

Review

Natural pedagogy as evolutionary adaptation

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We propose that the cognitive mechanisms that enable the transmission of cultural knowledge *by communication* between individuals constitute a system of ‘natural pedagogy’ in humans, and represent an evolutionary adaptation along the hominin lineage. We discuss three kinds of arguments that support this hypothesis. First, natural pedagogy is likely to be human-specific: while social learning and communication are both widespread in non-human animals, we know of no example of social learning *by communication* in any other species apart from humans. Second, natural pedagogy is universal: despite the huge variability in child-rearing practices, all human cultures rely on communication to transmit to novices a variety of different types of cultural knowledge, including information about artefact kinds, conventional behaviours, arbitrary referential symbols, cognitively opaque skills and know-how embedded in means-end actions. Third, the data available on early hominin technological culture are more compatible with the assumption that natural pedagogy was an independently selected adaptive cognitive system than considering it as a by-product of some other human-specific adaptation, such as language. By providing a qualitatively new type of social learning mechanism, natural pedagogy is not only the product but also one of the sources of the rich cultural heritage of our species.

Keywords: social learning; communication; evolution; cultural transmission; natural pedagogy

1. INTRODUCTION

Imagine that you are in a foreign country and observe a man as he turns a bottle upside down, twists its cap three times to the left and then another time to the right, turns it upside again, then opens it and drinks its content. What should you learn from this observation? The action sequence does not make much sense as it is not clear why he has performed it. Part of your problem is that the action sequence appears *teleologically opaque* to you. You may attempt to resolve this by assuming that the (familiar) outcome (i.e. drinking the bottle’s content) is the agent’s goal that explains his behaviour as a means action. You would still be puzzled, however, about what part of the behaviour was necessary to achieve this end result as the action sequence would remain *causally opaque* to you. Was turning the bottle upside down causally relevant for its opening or just the twisting? You may try to rely on your background knowledge about bottles to answer this question. At this point, you would still not know whether it is worth memorizing this action sequence or not. It may be useful to do so, but only if this manner of manipulation should be applied not just to this particular bottle, which you may never encounter again, but to all bottles of this kind. In other words, you need to infer whether it is reasonable for you to *generalize* your observation

outside the episodic bounds of the particular situation. In this regard, it would also help to know whether what you observed was just an idiosyncratic fact about that particular individual, or that the way the action was performed is common practice among other members of the cultural community as well. Is it *shared knowledge* in this culture that this kind of bottle is to be opened this way (whether because of its construction or because this is a convention)?

Teleological and causal opacity, and the uncertainty about genericity and sharedness of knowledge are common problems, with which any observational learner is confronted. These problems are not entirely insurmountable. For example, trial-and-error learning can help to clarify the causally relevant aspects of the action and its generalizability to other bottles, and statistical observational learning may help to figure out the extent of the genericity and the shared nature of the acquired knowledge. These learning processes take time and require significant cognitive resources.

There is, however, a special type of social learning that allows for the acquisition of reliable (shared and generalizable) cultural knowledge without the extended acquisition process that trial-and-error learning and statistical observational learning necessitate. If the man with the bottle does not merely perform his peculiar action sequence, but performs it manifestly *for you* by clearly indicating that this is a demonstration presented to you as its addressee, you will learn significantly more from the same action than you would from simply observing it performed. The demonstration can highlight the important action elements and direct

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One contribution of 26 to a Discussion Meeting Issue ‘Culture evolves’.

your attention to them as causally relevant, and can also mark the desired outcome as the goal of the action presented. In addition, the explicitly communicative nature of the demonstration can license the conclusion that the knowledge gained from it is likely to be generic to the object kind (i.e. the type of bottle) involved in the action and that this knowledge is shared by the cultural community. As a result, you would most probably conclude that the person is not just opening a bottle, but he demonstrates to you how to open that *kind* of bottle and that this is common practice and shared knowledge among locals.

