteria relevant to the decision-making problem: Here, criteria included lithic attributes (see Table S2).
2. Normalization of criteria: The criteria should be normalized to ensure they are on the same scale. This step allows for fair and accurate comparison among alternatives.
3. Constructing the decision matrix: A decision matrix is created by representing each observation and its performance with respect to each criterion. The matrix serves as the basis for subsequent calculations.
4. Determining weights: A weight vector provides the relative importance of each criterion. Generally, it is provided by the domain experts.
5. Impact vector: An impact vector is a vector of positive and negative signs indicating whether a particular criterion's higher/lower values are desirable.
6. Ranking and selection: Alternatives are ranked based on their proximity to the ideal solution vector (highest value or the lowest value, as the case may be). The alternative with the highest proximity to the ideal solution is considered the most favourable. The score for each observation is generated using the relative proximity to the ideal solution.

The current analysis has been carried out using the package "topsis" (Yazdi 2013) in R (R Core Team 2023).

The variables used for generating the scores for each set of experiments are listed below. The signs in the bracket indicate whether that variable's higher (+) or lower (-) value indicates a better performance. For every participant, TOPSIS generates one score for each set of experiments. To normalize the criteria, we have computed the z-scores, i.e., we have ensured that the mean value for every criterion is zero and that the standard deviation is one.

Experiments 1 to 5 (Bipolar knapping)

Here, we focused on splitting pebbles on an anvil using this method (see Section 4.1).

1. *The proportion of times symmetry was achieved out of the five experiments (+):* Although splitting the pebble is sufficient to achieve the desired result, we added the criterion of the ability to achieve two symmetrical segments suggestive of higher degrees of control in knapping.
2. *The average number of blows required for knapping the pebble (-):* Here, we counted the number of times the knapper had to strike the pebble to split it, thereby judging hand-eye coordination and the ability to estimate the correct angle for knapping.

3. *Deviation of the number of pieces from two (-):* As the task was to obtain two roughly symmetrical segments, a greater amount of shatter obtained reflected lower skill levels.
4. *The proportion of times that the task was completed by the participant (+):* This assessed basic skills in opening the pebble based on the assumption that a completely unskilled novice would be unable to achieve the same, as was noted in several instances.

All four criteria mentioned above are given equal importance in computing the scores.

Experiments 6 and 7 (free hand flaking of a cobble core with a hard stone hammer) (see Section 4.2)

1. *Average core-to-cobble weight ratio (-)*: This estimated the degree of reduction of the cobble comparing weights before and after flaking.
2. *Number of flakes per unit of the core volume (+):* This provided an estimate of the number of flakes that a novice could detach with respect to the volume of the core, thereby providing an assessment of abilities to estimate the correct angle and position for detaching flakes to reduce the core completely.
3. *The average weight of flakes (+):* This provided an estimate of the skill in detaching suitable flakes, as the goal was to obtain flakes that could be functional.
4. *The average length of flakes (+):* This was based on the goal of being able to knap the core to detach flakes that could be used, having suitable dimensions and cutting edges.
5. *The proportion of complete flakes (+):* Breakage arising from excessive force and/or wrong angles often suggests lower degrees of control, resulting in a higher proportion of broken flakes and shatter.
6. *The proportion of broken/step/abrupt/unclear flake terminations (-):* The same as above.
7. *Number of siret breaks per flake (-):* The same as above.
8. *The ratio of flakes as defined by Toth (1987) (Type 1-2 to 3-6)* provided an estimate of the cortex percentage and position, thereby estimating how invasive the flaking was and to what extent the novice could reduce the core.

The first two criteria are deemed more critical; hence, the weights given to these two criteria are twice the weights given to the remaining criteria while computing the scores.

Experiments 8 to 10 (handaxe façonnage) (see Section 4.3)

1. *The proportion of complete flakes (+):* this was an estimate based on KA's experience, where the proportion of complete flakes increased with increasing skill. The probability of broken flakes increases greatly with faulty angles and force, particularly those with siret breaks or step terminations.
2. *Number of flakes per handaxe (+):* This is based on the degree to which the knapper could achieve the task by detaching flakes. As this was an experimental set-up, we could count the

total number of flakes obtained, an advantage that cannot be measured accurately in the archeological context.

