**Supporting Online Material**

**Minds on Fire: Cognitive and Archaeological Aspects of Hunter-Gatherer Firemaking**

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**Section 1: Summaries of the cognitive frameworks used in this study**

**SOM Table 1** Seven grades of causal cognition and associated orders of ToM (adapted from Lombard & Gärdenfors 2021; Lombard & Högberg 2021).

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| **Grade of causal cognition & order of ToM** | **Definition** |
| 1. Individual causal cognition:  Zero-order ToM | This most basic type of causal understanding involves a direct connection between a motor action that an individual exerts and the resulting effect. Both the cause and the effect are immediately perceived, with the result that the individual experiences their own difference-making agency. It does not involve strong cognitive or socio-cultural mechanisms and can be learned through ordinary instrumental conditioning without any social transmission. |
| 2. Cued dyadic-causal cognition: First-order ToM | This type of information processing involves at least two individuals taking turns in performing a similar action. They can understand that the action of someone else causes an effect *via* an inferred mapping onto their own actions, because it gives the same result. Such understanding allows one individual to understand the difference-making agency of another and that by copying/imitating the actions of another, they may achieve similar effects. |
| 3. Conspecific theory of mind: Second- to third-order ToM | Humans today have a highly developed ToM. We observe and think about our actions (self-awareness or autocuing) by imagining ourselves, our actions, and their consequences in the past as well as in future. Through various processes of social learning, we also infer the state of mind of other humans. ToM includes representing the attention, intentions, desires and beliefs of other individuals. |
| 4. Detached  dyadic-causal cognition: Increase in ToM a matter of degree rather than kind | This type of thinking allows us to perceive someone else’s or something’s presence detached through time and/or space. For example, it enables us to understand that the tracks of a person or animal meant that they were at a certain place sometime in the past. Such thinking depends on the capacity to entertain two mental representations at the same time, i.e., the current perceptual state of seeing a trace/object together with the imagination of who/what caused it. |
| 5. Non-conspecific theory of mind: Increase in ToM a matter of degree | This type of causal reasoning allows for the dyadic-causal understanding of the actions and intentions of species other than our own, even though their motor actions and cognitive processes are different from ours. In terms of human evolution, it denotes the hominin ability to understand aspects of non-human animal mentality. |
| 6. Inanimate causal  cognition: Third- to fourth-order ToM | This type of causal cognition allows for the attribution of causal roles to inanimate objects. Unlike the previous types of causal cognition, there is no animate agent that performs an action. Instead, causation is seen as force transmission or an extension of agency. We thus see a further extension of the hidden variables involved in the causal reasoning, from the ToM components that function as causal forces in other humans, to those in non-human animals, and now to more abstract forces exerted by inanimate entities. |
| 7. Causal network  cognition: Higher-order ToM | This type of cognition involves the understanding of how domain-specific causal node sets connect or link to interdomain causal networks. The most advanced form of causal network thinking is hypothetical reasoning that allows speculative thinking about how the world works, either physically or socially. It allows for mapping between the physical and cultural domains so that we are able to integrate aspects of all the previous grades of causal understanding – mapping them onto each other into never-ending patterns of recursion and complexity – including higher order ToM. Causal network thinking allows for the division of conceptual structures and their subsequent rearrangement into new contexts, so that novel structures can be conceptualised in their place. |

