Abstract: The purpose of this work is to analyze in which way the technical system of the Early Neolithic flint mine of Casa Montero (5350–5220 cal. BC) was organized to manage different flint-based reduction sequences. The particular features and genesis of Casa Montero's flint limited the efficiency of one of the main goals of the mine: blade production. As a result, a great amount of the extracted raw material was discarded throughout the process. However, an efficiently planned management allowed its reuse for other purposes. One of the key social activities that took place at the mine was knapping apprenticeship. Younger community members were progressively introduced to this complex technical system, taking part in a many-sided set of tasks and parts of the whole production process, from extraction to recycling and waste management. However, knapping learning, as an operative sequence itself, needs a great amount of raw material. By means of the factorial analysis of the relationships between skill levels and raw material varieties and features of blanks, we can understand the complex organization of this technical system in which some strategies were carried out to avoid competition for raw material and allow motivation of apprentices. The spheres of mining, knapping, and learning coexist harmonically and benefit each other. Younger people of the community participated in mining as a workforce, knapping offers them abundant waste to practice, and learning allows social reproduction.

Keywords: Early Neolithic, Casa Montero, flint mining, knowledge transmission, blade production
in Spain. Neolithic flint mines are the expression of collective labor (Capote & Díaz-del-Río, 2015). The organization of work among miners and the interaction of a variety of factors that converged in Neolithic flint mines is one of the most interesting questions addressed in the current research. Different models have been proposed, from control by small groups of specialized miners (Bostyn & Lanchon, 1992, p. 221) to the manifestation of a communal effort of an aggregation of groups with all their members implicated (Capote, 2011; Consuegra et al., 2018; Díaz-Del-Río & Consuegra, 2011, p. 228). Despite the number of people involved, it necessarily implied an organization system.

The Early Neolithic flint mine of Casa Montero (Madrid, Spain) was exploited by aggregation of groups during different mining events at a certain time (5400–5200 cal. BC) in which the population density of the inner Iberian Peninsula was very low and the groups were small and mobile (Consuegra et al., 2018; Díaz-Del-Río & Consuegra, 2011).

Such circumstances would require an efficient organization to avoid conflicts. This organization may have been both the result of common experience and a cohesion tool. The way in which Casa Montero miners managed their tasks, from raw material extraction to the final distribution of the products (blades and cores), from subsistence tasks to symbolic and social interactions, was known, shared, and transmitted by all the members of the large community that converge at Casa Montero mining events.

The objective of this paper is to analyze the technical organization of work carried out at Casa Montero flint mine, highlighting the interaction between economic and social tasks, particularly between blade production and the transmission of knowledge of flint knapping to the next generation. Both tasks were the main goals of the mining events and both compete for the same raw material. However, they must coexist in a harmonic way to guarantee the success of the whole technical system, its reproduction, and the integration of younger members within the group and the community.

## 2 Casa Montero Flint Mine and Its Technical System

Casa Montero was located in the center of the Iberian Peninsula, next to the convergence of the Jarama and Henares rivers in one of the elevated moors (Figure 1). The region is well known for its abundance of siliceous material that was exploited since the Lower Palaeolithic (e.g., Bárez et al., 2016). Until the discovery of Casa Montero in 2003, no prehistoric flint-related mining or quarry works had been identified in the area, although some related to certain historical periods had been. It was the first Neolithic flint mine to be confirmed and excavated in the Iberian Peninsula (Consuegra, Gallego, & Castañeda, 2004).

The archaeological fieldworks from 2003 to 2006 affected an area of 4 ha in which 3,794 Neolithic flint mining shafts were documented. These vertical shafts were deep and narrow. Their average diameter is 1.12 m and a depth that varies from 0.98 to 9.26 m. The shafts were dug across the three upper silification episodes documented in the geological formation (Bustillo et al., 2009). The mining shafts are very close (from 1.38 to 0.04 m) and they do not cut previous structures.

A strategy was carried out in the process of excavation of the shafts. They were perfectly organized and planned to prevent collapses and accidents (Capote, Castañeda, Consuegra, Criado, & Díaz-Del-Río, 2008). Not only the narrow diameter of shafts was calculated to be secure and allow easy circulation but also the immediate refilling in with the extracted sediment and knapping waste avoid accidental falls and reinforce the soil resistance. Shaft fillings are characterized by a homogeneous pattern of low degree of human alteration and frequent absence of organic remains (Consuegra et al., 2018, p. 58).

Most of the deposits were thick and horizontal, and only seldom of the 338 excavated shafts presented the evidence of deteriorating walls by erosion or collapse. These features together with the perfect preservation of tool marks in 76 shafts indicate that they were refilled intentionally in a very short lapse of time after their excavation.