3. *The average number of flake scars on the handaxes (+):* This would be comparable to what is seen in the archeological record in terms of the flake scar counts on both faces, providing an idea of the extent and location of flaking signifying decision-making processes of the knappers.
4. *The proportion of flakes with broken terminations (-):* This is common in novice knappers.
5. *Flake thickness (-):* as novices proceed to develop skills, flake thickness reduces.
6. *Average elongation of flakes computed as the ratio of the length to the breadth: (+):* skilled knappers tend to produce more elongated thin flakes as handaxe façonnage proceeds.

While computing the scores, the weights given to criteria number 2, 3, 5, and 6 are twice those given to the remaining criteria as they are deemed more important. The final scores were computed by simply taking the average score of each participant for the above three groups of experiments, which are discussed at the end of the paper.

Table S1. Details of the participants in the experiments showing: **A**. Summary of physical characteristics of all participants as per gender; **B.** Details of individual participants as regards physical characteristics; **C.** Skill levels as regards athletic and art/craft activities and prior knowledge of the subject (Note that names were replaced by code numbers, M standing for male and F representing female participants).

A

Gender		Weight (kg)	Height (m)	Age
Female	N	6.00	6.00	6
	Mean	59.67	1.57	28.5
	Minimum	49.00	1.53	23
	Maximum	70.00	1.65	35
	Std. Deviation	9.50	0.04	5.32
Male	N	7.00	7.00	7
	Mean	79.29	1.72	37.14
	Minimum	56.00	1.63	25
	Maximum	92.00	1.78	66
	Std. Deviation	11.63	0.06	14.77

B

Participants	Weight (kg)	Height (m)	Age
F1	55	1.55	35
F2	70	1.57	26
F3	65	1.575	28
F4	69	1.525	35
F5	49	1.57	23
F6	50	1.65	24
M1	56	1.625	26
M2	85	1.775	25
M3	92	1.675	30
M4	78	1.65	40
M5	75	1.75	28
M6	85	1.78	45
M7	84	1.75	66

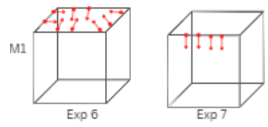
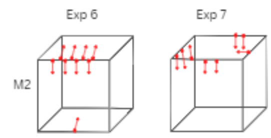
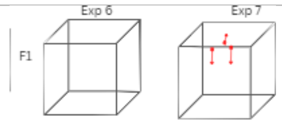
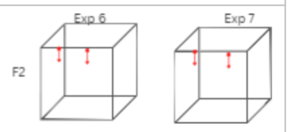
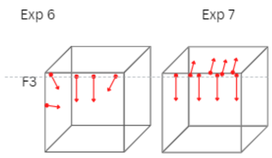
C

Activities		Female Count	Male Count
Sports	*N*	5	2
	Y	1	5
Art and Craft	*N*	4	4
	Y	2	3
Regular other hands-on activities	*N*	3	1
	Y	3	6
Attended a knapping workshop	*N*	3	6
	Y	3	1
Self-taught lithic knapping	*N*	5	6
	Y	1	1
Viewed videos on lithic knapping	*N*	2	0
	Y	4	7
Attended lectures on lithic knapping and prehistory	*N*	2	3
	Y	4	4