**SOM Table 2** Six levels of intentional teaching following Gärdenfors and Högberg (2017, 2021).

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| **Level of teaching** | **Definition** |
| 1. Intentional evaluative feedback | Here, teachers intervene with the behaviour of learners with the intention that they exhibit correct behaviour. Learners need not employ any form of ToM, but only react to the signals of their teachers. The only communication that is required for this form of teaching is evaluative expressions, say a grunt or a protesting sound. |
| 2. Drawing attention | The intention of teachers is that learners’ direct attention to something relevant in a learning situation. This is typically done by declarative pointing that involves directing the attention of learners towards a focal object. Hence, teachers need to understand what learners know and do not know, and interact with their learners with the purpose to change this. |
| 3. Demonstrating | When demonstrating, teachers show learners how to perform a task or solve a problem. The intention of teachers is that their learners exhibit the right actions in the correct sequences. It builds on ToM capabilities. In this case, the demonstration itself is what is communicated, but it is often combined with drawing attention. |
| 4. Communicating abstract concepts | The intention of teachers is that learners perceive particular patterns pertaining to an object or an action. The prevailing way to teach concepts in modern societies is to use words that represent concepts, but other sounds or iconic gestures together with pointing or some other technique for drawing the attention to what characterizes the category are also commonly used. It is important to note that this form of communication is detached, meaning that it can refer to entities not present in the immediate environment. It is a form of teaching that relies on well-developed ToM, as it presumes that learners understand that their teachers are intentionally using gestures or sounds as communicative signs, representing something not necessarily present or tangible in the teaching situation. |
| 5. Explaining relationships between  abstract concepts | Teaching by explaining relationships between abstract concepts involves detached communication and causality. Here, the intention of teachers is to explain so that their learners understand the causal relationship between two or more abstracted concepts. This form of teaching relies on an advanced capacity for ToM. |
| 6. Narrating | In its simplest form, teaching by narrating can be explained as a sequence of expressions describing causal relations. However, most uses of narrations are for gossip or entertainment and they are not directly cases of intentional teaching. Nevertheless, narratives often involve a moral that can be interpreted as a pedagogical intention of the narration. Thus, the listeners will indirectly learn from what is presented in the narration and gain experience in the imagination through the feelings or actions of other persons or performers in the story told. |

**SOM Table 3** Advantages of prospective cognition and rehearsal. Modified after Bulley et al. (2020).

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| **Advantage** | **Definition** |
| 1. Affective forecasting and goals | The ability to evaluate alternative future scenarios and actions in terms of an anticipation of how we would ‘feel’ if they happen. Goals are desired possible future states that imply an emotional assessment of potential scenarios, serving as motivators. Once emotions (personal objectives) have been forecasted, they can direct cognitive and behavioural resources and/or responses towards or away from possible future scenarios. |
| 2. Preparation for risk and threat | The ability to anticipate future emotions, and to organise our thoughts and behaviours accordingly. It facilitates flexible and advanced preparation for future risks and dangers – real or imagined. In addition to extending our ability to prepare through time, it is the flexibility of imagining different scenarios and their outcomes that makes human risk management and defence responses so powerful. |
| 3. Flexible decision-making | The ability to fine-tune behaviours to optimise outcomes based on imagining the future. Buffering against the need for immediate gratification in favour of reaching a long-term goal, is often seen as a powerful human cognitive capacity, but, in nature and in human cultural systems there are many circumstances where it may be smarter to take an immediate smaller reward. Flexible decision-making provides us with the ability to assess when to pursue immediate gain and when to work towards longer-term goals. |
| 4. Deliberate rehearsal | Producing and/or using most technologies requires skill development. Rehearsal is the way to achieve expertise. It requires thinking about one’s future self as mutable. Once an ‘upgraded’ future self can be envisioned, humans become motivated to take action towards its realisation. |

**Section 2: Ethno-historical firemaking report**

Below we cite from Lorna Marshall’s (1976) *The !Kung of Nyae Nyae* that represents one of the most complete ethno-historical accounts of southern African hunter-gatherer fire use and firemaking. Apart from touching on some of the aspects in our text, she also describes the socio-spatial context of fires, ritual firemaking and use, and provides us with ta !Kung tale of how fire was given to humankind. Her observations were made during expeditions the Marshall family made into the northern Kalahari Desert along the Namibian border with Botswana between 1955 and 1961.

Page 69: Veld fires are a common sight. Bushmen set fires to attract game. After a fire has passed, the grasses put forth green shoots and the game come to graze. The fires run raging before the winds till the winds shift and blow them back on themselves. We have seen around us as many as eight fires at a time.

Page 79-86: The !Kung have no permanent dwellings. Although a !Kung band, moving from one place to another to gather food and obtain water, returns season after season and year after year to the same waterholes and to the same areas in which their plant foods grow, the people do not reoccupy old camp sites – not, at least, until the time and the winds have torn apart the abandoned shelters and blown away or covered up the piles of ashes from the old fires. The !Kung may settle near an old camp site, but they will make a new encampment, one that has never existed before. In that vast land there is plenty of ground for new camp sites. The !Kung do not want to kindle a new fire exactly where old fires have been. New fire is associated with fresh hope, fresh chance for good fortune. To build new fires on old sites might nullify the fresh chance and invite misfortune.