The refitting of minoritarian elements such as pottery, brought as sets of drinking/eating, serving, and storage/transporting containers (Consuegra et al., 2018, p. 61), and quartzite percussion tools has provided the information of the number of structures that were opened at the same time. Groups of 6 to 22 shafts were simultaneously opened and organized in mining events (Capote, 2011, p. 238). Radiocarbon dating indicates...
that the exploitation of the mine lasted from 5337 to 5218 cal. BP at 1 sigma (Díaz-Del-Río & Consuegra, 2011, p. 226), a brief 100-year period, without spatial differences in the mine.

These results contrast with the limited available data related to the Neolithic in the region (Díaz-Del-Río & Consuegra, 2011, p. 228). During this period, the scarce population lived in small, dispersed groups with high mobility, whose economy was based on pastoralism and agriculture (Díaz-Del-Río et al., 2011, p. 119). Consequently, to tackle the excavation of a flint mine with the dimensions of Casa Montero must have required an aggregation of different groups at a regional scale.

In light of this context, the mine was allowed to be the place for social interactions and, of course, for flint supply (Díaz-Del-Río et al., 2011). The documentation of other non-extractive and maintenance activities, together with some features of the mining structures, suggests that whatever was the age or sex of the members of the group, they all came and participate in the mine events (Consuegra et al., 2018, p. 64).

Flint supply must have been organized in an eminently practical way within the social-economical context of Casa Montero. The small and mobile groups that concurred at the mine could not carry large volumes of raw material. These groups usually put into practice lighten strategies as including crushed bone as temper in pottery containers (Díaz-Del-Río et al., 2011). Stocking on enough blade supports and configurated cores could have been the best tactic to deal with the mobility problem. As a result, the main part of the lithic reduction was carried out at the mine.

One of the benefits of Casa Montero’s research is the number of lithic pieces that have been studied in which hypotheses are supported. To understand the lithic production and the management of flint resources on a technical and social level, a significant sample from 62 mining shafts has been studied (18.34% of the excavated structures). The shafts were selected because they present some Early Neolithic markers as pottery or radiocarbon dates. This sample is composed of 168,000 lithic items, of which 2,867 are
cores and 4,565 are discarded blades, being the largest collection of lithic elements belonging to the Peninsular Neolithic.

The study has allowed the identification of Casa Montero as a large center of blade production, unique to date. Its double nature, as a large-scale extraction and production center, gives this site a unique character that impedes its comparison to other contexts from the same period. The main production at the mine was oriented to obtain blades for deferred use, such as sickles (Castañeda, Criado, Nieto, & Casas, 2015b). Blade products have a mean predetermined length of around 5 cm. This means that, even though the size of the flint nodules of Casa Montero allows the extraction of longer blades, this length was previously and intentionally established (Castañeda et al., 2015b, pp. 482–483). There were two methods to obtain this predetermined dimension of products: by the orientation of the blank or by removing a rejuvenation tablet at the beginning of the reduction process.

The purpose for obtaining a product with a specific size indicates that the blades must comply with certain specifications at the moment of hafting or use to facilitate a fast and simple replacement. Consequently, it is a highly anticipated production almost invisible in other archaeological contexts such as habitats. Casa Montero has provided two sickle blades with diagonal hafting, scarcely documented in the Iberian Peninsula (Ibáñez et al., 2008, p. 190; Terradas, Clemente, & Gibaja, 2011, pp. 248–249) (Figure 2). This type of tool was probably the final purpose of the blade production.

Although the production of blades was the main goal of Casa Montero flint mine, it had to coexist with other Flint-based operative sequences with different objectives. They were organized in a harmonic way...
that allowed the correct functioning of each of them and all the technical system as a whole, like if they were a set of gears of an engine.

Not only blades were produced but also diverse tools, as sidescrapers, denticulates, and perforators, performed probably for multiple tasks involved in mining like rigging, woodworking, and food processing (Consuegra et al., 2018, p. 59). These tools were of different consideration if we take into account that the most expedient ones were made on recycled blanks while those made for a longer use were made on ad hoc produced flakes (Castañeda, Casas, Criado, & Nieto, 2015a, p. 478). Therefore, recycling, understood as the use of discarded waste from the main production, played a critical role in the mine organization in which several reduction sequences were using the same raw material, even though the abundance of flint is astonishing.