The theory of natural pedagogy [1] states that the latter scenario illustrates a fundamentally new type of social learning system in humans. Human communication makes it possible to efficiently convey knowledge with opaque content to others in a single act of demonstration not only because the recipient is prepared to recognize such actions as communicative demonstrations, but also because the addressee has the default expectation that the content of the demonstration represents shared cultural knowledge and is generalizable along some relevant dimension to other objects, other occasions or other individuals. The most obvious beneficiaries of such a cultural transmission system are children, who have to acquire the technological, social, conventional and institutional knowledge and skills that are necessary for survival in their culture.

During recent years, we have documented that human infants and children possess specialized cognitive mechanisms that allow them to be at the receptive side of such cultural transmission. By being sensitive to *ostensive signals* (such as direct eye contact, infant-directed speech or contingent reactivity), infants are prepared to identify and interpret others' actions as communicative acts that are specifically addressed to them [2,3]. They also display interpretive biases that suggest that they expect to learn generic and shared knowledge from such communicative acts. For example, infants expect that ostensive signals will be followed by referential signals [4], pay preferential attention to generalizable kind-relevant features of objects that are referentially identified by demonstrative communicative acts addressed to them [5,6], learn causally opaque means actions from communicative demonstrations [7] and assume that communicated valence information about objects (i.e. whether they are evaluated positively or negatively) is shared by others [8]. These and other findings suggest that pre-verbal human infants are prepared to receive culturally relevant knowledge from benevolent adults who are, in turn, spontaneously inclined to provide it.

This paper advances the hypothesis that the cognitive systems that make natural pedagogy possible reflect an evolutionary adaptation in the hominin lineage. This account can be contrasted with other explanations, according to which this type of social learning is not human-specific, or is the result of cultural rather than cognitive (hence biological) evolution and therefore not universal across human cultures, or is a by-product of some other basic adaptation. We think that empirical and theoretical arguments can be advanced against these proposals.

2. IS NATURAL PEDAGOGY HUMAN-SPECIFIC?

One way to characterize natural pedagogy is that it is a particular kind of social learning in which knowledge or skill transfer between individuals is accomplished by communication. Both social learning and communication are widespread in non-human animals. It is thus a plausible assumption that these two phenomena will overlap in some species, producing instances of communication that transfers knowledge from one party to another. However, so far we have not been able to find convincing examples for this kind of communication in non-human species.

To convey generalizable knowledge, communication must be 'referential' in order to anchor the manifested content to the kind of referents to which it can be generalized beyond the 'here and now'. Whether animal communication can be referential in the same way as human language is a matter of debate [9]. Nevertheless, there are several examples of animal signals that are functionally referential: their 'meaning' is restricted to a specific stimulus class in the environment, and they are interpreted appropriately by receivers even when the corresponding stimulus is not present [10]. Well-known examples of these signals are alarm calls that functionally refer to predator classes [11], food calls [12] or recruitment signals [13], and even the bee dance that refers to specific locations of food sources and quantities of food retrievable from those locations. Note, however, that, unlike referential noun phrases of human languages, these signals cannot identify just a specific stimulus class (like 'aerial predator') as their referent: they can make reference only to an inseparable configuration of a referent with a fixed predicate content (such as 'aerial predator approach'). In addition, their referential scope is also severely restricted to episodic facts in the 'here and now' and cannot express content that is generalizable to other situations, other locations or other individuals. (Monkey alarm calls cannot communicate that 'aerial predators usually come during daytime'.) In this sense, referential communication in non-human animals tends to be inherently *episodic* in nature, transferring only pre-specified types of information about particulars, but not generalizable knowledge.

By emphasizing the episodic nature of animal communication, we do not mean to imply that such communication cannot be involved in learning. A pied babbler that gets fledglings' attention to a food source by purr calls communicates an episodic fact, but the resulting behaviour of the youngsters (approaching the indicated location) provides them with an opportunity to learn about properties of likely food sources [14,15]. One can even assume that one of the functions of emitting the call is to facilitate such learning by luring the targeted youngsters to the food source (although local benefits, such as allowing fledglings to find food, could also explain such a behaviour). Note, however, that the generalizable knowledge gained in this situation does not come from the content of the communication, but is produced by individual learning, which is, in turn, triggered by the responses to the food call. If one accepts that such communicative behaviours serve

the purpose of training of youngsters, these would also be qualified as acts of teaching. However, they are not examples of natural pedagogy in the specific sense we propose for this term.