Table S2. Attributes selected for lithic analysis

Experiment Number	Nature of the Experiment	Attributes selected for lithic analysis
Exp 1,2,3,4,5	Bipolar technique	1. Dimensions of hammerstones, anvils and pebbles: length, breadth, thickness (in mm), weight (gm) 2. Raw materials of hammerstones, anvils and pebbles 3. Number of blows required to split the pebble 4. Number of segments obtained after splitting the pebble 5. Dimensions of segments obtained: length, breadth, thickness (in mm), weight (gm) 6. Percussion marks on the hammerstone and anvil 7. Symmetry achieved by splitting the pebble (yes or no)
Exp. 6,7	Detachment of flakes from cobble cores by freehand hard-hammer percussion	1. Dimensions of hammerstones and cobbles (length, breadth, thickness (in mm), weight (gm) 2. Raw material of hammerstones and cobbles 3. Core dimensions: length, breadth, thickness in mm, weight (gm). 4. Number of flake scars on the cores 5. Number of flakes detached 6. Organization of flaking patterns on cores (see Table S3) 7. Degree of core reduction based on estimates of flake density per unit mass (weight in grams, correlated with geometric size, i.e. length x breadth x thickness) [Caruana et al. 2014]. 8. Flake attributes: dimensions (length, breadth, thickness (in mm), weight (gm); state of completeness, presence of siret breaks, striking platform (plain, facetted, cortical, pointed, broken); number of dorsal flake scars, flake termination (step, hinge, feather, abrupt, other breakages), presence of eraillure (present/absent). 9. Analysis of flakes as per N. Toth (1987) 10. Cortex percentage on the core (0%, 0-25%, 25-50%, 50-75%, 75-100%, 100%) 11. Reasons for the discard of cores.
Exp 8,9, 10	Handaxe façonnage on flake blanks	1. Dimensions of the hammerstones and flakes selected: length, breadth, thickness (in mm), weight (gm) 2. Raw material of hammerstones and flakes 3. Dimensions of the final handaxe (length, breadth, thickness (in mm), weight (gm) 4. Number of flake scars on the handaxe 5. Actual number of flakes detached from each handaxe 6. Flake attributes: dimensions (length, breadth, thickness (in mm), weight (gm); state of completeness, presence of siret breaks, striking platform (plain, facetted, cortical, pointed, broken); number of dorsal flake scars, flake termination (step, hinge, feather, abrupt, other breakage), presence of eraillure (present/absent). 7. 3D Geometric morphometrics of the handaxes and resulting statistics related to shape and symmetry

Table S3: Change observed in flaking strategies and decision-making by individual novice knappers noted between Exp 6 and Exp 7 (detaching flakes off cobble cores using a hard stone hammer).

Participant	Exp 6	Exp 7	Strategies adopted	Learning Curve (0-5)	Skill level	Schematic diagram
M1	• Centripetal flaking ending in step terminations • Plano-convex with a lower cortical face.	• Adoption of a single striking platform from which two generations of laminar flakes were detached.	• Shift in decision-making adapting to the cobble shape. • Fewer step terminations and greater success in flake detachment and controlled flaking • Previous knapping experience possibly influenced better decision-making in both cases • No significant improvement, but a change in strategies adopted	1	5	
M2	• Peripheral bifacial flaking unintentionally achieves a morphology resembling a bifacial chopper with attempts to peripherally flake the opposite edge. • Shallow scars, some ending in step terminations	Multifacial, peripheral	• Similar strategies were followed in both experiments. • Thin, shallow flakes were detached in both cases. • Two generations of flaking • No significant learning curve and no change in strategy was noted	0	2	
F1	• Could not initiate flaking. • This piece could have been classified as a hammerstone with extensive battering marks in the archeological record.	• Three multidirectional flakes were detached, following which the core broke	• Improvement in flaking control, with the ability to open the cobble and use scars to detach more flakes by rotating the cobble	4	1	
F2	• Removal of a single flake • Battering marks suggestive of intensive percussion and wrong angles • This piece could have been classified as a modified cobble in the archeological record	• Two flake scars but a similar strategy as in Exp_6	• There is no learning curve and no improvement	0	0	
F3	• Unidirectional flaking along the periphery of the core leads to inadvertent chopper-like morphology.	• Peripheral bidirectional bifacial flaking inadvertently achieves a morphology like a chopping tool.	• The learning curve is seen in an increased number of flake scars, control over flake detachment, change of strategies adopted	4	3	