As regards to raw material, the different siliceous episodes of Casa Montero formation were affected by an aging process that leads to the inner re-crystallization of the opaline nodules, transforming them into flint with high quartz contents (Bustillo et al., 2009, pp. 193–194). As a consequence of this process, up to three siliceous varieties – Opal CT, opaline flint, and re-crystallized flint – can occur within a Casa Montero nodule. These varieties have different levels of silicification and different knapping properties.

Casa Montero knappers developed a strategy in which the opal and opaline flint outer parts of the nodules were systematically discarded at the beginning of the reduction process during the initial configuration or by selecting initial blanks that did not contain these varieties (Castañeda et al., 2015b, p. 481). This strategy, in addition to the inherent heterogeneity of continental flint, led to the abandonment and discard of a high percentage of flint (99.81% of the total mined weight). Consequently, the amount of good raw material available for learners was limited, considering that knapping learning needs a large amount of stone. It is reasonable to think that to solve the problem of competition over flint carrying out blade production and learning at the same time, knappers would use the discarded less silicificate raw material for the operative sequence of apprenticeship.

3 Methods

This study is based on the principle of considering knapping learning as an operative sequence. Knapping apprenticeship has distinctive tasks: learn how to find and extract the raw material, learn how to obtain and select the proper blanks depending on the production, learn to use the proper tools, learn the gestural procedures, learn to anticipate the changes in the shape of each removal, and learn how to fix errors, among others. Learning to knap is a process of constantly improving that can be divided into different stages: impregnation and active practicing (Karlin, 1992, p. 105; Milne, 2012, p. 126; Stout, 2002, pp. 702–703; Takakura, 2013, pp. 169–170). To distinguish the residues produced in each stage is critical to explain how apprenticeship is produced. However, it is very difficult to assign pieces to a stage of learning as improving is continue and intermediate stages are not only possible but predictable.

Casa Montero’s lithic remains show tracks of knapping learning. The present work is built based on a previous one in which differences in skill were analyzed in a sample of 822 cores (Castañeda, 2018). Three skill levels have been identified in Casa Montero blade production, called from higher to lower: expert, advanced apprentice, and novice (Castañeda, 2018, pp. 721–729). The criteria used to identify and distinguish these levels are based on the presence of two types of errors: selection and execution mistakes, since knapping combines both conceptual and procedural knowledge (Castañeda, 2018, p. 721) (Table 1).

There are three types of selection mistakes: raw material quality, size, and shape of blanks and knapping tools. Inexperience in differentiating the mechanical properties of raw material varieties produces the selection of nodules or fragments with a high level of heterogeneity or low level of silicification (opaline flint). Opaline parts of nodules at Casa Montero were systematically discarded due to their fragility (Castañeda, 2018, p. 717). The question is if novice knappers could freely choose this raw material or they had limited access to good varieties of flint to practice (Castañeda, 2018, p. 725).

The presence of an important number of cores that could have continued been worked on (18.30%), abandoned by experts and advanced apprentices, together with some very elaborate elements made on
low-quality raw material blanks, systematically discarded at the site, support the hypothesis regarding guided learning by means of demonstrations that would have been imitated by the apprentices (Castañeda, 2018, pp. 725–726) (Figure 3).

The selection of an appropriate size and shape of the blanks used to start the reduction process, depending on the final product, expresses the knowledge and experience of the knapper concerning the ability in anticipating volume needs.

Finally, the selection of a proper knapping tool (soft mineral hammers in this case) in shape, size, and weight, needs practical experience in using it including self-knowledge and anticipating the consequences of the strike. Although there are some knapping accidents that were related to hammers in literature (e.g., Hovers, 2009 and references therein), it is not easy to evaluate if a knapping error was produced due to an unbalanced relationship between core and hammer mass, bad gripping, or force on hitting.

The mistakes regarding execution indicate the inexperience in the gestures or the abstraction of the final product (Castañeda, 2018). This type of mistake includes knapping accidents (e.g. hinges) (Figure 4), excessive or insufficient convexity of the knapping surfaces, inadequate location of the removals and parts of the core, and evidence of insistent percussion on edges or inadequate places of the core (Figure 5).

4 Results

To analyze the relationship between the operative sequence of apprenticeship and its source of raw material, a multiple correspondence analysis of 822 cores was carried out (Figure 6). The variables used are the three identified skill levels (expert, advanced apprentice, novice); the predominant siliceous variety present in the blanks (opaline, recrystallized), the quality of the blank (heterogeneous, homogeneous, considering the presence/absence of geodes, veins, or fissures), the origin of the blank (original, such as flakes and nodules, or recycled/reconfigured), and their size (extremely small for blade reduction or of the proper size). The first two obtained factors explain 40.81% of the variance of the sample (F1: 21.35%; F2: 19.46%).