A similar argument can be made about other examples of animal teaching as well. The most studied kind of teaching in non-human animals is ‘opportunity teaching’ in meerkats and other carnivores [16–18]. Adult meerkats supply the pups with intact, disabled or dead scorpions according to the perceived age and skills of the young, which provides them with optimal conditions for learning prey handling. These behaviours do not just satisfy generally accepted criteria for teaching [19], but also demonstrate the teachers’ behavioural adjustment of the curriculum to the pupils’ knowledge, which strongly suggests a pedagogical function. However, no communication is involved in this kind of teaching, which resembles more the type of environmentally supported learning called ‘scaffolding’ in developmental psychology [20]. A further significant difference between natural pedagogy and the type of animal teaching through coordinated scaffolding is that the latter is restricted to facilitate learning about a fixed, domain-specific content.

Another recent finding reported teaching by communication in tandem-running ants [21]. In this species, knowledgeable individuals (leaders) guide naive ants (followers), by running in tandem, towards a food source. In fact, the leader in the tandem not only directs the follower to a location but also adjusts its behaviour to its pupil: it slows down or stops to allow the follower to ‘memorize’ the route, and if the teaching is interrupted, it waits for the pupil to return [22]. Thus, this behaviour is based on bidirectional signals, and transfers valuable information to the pupil, who will find the food faster with guidance than without it. However, whether or not this behaviour is qualified as teaching [23], it is clear that it transfers episodic information about temporary food sources that are not generalizable. The sophisticated bidirectional communication that allows such information to be passed on from the leader ant to the follower ant serves the coordination problem of getting from location A to location B together rather than transferring knowledge between individuals. And again, the type of information acquisition that this teaching system is designed to facilitate seems highly domain-specific: there is no evidence that the bidirectional communicative signals could be recruited in the service of transferring any other kind of functional information (even if it is only episodic: say, leaders directing followers away from danger).

We suggest, therefore, that at present none of the documented cases of animal teaching [24] seem to qualify as communicating generalizable knowledge, i.e. as an example of natural pedagogy. This does not necessarily mean that it would be impossible to find such an adaptation in non-human animals. Some types of behaviour come very close to actions that would be classified as demonstrations for novices. For example, mother hens seem to attract chicks to palatable food by increased pecking, especially when they perceive that the chicks are feeding on unpalatable food [25]. If it could be shown that the hen’s

behaviour is directed to demonstrating that a particular *type* of food is palatable rather than to directing the chicks to the location of a particular supply of palatable food, and that the chicks learn from these demonstrations better than they do from pure observation of the hen, this would be an example of natural pedagogy. Another, more recent, study found that mother dolphins slow down and modify their hunting behaviour when their infant observes them from a close distance [26]. If this effect is not produced by the divided attention demanded from the mother by the situation, and the mother dolphin’s behaviour modification is prey-specific and does facilitate the calf’s acquisition of hunting, the modified behaviour will qualify as pedagogical communication under our account.

We do not find it inconceivable that these or other examples of animal teaching will be shown to be analogous to human natural pedagogy described in the previous section. If this is proved, it will show that natural pedagogy is not human-specific. Nevertheless, this would not disconfirm our hypothesis that the cognitive systems that enable pedagogical knowledge transmission in humans represent a hominin adaptation, because analogous adaptations can emerge independently in distinct lineages. Crucially, no convincing example of teaching has been found in non-human apes or other primates [24]. Thus, if natural pedagogy is an evolutionary adaptation, it must have emerged in the hominin lineage.

Why is it then that, despite the fact that neither social learning nor communication is human-specific, and knowledge transmission to kin seems to be adaptive [27], one cannot find good examples of overlap between these phenomena in non-human species? We suggest that at least two factors explain the lack or scarcity of pedagogical knowledge transmission in non-human animals. The first one is that it is not needed. Non-human animals’ behavioural repertoire, even when it incorporates local traditions, does not include opaque elements that characterize many human instrumental actions and social conventions. In the absence of long chains of instrumental actions involving various artefacts and/or time delay or spatial separation between interventions and effects, the adaptive nature of to-be-acquired actions is usually evident from observation of their outcomes and does not require active social guidance to be recognized. In other words, behavioural skills of non-human animal species, even when they involve population-specific cultural traditions, tend to be teleologically and causally ‘transparent’ to the observer. In contrast, the inter-generational transfer and cultural stabilization of cognitively opaque knowledge exemplified by human technological skills and cultural traditions would pose a learnability problem for the purely observational learning mechanisms of non-human species [28]. In human cultures, almost any action, even when it seems arbitrary, unnecessary, or even counter-productive, could, for some reason, be relevant and important to be learnt [7,29–31]. A benevolent teacher who highlights through selective marking and manifest foregrounding (i.e. explicitly emphasizing [32]) the relevant aspects of these actions, or the