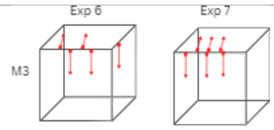
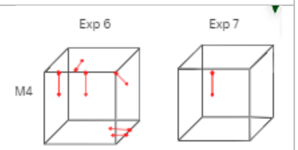
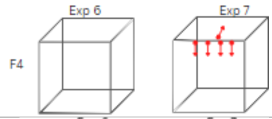
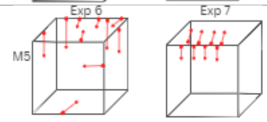
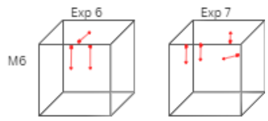
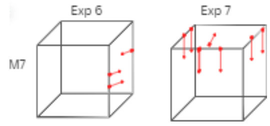
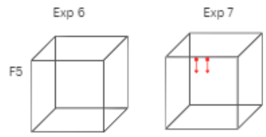
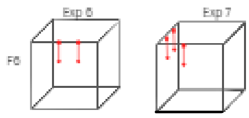
Participant	Exp 6	Exp 7	Strategies adopted	Learning Curve (0-5)	Skill level	Schematic diagram
M3	• Removal of a striking platform that was subsequently used to detach further flakes.	• Peripheral bidirectional bifacial flaking inadvertently achieves a morphology like a chopping tool.	• Change in strategy. • Could not flake the core-periphery beyond a certain point • Utilisation of available platforms	1	4	
M4	• Along a periphery, bidirectional but very small scars	• Core broke	• No learning curve and no success	0	0	
F4	• Could not initiate flaking	• Bifacial flaking along a periphery of the core	• Improved learning curve	5	4	
M5	• Multidirectional, flaked all over	• Peripheral bidirectional bifacial flaking inadvertently achieves a morphology like a chopping tool	• Shift in strategy in Exp 7. • Increased controlled flaking suggestive of a learning curve	4	4	
M6	• Removal of a striking platform that was subsequently used to detach further flakes.	• Bidirectional flaking inadvertently achieves a morphology like a chopping tool	• Shift in strategy in Exp 7, however, decrease in controlled flaking	2	2	
M7	• Removal of only few flakes	• Multidirectional, amorphous core, with use of flake scars as platforms for further flaking, with increase in number of flakes	• Increased skill, flaking control and planning	4	3	
F5	• Could not initiate flaking	• Few flakes were detached unidirectionally, with evidence of percussion marks suggestive of attempting to flake	• Learning curve with some success in Exp 7	3	1	
F6	• Minimal flaking with one scar detached	• Peripheral unidirectional flaking along the periphery of the core	• Minimal skill improvement	4	2	

Figure S1. Self-assessed emotional states on a scale of 1 to 5 showing details of each participant.