The!Kung usually settle at some distance – half a mile or so – from their waterhole. This is discreet: lions, leopards, and hyenas share waterholes with the Bushmen, and the Bushmen think it wise to let the predators have the waterholes to themselves at night.

A place is selected that is relatively free from thorny bush and high grass. Soft, sandy ground is preferred; ideally there will be a tree or two for shade and bushes on which people may hang their belonging. When the site is selected the men put down their carrying-sticks and the bundles hung on them. From the pouches of their cloaks the women unload the ostrich-eggshell water containers and their belongings. The band is settled.

After the bundles have been put down, the next act is to make fire. The process of making fire requires two fire sticks, called male and female, and a bunch of woolly grass for tinder. (//Galli grass or /gam grass is used.) The male stick, held vertically, is twirled rapidly in a small notch in the female stick, which is placed horizontally on the ground, till the fine wood dust produced by the twirling is ignited by friction. The smouldering wood dust is quickly tipped into the bunch of grass, which is picked up and gently blown on till the grass bursts into flame. The grass is then placed on the ground. Small twigs ready at hand are placed on the grass for kindling, and as soon as they are ignited pieces of wood are added.

The male stick is usually made of a hard wood, the female stick of a soft wood. *Catophractes alexandri* is often used for the male stick and *Grewia retinervis* for the female stick. Robert Story [1958] says of the *Grewia*: “The dry stems of this plant nearly always contain the tunnelings of grubs, and the tunnelings are packed with excreta in the form of a brown pith-like substance which forms a useful tinder. The Bushmen split the stems down the centre, make a slight depression in the flat surface and use this as socket for the fire-drill.” Another wood we observed used was baobab wood – for both sticks.

The male stick of one set I have is 28 inches long and just over ¼ inch in diameter. The female stick is 19 inches long, ¾ inch in diameter. A notch is cut 1½ inches from the one end of the female stick. The male stick must fit into the notch exactly.

When preparing to make fire, a man places the grass tinder on the ground and lays a knife on it. The end of the female stick which has the notch is placed on the knife blade at a right angle. A digging stick is laid across the fire stick near the other end and the man holds it down firmly with his foot. This keeps the female stick steady. The male stick is held upright, its end placed in the notch. The man twirls the stick between his hands with rapid motions of about an inch back and forth. He works his hands from the top of the stick to the bottom, strongly pressing the stick downward into the notch as he rotates it. He then slides his hands to the top of the stick without twirling or pressing so that his hands do not become so heated from friction, and repeats the twirling. The speed with which the man slides his hands up and starts twirling again is a crucial factor in success.

Frequently two men make fire together. As one pair of hands reaches the bottom of the stick, the second pair is ready at the top to keep the twirling continuous. The shortest time of twirling I observed was twenty-five seconds with two men working. They made their downward twirl five times. The longest time, with one man twirling, was sixty-five seconds. The process looks deceptively easy when an adroit man is twirling. The men differ in ability. /Qui was so lacking in adroitness that he said he had given up trying to make fire and had thrown away his sticks. I understood his frustration. I did not once succeed in making a spark though I tried earnestly several times.

Making fire is the work of men. Men carry their fire sticks with then constantly in their quivers with their arrows. We were told that there was no law of avoidance that forbade a woman from using fir sticks if she needed to make a family fire or cooking fire, presumably in emergency. However we never saw a woman using fire sticks. The women had no occasion to do so. They were never away from their men except during the days when they are on routine gathering trips. Ritual fire is another matter. Fire is deeply associated with !Kung ritual. Ritual fires must be freshly made by a man with fire sticks, not with brands from family fires. Women would have nothing to do with the making of ritual fire, and they must not go near the fire while the rituals are being conducted.

The making of a new fire in a new encampment has the aura of ritual, but the new fire is not strictly a ritual fire. Making the new fire is the responsibility of the oldest man in the band if he is still able to use his fire sticks; he may be helped by a younger man. When ritual fires are made after a death or severe misfortune or for changing bad luck to good in hunting, they must be made by an old man and they must be made with fire sticks. When we were observing and filming Band 1 settling in a new encampment, they took care that the old man made the fire with fire sticks in the traditional manner, but on other occasions the first fire was lit with matches, which were a gift from us. This was characteristic of the !Kung, who are flexible in most matters, even spiritual matters, though by no means in all.