kind-relevant properties of the objects involved, could thus not just facilitate, but in fact make such learning possible [33].

The second factor that explains the apparent uniqueness of human pedagogy is that it does not come for free. Even if a species has excellent social learning abilities and a well-developed communicative system that incorporates referential signals, it does not guarantee that the members of the species will be able to transfer generic knowledge to each other. Communicating knowledge about categories of objects, actions or situations requires either signals that refer to kinds of objects, actions and situations without fixed predicates, and/or mutual assumptions between communicators with respect to the possibility and scope of potential generalization of the information conveyed. The evolution of such specialized, hence costly, cognitive systems may not be expected in the absence of a significant body of adaptive but, from an evolutionary point of view, arbitrary knowledge that characterizes human cultures.

3. IS NATURAL PEDAGOGY UNIVERSAL?

The second implication of the hypothesis that natural pedagogy is a hominin evolutionary adaptation is that it must be universal across human cultures. The cognitive mechanisms that enable people to transmit and receive generic knowledge by communication must be present in virtually all members of the species and must be used whenever it is in the interests of the individuals of a community to preserve their cultural traditions and pass on the to-be-acquired knowledge or skills that are opaque. This prediction does not entail that pedagogy emerges in the same form or is practised in the same amount in every society. Cultural and environmental factors, for example, the extent of cognitive opacity of local traditions and artefact use, should also influence what kind of knowledge is communicated to novices and how much pedagogy is required for children to become full members of their community. Nevertheless, if there were a human culture where no generic knowledge was communicated to others in any form, it would seriously undermine the hypothesis according to which natural pedagogy is a hominin evolutionary adaptation.

It is a widespread belief among anthropologists and cultural psychologists that teaching, of which natural pedagogy is a subspecies, is not practised at all in many non-Western societies [34]. In an unpublished but frequently cited manuscript, Fiske [35] asserts, ‘children learn most of their cultures on their own initiative, without pedagogy’. This is probably correct and applies also to Western societies. Children’s learning is supported by domain-specific mechanisms in many cognitive domains [36], and social learning is also available to them in non-interactive, observational forms [37]. The question to be answered in order to evaluate the claim about universality of natural pedagogy is whether there is a society in which novices are left with these options without having opportunities to learn from experts by communication. Note that we use the terms ‘novices’ and ‘experts’ here because they describe their functional role in pedagogical

knowledge transmission. Although these roles map naturally to children and adults, respectively, adults also learn new skills from others by communication, and children may play the role of teachers of younger children, especially in traditional societies [38].

In an influential paper on ‘cultural panthropology’, Whiten *et al.* [39] argued that chimpanzee ‘cultures’ share many characteristics of human cultures—except teaching practices. This does not, however, imply a sharp difference between the species because ‘the role of teaching in the human case must also be questioned. In observational studies of everyday interactions between children and caretakers, relatively little sign of overt teaching was found, particularly in a traditional African society [40]. Anthropologists appear to have come to similar conclusions. In particular, to the extent that hunter–gatherer societies provide our best models for the kind of childhood experiences likely in the greater part of ancestral, pre-agricultural human life, a repeated message of ethnographers is that little overt teaching occurs among foraging peoples [39, pp. 96, 41, 42].