The results relate the three levels of dexterity with different qualities of the blanks that were used. Novices appear next to the most heterogeneous material. During this phase of apprenticeship, initiation to knap would be focused on acquiring the gestural practice. This phase consumes a large amount of stone since inexpert strikes produce internal fissures on the core and failed removals produce the destruction of appropriate surfaces and edges. The abandonment of these cores happens at an early stage (Castañeda, 2018, p. 724). Therefore, novices would use the lowest quality raw material that was discarded even during
the phase of extraction from the shaft. Nevertheless, the use of this type of low-quality material makes it difficult to improve skills and continue learning (Castañeda, 2018, p. 725).

Advanced apprentices are mainly related to opaline varieties of flint blanks, discarded in the initial configuration of blade cores. Opaline flint contains less quartz than re-crystallized variety (Bustillo et al., 2009, p. 185), which makes the former more fragile and, consequently, worst in use. Nevertheless, it presents good attributes for learning how to manage the volume of the core and how to shape it. Furthermore, the use of this discarded material for learning does not reduce the productivity of blade production of the mine. In the same way, advanced apprentices occasionally use nodules that, due to their small size, cannot be complex-shaped but may have a better quality to practice with.
Figure 4: An opaline flint core from an unskilled knapper with successive removals with deep hinge terminations. Number: 1296/10. Photograph: N. Castañeda.

Figure 5: Examples of execution mistakes documented in Casa Montero cores: (a) deep hinges, (b) stacked unproductive hitting, and (c) tracks of Hertzian cones due to lack of accuracy. Photograph: N. Castañeda.
Finally, the cores made by experts are related to the best quality homogeneous blanks in recrystallized flint, which are also reconfigured for maximum exploitation.

Considering these results, blade production and apprenticeship were possible and compatible, in Casa Montero flint mine, due to the implementation of a strategy of raw material selection and management, that can be qualified as extraordinary because of its complexity and because is the first time that it has been explained in these terms in a Neolithic flint mine. This strategy consists of three main points (Figure 7(i)). First, the selection of discarded nodules, both the heterogeneous and extremely small ones; second, the recycling of opaline waste from blade production; and third, the reconfiguration of cores that were productive and still preserve high-quality flint. The first two principles contribute to prevent the competition with blade production over raw material and to reduce the cost of errors. Nevertheless, the last one would be linked with motivation (Castañeda, 2018, p. 725; Grimm, 2000, p. 64; Lave & Wenger, 1991, p. 101ff; Stout, 2002, p. 694), since products made with good quality flint could be useful, which would allow apprentices to get engaged with their learning.

According to learning in context theory, apprenticeship takes place whenever it is useful for the whole group, beyond the transmission of knowledge itself (Barkai & Gopher, 2013, p. 129; Lave & Wenger, 1991, p. 110ff). The objects made by an apprentice cannot only stay at a level of pedagogical practice; rather they must be able to be used. The final use of an object works as a reward and an acknowledgment for the apprentices and reinforces their motivation for further learning and the improvement in their final goal of becoming full members of the group. This would be a benefit that would allow social reproduction.

Therefore, the youngest members of the community would progressively be introduced into this complex technical system, participating in different peripheral tasks and phases of the complete production process, from extraction to the recycling and management of waste. Mining offered them discarded raw materials, social experiences, and knowledge; blade production would give them large amounts of waste, technical experience, and skill; while the participation of new generations would provide the community with a workforce and would allow social reproduction (Figure 7(2)).
5 Discussion

Neolithic flint mines are such special places that often have been lithic production centers. As a result, they habitually contain abundant knapping waste. These remains constitute an important source of information, not only of the main goal of the lithic production and the selection of preferred varieties of raw material but also about the skills of the knappers.

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**Figure 7:** (1) Knapping learning raw material selection sources from blade production waste and (2) relationship between mining, knapping, and learning.
Although younger individuals from a Neolithic community would have been exposed to a phase of impregnation (e.g. Bamforth & Finlay, 2008; Nishiaki, 2013, p. 179), in which they have subconsciously learned through observation how the adult members of their group made and use different tools, they may not have experienced the initial phases of working with flint. Additionally, in the places of the final use of lithic tools, there is usually no storage of silica rocks available to practice knapping, as knapping learning is an activity that needs a great amount of raw material.