While the old man makes fire, others go about picking up dry wood to lay on the new fire, and when it is burning well each family takes a brand from it to start his family fire, beside which the family will live. The original fire started by the old man is not regarded as a ritualistic, perpetual fire. If it is in a place convenient for the old man, he may settle by it and keep it going; otherwise he takes a brand, makes another fire for himself, and the first fire is allowed to burn itself out. Rarely is it necessary to make fire with the fire sticks a second time as long as the people remain in the encampment. They bank their fires with ashes during the day and usually find glowing coals on which to build the evening fires. If someone’s fire does go out, he asks a neighbour for coals to start a new fire; almost always someone will have coals. There are no restrictions on women making new fires with old coals. Anyone may do so, man, woman, or child.

[…]

The clearest visible indication of a family’s location is the fire. One can see who lives at each. Always, summer and winter, every nuclear family has its fire, which is kept burning all night. The fire is the nuclear family’s home, its gathering place, its rightful place to be. In a way, a fire is more of an unchanging home than is the house on a plot of ground, from which a family might depart. A fire-home is always where the family is. The family hangs its possessions in the bushes near the fire, sits around the fire, cooks at it, sleeps at it. At night, the light of all the family fires in the encampment forms the protecting wall that encloses the people, holding out the prowling beasts and the darkness. An old man once said to us, “Fire, water, and food hold our lives. We have been so created. Without fire we would have no light, no warmth; food could not be cooked. Even an old person can live by his fire. Someone will give him food and water, and he can be warm.”

Fortunately for the !Kung they live in a country that produces plenty of wood. Each family provides its own firewood. Both men and women gather it: they pick up dry logs as they return from hunting or gathering trips, or they may go out from the encampment in the late afternoon to look for large branches and for dead trees, which the women can push over or the men chop down. They do not chop the logs or branches into sticks. For the fires that they keep burning all night they place the whole log flat out on the ground – perhaps three at a time – with their ends together, so spaced and tended that they produce a steady small fire with flames a foot or so in height. People push the logs in as they turn down; they awaken at night, from time to time, to do so. They like to draw near to a fire without being scorched or getting too much smoke in their eyes, so they keep the blaze small. Every day, to keep the space around the fire neat and pleasant for sitting or sleeping, the women clear away some of the ashes, scraping them up with their fire-paddles into a tortoise shell or an old scrap of leather, and deposit them in a pile at some distance from their dwelling place. The fires are customarily banked with ashes during the day, and the coals are fanned up only when they are wanted for cooking. The desert sun gives enough warmth on the clear dry winter days to make them comfortable unless a fierce south wind is blowing. If a family is away for more than a day, or if its fire goes out for some other reason, someone will give coals or brands to start the fire again. Or a man will twirl new fire with his fire sticks.

[…]

Within the encampment, the families demarcate themselves consistently. The fires of the nuclear families that compose an extended family are always near each other, not scattered about among other families in the encampment. Adult dependents have their own fires near the families with whom they live. Visitors have their own fires near the families they are visiting. In other ways the settlement pattern is variable. The encampment can take almost any shape – roughly circular, oddly angular, or serpentine (but I never saw one look much like a square). Fires are not placed in a fixed pattern with reference to the father of an extended family, nor with reference to the points of the compass or to anything I know of except nearness together. A nearby bush to hang things on, a bit of shade, a relatively smooth and thorn-free spot on the ground determine the particular choice of place.

I have been referring to the settlement in terms of family fires rather than shelters because the fires are constant – the shelters are whims. The women may or may not build shelters (tshisi) for their families. […]

Page 88-91: The shelters are literally shelters – not dwellings. A family crowds into one during a downpour; it sits in the bit of shade it provides in hot weather. People may keep their belongings in them, but they live very little inside them. A few sleep in their shelters, but for the most part life takes place outside the shelters, beside the fires. The fire is the home.