We think that the examples cited in this short section are not convincing concerning the absence of teaching in traditional societies. In their observational studies, Whiten & Milner [40] did not find any evidence of teaching of young children in rural Nigeria, but their specific definition of ‘teaching’ required that adults should help the infant by actively intervening in the execution of difficult actions. By contrast, they found clear examples of ‘demonstration’, in which the adult showed to the child how to perform certain actions, and frequent incidents of providing information about object properties specifically for the child. Both of these types of child-directed actions exemplify communication of generic knowledge and satisfy the criteria of natural pedagogy. Thus, parents of these Nigerian infants did practise natural pedagogy. Note that when Whiten applied the same coding scheme to the analysis of the parenting behaviour of a gorilla, he found no examples of teaching but also no cases of demonstration either [43].

The second work cited for showing the lack of teaching by Whiten *et al.* [39] is a description of children’s life among the !Kung [41]. !Kung adults have a *laissez faire* attitude towards children, intervening seldom in what they do. However, even in this society, adults interrupt and change children’s behaviour about 1.5 to 2 times an hour [41]. It is not clear how many of these interruptions are pedagogical in nature, but even if only a small fraction of them (e.g. a single occasion a day) allows the child to learn directly from the adult, it would expose !Kung children to more teaching than a young chimpanzee ever receives. In addition, other characteristics of the same society suggest that the concept of teaching is not alien to them. In the same volume, Blurton Jones & Konner [44] reported ‘an enlightening argument between some younger men who hunt very little and some older and more active men. The inactive young men accused the older men of having neglected to teach them hunting. The older men countered that this was something that one just did. ‘You teach yourself’—a very common phrase among the !Kung—would be applicable here’

(pp. 338–339). While this report provides evidence of the absence of teaching of hunting among the !Kung, it also demonstrates that (i) the !Kung have a concept and a word for *teaching*, and (ii) the norm that adults are expected to conform to is teaching since they had to justify why they had *not* taught a certain skill. Thus, while the !Kung illustrate how different a traditional society could be from Western cultures in terms of child-rearing practices, they hardly demonstrate the complete absence of natural pedagogy.

Whiten *et al.* [39] also cite the work by Hewlett & Cavalli-Sforza [42] among the Aka in West Africa. They found that the dominant mode of cultural transmission among the Aka is *vertical* (parent-to-child and one-to-one) as opposed to *oblique* (teacher-to-pupil and one-to-many). People reported that they had learnt most (80%) of their skills from their parents, often by teaching. This indicates that there is hardly any *institutionalized* teaching in this society. However, most skills were reported to have been acquired from the parents by *demonstration* and *instruction*, indicating pedagogical practices.

David Lancy is one of the anthropologists who argue strongly against the universality of pedagogy [45], and his monograph on the development of Kpelle children in Liberia [46] is often cited as an illustration of a society without teaching practices. Indeed, he insists that Kpelle ‘parents influence children by example and by setting limits on their behaviour, but not through direct *teaching*’ (p. 78). The evidence presented in the book, however, does not seem to support this conclusion. The section that concludes with the sentence above cites direct quotes from Lancy’s informants that seem to contradict the above conclusion. They say, for example, that ‘If I am cutting brush, I give him [his son] the machete for him to know how to cut brush. If work becomes hard, I’ll show him how to make it easier’ (p. 76). ‘Showing how to make it easier’ is a prototypical pedagogical activity of demonstrating a means action and functional artefact use. Furthermore, Lancy also cites one of his informants as explicitly saying that ‘We will teach our children our work’ (p. 76). And the book provides many more examples of pedagogical activities. To mention only a few, knowledgeable adults teach their children about medicines (p. 68) and board games (p. 116), give advice about making traps (p. 146), guide children’s hands when learning how to weave a bag (pp. 151–152) and demonstrate how to make a hammock (p. 154).

Other societies that have been suggested to us by anthropologists as examples of pedagogy-free cultures do not seem to show a complete lack of teaching either. Ultimately, whether there is such a society is an empirical question, and ongoing studies in several traditional societies will testify how much of the predictions of the theory of natural pedagogy can be confirmed outside Western cultures (see [47] and <http://www.philosophy.dept.shef.ac.uk/culture&mind/>). Nevertheless, the sharp contrast between some anthropologists’ insistence of the non-existence of teaching and the empirical data demands an explanation. We think that at least three factors contribute to this apparent contradiction. The first one is a certain type of

methodological commitment to participatory data collection, as opposed to relying on verbal interviews, for understanding how other cultures work [35]. People in many non-Western societies are reluctant or even unable to explain or justify their customs or beliefs, and do not readily give instructions to an outsider when he or she attempts to acquire their skills. Thus, an anthropologist had better try to integrate into the society he or she studies and acquire their culture by participation in its life rather than expecting the locals to enlighten them by revealing crucial information about their culture. We are not in a position to decide whether this methodological commitment represents the right way to study other cultures. But we think that it contributes to some anthropologists’ conviction that teaching is almost non-existent in certain cultures.