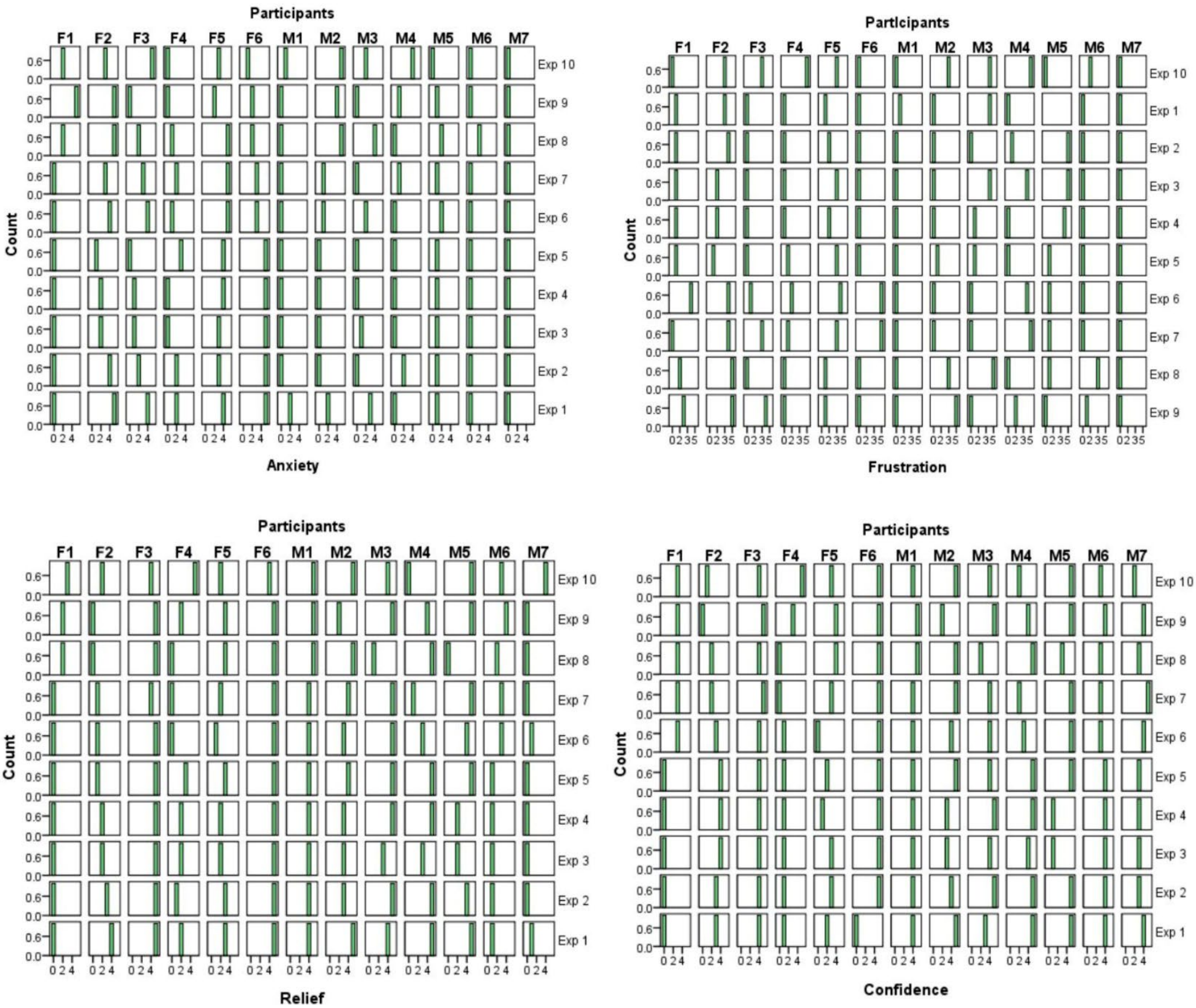


Figure S2A. Examples of cores and flakes obtained during Experiments Exp 6 and Exp 7 (M1-M7). The dorsal and ventral views are with respect to the flakes generated.


M1 Exp 6 Dorsal view


M1 Exp 6 Ventral view


M1 Exp 7 Dorsal view


M1 Exp 7 Ventral view


M2 Exp 6 Dorsal view


M2 Exp 6 Ventral view


M2 Exp 7 Dorsal view


M2 Exp 7 Ventral view


M3 Exp 6 Dorsal view


M3 Exp 6 Ventral view


M3 Exp 7 Dorsal view


M3 Exp 7 Ventral view


M4 Exp 6 Dorsal view


M4 Exp 6 Ventral view


M4 Exp 7 Dorsal view


M4 Exp 7 Ventral view


M5 Exp 6 Dorsal view


M5 Exp 6 Ventral view


M5 Exp 7 Dorsal view


M5 Exp 7 Ventral view


M6 Exp 6 Dorsal view


M6 Exp 6 Ventral view


M6 Exp 7 Dorsal view


M6 Exp 7 Ventral view


M7 Exp 6 Dorsal view


M7 Exp 6 Ventral view


M7 Exp 7 Dorsal view


M7 Exp 7 Ventral view

Figure S2B. Images of cores and flakes obtained during Experiments Exp 6 and Exp 7 (F1-F6).