Mines, quarries, and outcrops are the unique places where we can apprehend the part of the lithic techniques related to extraction, selection, and initial management of raw material, that usually we cannot find in other domestic and productive contexts (Castañeda, 2018, pp. 720–721). Knapping learning must include the know-how of all the aspects of the chaîne opératoire: from the obtaining and selection of the appropriate nodules (Barkai & Gopher, 2013, p. 130; Stout, 2002, p. 696) to the management of the residues that are generated during knapping, recycling, reuse, or reconfiguration (Barkai & Gopher, 2013, p. 130).

Therefore, the sources of lithic supply, with raw material abundance (for example Audouze & Cattin, 2011; Milne, 2012, p. 119) and where the first phases of extraction and selection were carried out, would be the ideal places to acquire the knowledge of the complete work process and to practice knapping.

In addition, these places included social experiences important for young and children as moving to a different place (Milne, 2012, pp. 120, 138–140) and the better perception of the territory that they frequent. Where collective work was carried out, the apprenticeship of an individual also included meeting members of other groups and cooperating with them.

Consequently, the value of mines for technical and social learning was so important in Prehistoric societies that be present and participate in mining activities could be understood as part of a rite of passage for the youngest members in their process of becoming full members of their communities (Castañeda, 2018, p. 728).

Novice knappers were present at Casa Montero flint mine and they practiced blade reduction (Castañeda, 2018). Early Neolithic evidence from the Interior of the Iberian Peninsula point out a scarce population with a high dispersion of small and mobile groups of low life expectancy (Díaz-Del-Río & Consuegra, 2011, p. 228). Given this demographic framework, the transmission of knowledge to the next generation would be of critical importance to assure the continuity of the survival and way of life of a group. Learning how to knap would be a transcendental task, as so was extraction and production in a mine or quarry (Castañeda, 2018, p. 716).

For that reason, miners and knappers at Casa Montero designed a complex organization strategy to make compatible the needs of lithic production and knapping learning. The way in which blade production and apprenticeship sequences relate to each other at Casa Montero depends, at least, on two factors: the characteristics of the raw material and learning in a community of practice.

In addition, apprenticeship must be considered as an operative sequence in itself, with its distinctive tasks, its specific phases, its own residues, its own execution times and, as it has been previously described, its appropriate places.

6 Conclusion

Research on the lithic assemblage from Casa Montero has provided a unique and complete view of a complex technical system that was put into practice in the early formation of Neolithic societies of the interior of the Iberian Peninsula. Within a framework of a low dense population of high mobility groups, the flint mine was a center of production and for knowledge transmission, favored by social aggregation, that assured the reproduction of this new and fragile social system.

Taking into account that knapping learning evidence has been identified at the mine (Castañeda, 2018), this apprenticeship, itself, must be considered as an operative sequence, in which different phases in the acquisition of knowledge produce their own remains can be distinguished.
The technical system performed at the mine was a sort of network in which learning interrelate with other operative sequences. This paper has evaluated the interaction between the sequences of apprenticeship and blade production that were simultaneously carried out at the same place, using the same lithic resources.

The analysis has determined that its coexistence was possible due to the existence of a strategy that solved the two main problems of learning: the restrictions of raw material and the necessity of motivation. In the first case, the use of discarded material from blade production as a raw material source for learning prevented the competition of both sequences over flint. In the case of the second problem, the inclusion of younger individuals in production tasks as they learned together with their progressive access to higher quality flint allowed for a better apprenticeship and their inclusion as complete members of the group.

In a technological framework in which the operative sequence of blades takes place in different specialized locations all over a determined territory, the knowledge linked to them is also fragmented in the space. An individual who had never visited the mine could ignore how to make a sickle, which use could only be learned by observation and participation in the harvest. Casa Montero, like a blade production center, concentrates almost the totality of the know-how of blade operative sequence but its use. As a result, this place would have an important role as a disseminator of the technical knowledge regarding flint in all the community. All knappers must have participated in Casa Montero activities to learn all about flint extraction, blade production, waste recycling, and probably sickle repairing.

Far from the evolution of human cognition that focuses the research on Pleistocene contexts, investigating Holocene assemblages allows us to go further in the apprenticeship phenomenon around which human groups developed strategies ad hoc for the generational transmission of technological knowledge. Knappable rock mines, together with quarries and outcrops, can be favorable places for the identification of evidence regarding knapping apprenticeship (Audouze & Cattin, 2011), which on many occasions is only mentioned or assumed but is not explicitly studied.

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**Data availability statement:** The datasets generated and analyzed during the current study are available in the Casa Montero Spatial Data Infrastructure, http://www.casamontero.org/wui/inicio/introduccion.html and the UAM repository, https://repositorio.uam.es/handle/10486/661865
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