A related factor behind this controversy is that anthropologists may apply a different concept of pedagogy from ours. While animal behaviourists’ definition of teaching is much wider than our notion of natural pedagogy, anthropologists’ examples for the lack of teaching suggest a much narrower concept. What they find lacking in traditional societies is the habit of systematic teaching, explanations that accompany demonstrations, verbal instructions and enforcing behavioural norms [48]. While these behaviours exemplify some characteristics of child rearing in Western societies [45], none of them is necessary for confirming that a society practises natural pedagogy. Occasional non-verbal but communicative (i.e. addressed and tailored to a novice) demonstrations of means actions, artefact functions or object properties that potentially result in knowledge acquisition in the addressee would count as acts of teaching, not just under our description of natural pedagogy but also under animal behaviourists’ functional definition [19].

This brings us to the third factor that explains why some anthropologists insist that natural pedagogy cannot be universal. Apparently, the baseline norm they apply for significant frequency of occurrence of teaching differs from ours. This is evident from phrases like ‘children learn *much* of their cultures ... without pedagogy’ [35], ‘adults ... *seldom* “teach”’ (Maretzki & Maretzki 1966, cited in [35]), ‘*relatively little* sign of overt teaching was found’ [39], or ‘in most small-scale human societies there is *very little* active teaching’ [34] (italics added). None of these claims asserts the actual absence of teaching practices in non-Western cultures, but they quantify it as much less than some unspecified norm. We suspect that the comparison baseline that these authors apply here is the frequency of teaching in Western societies. However, when the question is the universality of a human behaviour, the proper baseline is not the frequency of a behaviour in an admittedly ‘WEIRD’ culture [49] but that of non-human animals. As communicative teaching does not seem to exist among non-human animals, even ‘rare’ pedagogical activities that can be identified in some non-Western cultures confirm, rather than disprove, our hypothesis that natural pedagogy is a hominin adaptation.

Undoubtedly, there are enormous cultural differences in how societies organize child rearing and how they ensure that children acquire the knowledge

and skills they need [45,48]. Many societies do not institutionalize this learning process in the form of schools and may not even exert any coercion on children's learning. Whether or not there is a culture where no natural pedagogy is exercised at all is an empirical question, and so far we have not managed to identify one. Nevertheless, the fact that children in some traditional cultures that do not emphasize the importance of teaching display similar learning biases to Western children (when novel actions are demonstrated to them in a communicative context) suggests that the cognitive mechanisms of natural pedagogy are universal in humans [31].

4. THE EVOLUTION OF NATURAL PEDAGOGY

Even if natural pedagogy is human-specific and universal across cultures, it does not have to be an evolutionary adaptation. Whether or not it is an adaptation is primarily a historical question of when and how it emerged during human evolution, and secondarily a question of plausibility of the hypothesis that the cognitive systems supporting natural pedagogy were selected for achieving this very function. Although the archaeological record can speak to the first question [50], it is unlikely that sufficient data will ever exist to uncover hominin cognitive evolution in such detail.

The second question contrasts our hypothesis with claims according to which natural pedagogy could be a fortunate by-product of a more basic adaptation. There are several candidates for this role. The most obvious one is the ability for linguistic communication. As all human languages share certain essential features, like their predicate-argument structure and their combinatorial properties, which are ideal for expressing arbitrary contents, natural pedagogy may just be a specific domain where this extraordinary faculty, supposedly evolved to fulfil some other function, has found one of its uses. Indeed, it has been suggested that the primary function of linguistic abilities is to enable combinatorial composition of human thought [51]. As soon as such abilities are in place, and a natural language exists in which such thoughts could be expressed, generic sentences and other linguistic utterances that communicate knowledge that is valid beyond the 'here and now' make it possible to practise natural pedagogy between members of a linguistic community. However, we find it unlikely that natural pedagogy was a by-product of the evolution of language. Non-verbal communication, for example, demonstrations of artefact use, can express generic content, and, given the presence of ostensive signals, will be interpreted as such by addressees. In fact, even pre-verbal infants display biases to do so, as we have demonstrated in many studies [5–7]. Thus, we think that some form of non-verbal natural pedagogy is likely to have evolved before language, and can operate without direct linguistic support.