F1 Exp 6


F1 Exp 6


F1 Exp 7 Dorsal view


F1 Exp 7 Ventral view


F2 Exp 6 Dorsal view


F2 Exp 6 Ventral view


F2 Exp 7 Dorsal view


F2 Exp 7 Ventral view


F3 Exp 6 Dorsal view


F3 Exp 6 Ventral view


F3 Exp 7 Dorsal view


F3 Exp 7 Ventral view


F4 Exp 6 Dorsal view


F4 Exp 6 Ventral view


F4 Exp 7 Dorsal view


F4 Exp 7 Ventral view


F5 Exp 6 Dorsal view


F5 Exp 6 Ventral view


F5 Exp 7 Dorsal view


F5 Exp 7 Ventral view

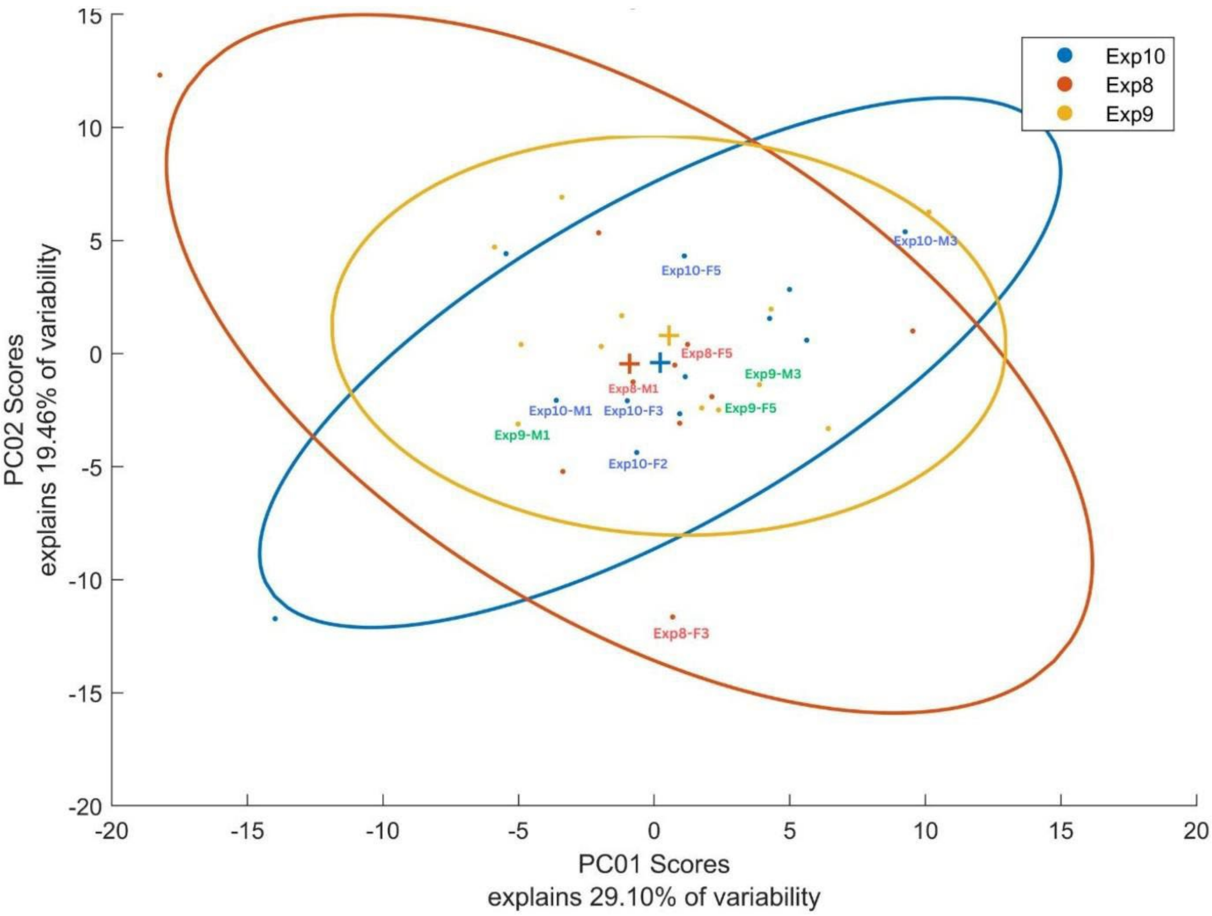

F6 Exp 6 Dorsal view


F6 Exp 6 Ventral view


F6 Exp 7 Dorsal view


F6 Exp 7 Ventral view

Figure S3. Geometric morphometric analysis (after Herzlinger et al. 2018) of handaxes showing scatterplot of the item scores on the first two PCs marked with the novice knappers who had some prior experience in lithic knapping. The code numbers for the participants with prior knapping experience as also the experiment numbers are marked.



References

R Core Team., 2023. R: A Language and Environment for Statistical Computing. https://www.r-project.org/. R Foundation for Statistical Computing.

Yazdi, M. M. 2013. TOPSIS method for multiple-criteria decision making MCDM_. R package version 1.0. https://cran.r-project.org/package=topsis.