Other fires also appear in the !Kung encampment. Many are extra cooking-fires. Although there is a tendency (not a strictly observed custom) for the mother or father to cook in the late afternoon or early evening whatever food is available for the family, anybody (children included) may cook at any time. Especially when the hunters have been successful and the meat of a large animal has been distributed, people can be seen cooking little snacks all day long. For the most part they cook meat, nuts, and roots in the hot coals and ashes of their family fires, covering the food until it is cooked and then scraping it out with their fire-paddles and whacking off the ashes. They also have a few pots (Ovambo pottery or European iron pots acquired in trade with the Bantu) in which they boil meat or mangetti nuts or tsi. If the day is hot, they set these pots on little special fires away from the place where they habitually sit. Regularly the heads of the large game animals are cooked during the day in pits, piled over with hot coals, ashes, and earth.

As with the cooking-fires, there are more sleeping-fires in a !Kung encampment than there are families. Boys and girls, beginning at about the age of eight or nine, sleep at fires apart from their parents' fires. Several boys sleep together at a boys' fire; the girls either sleep with a widowed grandmother or some other widow, or have little fires of their own, not far from their parents’. In a large encampment there might be four or five such extra sleeping-fires.

Finally, to complete this catalogue of the fires that appear in a !Kung encampment, there are the fires that are built for the ritual curing dance and for the performance of other rites. The dance takes place around a fire built in the center of the dance circle. In addition, people who are resting, or are for some other reason not dancing, sit at fires near the dance circle. The rites that require special fires include the Menarcheal Rite, the Rite of the First Kill (performed when a boy kills his first large game animal), another hunting rite, a rite for a novice medicine man, n/um k"xau ("owner of medicine"], and the rite for a child's first haircut.

An archaeologist of the future, examining a !Kung site, would be hard put to estimate how many families inhabited it, with such a variable number of piles of ash from fires that had such a variety of purposes.

Page 348-349: Long, long ago there was a man named /Ka /Kani. This man had fire, and the name of the fire was doro. With his fire /Ka /Kani cooked food for himself and his children. All other people ate raw food. /Ka /Kani had a food called //ham, a white root dug from the earth. There was a man named Huwe. One day Huwe went to visit /Ka /Kani. /Ka /Kani was not at home; only his children were there. The children were eating. Huwe asked them to give him some food. They gave him some, and when Huwe ate it, he said, "Oh, you eat nice cooked food. We eat raw food. How do you cook your food?" The children answered, "Our father has a nice thing and he always gives us cooked food. We do not eat uncooked food. He does all good things for us." Huwe said, "I shall come back tomorrow and eat this kind of food again."

The next day, Huwe came back. Before he reached their dwelling place he saw / Ka /Kani and his children digging for roots in the ground. Huwe hid himself behind a tree and watched. When /Ka /Kani and his children had dug enough roots, they returned to their dwelling place. /Ka /Kani went to the place where he hid his fire sticks. He took them and started to make a fire. He twirled and twirled the upper fire stick, and as he twirled he said, "Fire will come, fire will come." Fire did come, and /Ka /Kani built up the fire and started to cook the roots that he and his children had dug. He then hid his fire sticks again.

All the time Huwe was watching. He watched very carefully when /Ka /Kani hid the fire sticks. When the roots were cooked and /Ka /Kani and the children were preparing to eat them, Huwe came out from his hiding place and went to them as a visitor, and they all ate together.

Huwe then said, "Now we must play." /Ka /Kani asked what game they must play. Huwe made two djani that had guinea fowl feathers, and he and /Ka /Kani began to play. But the djani did not fly well, and Huwe could not get /Ka / Kani away from his dwelling place. So he said, "The guinea fowl feathers are no good. We must get paouw feathers." When they put the paouw feathers on, the two djani flew high. /Ka /Kani tossed his djani to the eastern side. Huwe tossed his to the western side. And then Huwe opened the wind, and the wind came from the eastern side and blew /Ka /Kani's djani over to the western side. /Ka /Kani followed it and passed Huwe and went farther. Huwe followed. When /Ka /Kani was far away, Huwe ran back to the place where the fire sticks were hidden. He seized the sticks, broke them into little pieces, and threw them over the whole world crying, "All the world is going to get fire now! Fire! Fire! Through the whole world!" /Ka /Kani stopped his play and came and looked at Huwe. Huwe told him, "It is not right that you alone should have fire. From now on you will not be a person. You will be a little bird." And /Ka /Kani was changed into a bird called ≠ore.

Since then there has been fire in every piece of wood, and all men can get it out and cook their food. These events were told by the old old people. They happened long ago.

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