If language is not necessary, then perhaps the general ability for human communication is the key for the emergence of natural pedagogy. Ostensive communication might have evolved to support the manipulation of the mental states of others [52]. In this scenario, specifically human communicative

abilities arose from our extended social cognitive skills, and in particular the metarepresentational capacities that allow sophisticated mental state attributions to be made to others, which, in turn, might have been the result of the increase in group size [53] or other factors. Alternatively, human ostensive communication may simply be a consequence of our heightened motivation to collaborate and cooperate with others [54]. Communication, whether it is verbal or non-verbal, allows mutual adjustment of actions towards common goals, sharing information that is necessary to build common plans and to confirm and verify commitments to collaborative efforts. The evolutionary pressure that produced the emergence of specific forms of human communication thus must lie in some environmental circumstances that made extended cooperation among humans inevitable at some point during hominin evolution.

While we acknowledge that human communication serves both competition and collaboration, we do not see how the communicative system that they necessitate would also satisfy the requirements of natural pedagogy. The crucial point here is that both Machiavellian and cooperative functions demand information transfer that is episodic in nature. Except in special circumstances, it is rarely in the interest of competitors to implant (true or false) beliefs about generic object kinds, action types or situations into the other's mind. This is why the question of trust and epistemic vigilance (protection against misleading information, see [55,56]) arises mainly with communicative contents that can be potentially deceptive [57]. Typically, these contents refer to particulars rather than kinds, and are restricted in validity in space and time. Similarly, most collaborative actions require information to be shared about the here and now, or about a particular episode in the past or future. Such communication calls for the establishment of an episodic, rather than a semantic, common ground [54]. Thus, neither the manipulative nor the collaborative function of communication explains why human communicators, including preverbal infants, display perceptual and cognitive biases to find generalizable content in the messages directed to them.

We propose that another evolutionary factor had a shaping influence on the cognitive systems that underlie human communication. This factor is the technological challenge that growing up and living in societies that employed more and more sophisticated artefacts and longer and longer means-end sequences posed to humans, and especially to children (see also [58]). Human artefacts and instrumental actions tend to be *opaque* both in terms of their adaptive function (teleological opacity) and in terms of their modus operandi (causal opacity). Much of this information can be acquired by trial-and-error or by passive observation, but not all human actions can efficiently be learnt this way [33]. Even Lancy [46], who denied the importance of teaching among the Kpelle, observed that there are always skills that are 'so complex [they] cannot be acquired through observation, imitation, trial, and error' (p. 163). This is when communicative demonstration, or even just directing the pupil's attention to the relevant aspects of the

situation, can make a difference in learning [58]. Crucially, such demonstration or verbal information subserves the acquisition of generic knowledge that is not tied to the particular situation or to the actual artefact used in the demonstration, but is generalizable to other locations, other times and other objects of the same kind.

We believe that what we know about human evolution supports our hypothesis at least as strongly as the alternative proposals with respect to the environment in which specifically human communication emerged. Our hominin ancestors made stone tools at least 2.5 [59], if not 3.4 Myr ago [60], and used them to produce tools of perishable materials (wood, hide) about 2 Myr ago. The production of these tools was so difficult that acquiring the skills to make them was likely to require extended learning periods, cultural transmission and active participation of the experts [61–63]. One cannot find these tools in the archaeological record, but other data also support an early emergence of human technological skills. In particular, our hominin ancestors made fire and cooked their food at least a million, possibly even 2 Myr ago [64]. In fact, Wrangham argues that changing the diet from raw to cooked food (both meat and plants) fundamentally changed the hominin physiology of digestion and contributed to human evolution by freeing up our ancestors' time. Making and maintaining fire is a complex skill, which may even vary from location to location because of differing ecologies. Food preparation by various modes of cooking is full of completely opaque elements that are maintained by local traditions and passed on through generations. The acquisition of these skills, and the social conventions attached to them, can surely be facilitated by demonstrations of cooking techniques, and by providing information about food kinds, ingredients, methods of preparation, etc. Thus, the technological diversity that might have made natural pedagogy useful was present in early hominin cultures.

When discussing its evolutionary origin, beyond its benefits, we should also consider the costs of natural pedagogy, especially that its costs and benefits may be asymmetrically distributed across teachers and pupils. If pedagogical activity can increase the (cultural) fitness of the recipient, we would expect that adults use this investment only if it benefits their offspring. However, neither ostensive communication nor cultural practices of pedagogy are restricted to kin-to-kin interactions. Although the emotional bonding between parents and their children remains special in human societies, children seem to be promiscuous in accepting adults as potential source of knowledge. Infants smile to any adult who communicates to them, more probably follow a strangers' gaze than that of the mother [65] and preferentially target them when they need more information about the situation [66]. This openness of children coupled with adults' willingness to teach non-kin children is explained by the fact that we are a *cooperative breeding* species [67]. In fact, we are the only apes who share the care of children within a group and have been doing so for at least a million years or so. This arrangement has made it possible that human (or even *Homo*

erectus) children enjoy a much longer childhood than any other mammalian species [68], which seems to be necessary for a protracted and metabolically costly development of the brain [69]. We propose that the co-evolution of the uniquely long childhood period and the cooperative breeding practices in early hominins is supplemented by the emergence of a communication system that provided 'food for thought' for the not only metabolically but also informationally hungry developing brain of children. In other words, the cognitive mechanisms of natural pedagogy, this asymmetric but cooperative social learning system, might have evolved together with the technological, neurobiological and social factors that made such an adaptation necessary and possible [70].

5. CONCLUSIONS

We have collected arguments to support the hypothesis that communicative knowledge transmission (as opposed to non-communicative social learning and communicative information sharing) is a hominin adaptation. Natural pedagogy is uniquely human because no such behaviour or cognitive mechanism is found in other species, though there are examples for other types of teaching. Natural pedagogy is also universal because, despite the huge differences across cultures, so far no society has been found that would not share knowledge by verbal or non-verbal communication. These claims can be falsified by finding a species that teaches by communication or a human society that does not do so.

Unlike other theorists, we do not think that there is a single cognitive or psychological factor (like language or motivation to cooperate) that makes humans unique. We do not think this, not because we do not believe that humans are unique in some sense, but because there are many differences between the cognitive makeup of humans and other species, just like between any two species that are separated by at least 6 Myr of evolution. It is also true that the cognitive mechanisms that underlie natural pedagogy grew out of cognitive mechanisms that were, and are, present in our ape ancestors and cousins. For example, the ostensive signals that humans employ to indicate their communicative intent evolved from signals that had already carried natural meaning for our ancestors [2]. We also agree that the special type of teaching that we call natural pedagogy could only have evolved because individual social learning mechanisms that extracted knowledge from the observation of conspecifics' actions [71] were probably well developed in early hominin societies (cf. [25]).

Our proposal is that the adaptation for natural pedagogy was made necessary by the cognitively opaque knowledge and skills required by technological inventions during early human evolution. This technology, including its materialization as artefacts and its know-how as expertise, was inherently cultural in nature. However, communicative knowledge transfer, with its assumptions about genericity and culturally shared information, must have opened up new domains of cultural contents to be preserved or stabilized by communicative means. Conventions, rituals

and novel symbol systems could also be transmitted to the next generation by natural pedagogy, and the operation of modern social institutions is unimaginable without communicative knowledge transfer. In this sense, natural pedagogy is not just the product but also one of the sources of the rich cultural heritage of our species.

We thank Emma Flynn, Robert Hinde, John. S. Watson and Andrew Whiten for their helpful comments on an earlier version of this paper. This work was supported by an Advanced Investigator Grant by the European Research Council (no. 249519, OSTREFCOM).

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