The Archaeology of Teaching and the Evolution of *Homo docens*

by Peter Gärdenfors and Anders Högberg

Teaching is present in all human societies, while within other species it is very limited. Something happened during the evolution of *Homo sapiens* that also made us *Homo docens*—the teaching animal. Based on discussions of animal and hominin learning, we analyze the evolution of intentional teaching by a series of levels that require increasing capacities of mind reading and communication on the part of the teacher and the learner. The levels of teaching are (1) intentional evaluative feedback, (2) drawing attention, (3) demonstrating, (4) communicating concepts, and (5) explaining relations between concepts. We suggest that level after level has been added during the evolution of teaching. We demonstrate how different technologies depend on increasing sophistication in the levels of cognition and communication required for teaching them. As regards the archaeological evidence for the different levels, we argue that stable transmission of the Oldowan technology requires at least teaching by demonstration and that learning the late Acheulean hand-axe technology requires at least communicating concepts. We conclude that *H. docens* preceded *H. sapiens*.

Introduction

Teaching is present in all human societies (Csibra and Gergely 2009, 2011; Strauss, Ziv, and Stein 2002; Tomasello, Kruger, and Ratner 1993). Even young children have a natural capability to teach (Strauss, Ziv, and Stein 2002). On the other hand, teaching within other species is very limited (Hoppitt et al. 2008; Thornton and Raihani 2008). So something has happened during the evolution of *Homo sapiens* that also made us *Homo docens*—the teaching animal.

There is a wide divergence between disciplines concerning what is meant by teaching. At one extreme are studies of animals, where teaching is given a behaviorist definition (e.g., Caro and Hauser 1992) and no intention is required on the part of the "teacher." At the other extreme are ethnographic studies, where teaching is often defined as explicit verbal instruction. An intermediate third type comprises more cognitively oriented definitions (Csibra and Gergely 2009; Kline 2015). As a background to our arguments, we present different concepts of teaching in the next section.

Instead of aiming for a unique definition of teaching, we present a series of levels of teaching that require increasing capacities of mind reading and communication on the part of the teacher and the learner. First of all, we separate nonintentional teaching from intentional. Regarding nonintentional teaching, we discuss, in "Learning without Intentional Teaching," enhancement and evaluative feedback and analyze examples from nonhuman species. Our main focus, however, is on intentional teaching. In "Levels of Intentional Teaching," we distinguish between the following levels: (1) intentional evaluative feedback, (2) drawing attention, (3) demonstrating, (4) communicating concepts, and (5) explaining relationships between concepts. Since all levels of teaching occur among modern humans, whereas only the basic levels have been found in other species, we hypothesize that level after level has been added during the evolution of teaching.

Our classification partly overlaps that of Kline (2015). She distinguishes between teaching by social tolerance, teaching by opportunity provisioning, teaching by stimulus or local enhancement, teaching by evaluative feedback, and direct active teaching. Some of the teaching types considered by Kline map quite clearly onto our variations of learning, nonintentional teaching, and the first levels of intentional teaching. For example, teaching by social tolerance corresponds to what we sort under imitation and emulation, together with the assumption that the "teacher" does not prevent the imitator from observing.

However, Kline's category "direct active teaching" is, in our opinion, too broadly defined (Gärdenfors and Högberg 2015). In particular, it should be divided into subcategories that separate forms of teaching that require displaced communi-

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 0011-3204/2017/5802-0003$10.00. DOI: 10.1086/691178

cation (gestures or words) from those that do not. We argue, in "Levels of Intentional Teaching," that teaching by demonstration can be accomplished without such communication, whereas teaching concepts and explaining causal relationships cannot. In general, we put more emphasis on the intentionality of teaching than Kline does.

Kline does not apply her classification to archaeology, but this domain is our concern in "Archaeological Applications: Teaching Oldowan and Late Acheulean Technologies." A central empirical question is what archaeological evidence one can find for when the different levels of teaching emerge in the hominin line. With stone tool production known from 3.3 million years ago (Mya; Harmand et al. 2015), knapped stone implements and the waste material from their production provide excellent source material for the study of the evolution of teaching (Haidle 2010). Our main theses in "Archaeological Applications: Teaching Oldowan and Late Acheulean Technologies" are that, for stable cultural transmission, (1) learning Oldowan technology requires at least teaching by demonstration and (2) learning late Acheulean hand-axe technology requires at least communicating concepts. It follows from these theses that several levels of intentional teaching predate *H. sapiens*. In the concluding section, we also discuss the implications of our analysis for the evolution of language.

Concepts of Teaching and Their Cognitive and Communicative Requirements

Three Kinds of Definitions

There exist many proposals to delineate the meaning of teaching (e.g., Caro and Hauser 1992; Leadbeater, Raine, and Chittka 2006; Strauss, Ziv, and Stein 2002; Thornton and Raihani 2008). In a unifying analysis, Kline (2015) presents an account of three major forms that she calls functional, mentalistic, and culture based. The following definition is a well-known example of the functional type:

> An individual actor **A** can be said to teach if it modifies its behavior only in the presence of a naïve observer, **B**, at some cost or at least without obtaining an immediate benefit for itself. **A**'s behavior thereby encourages or punishes **B**'s behavior, or provides **B** with experience, or sets an example for **B**. As a result, **B** acquires knowledge, or learns a skill earlier in life or more rapidly or efficiently than it might otherwise do so, or would not learn at all (Caro and Hauser 1992:153).

The definition can be seen as belonging to the behaviorist tradition. Caro and Hauser argue that it requires neither mind reading nor any intentionality on the part of the teacher. On the basis of this definition, it is claimed that meerkats (Thornton and McAuliffe 2006), pied babblers (Raihani and Ridley 2008), and tandem-running ants (Franks and Richardson 2006) teach. In contrast, Leadbeater, Raine, and Chittka (2006:R325) argue that the example of the tandem-running ants should rather be seen as an example of "telling a fact"—that is, in this example, where to find the food—than as a case of teaching. This also holds for the pied babblers, since their purr calls are produced when they find a patch that is abundant in food. Leadbeater, Raine, and Chittka (2006:R325) propose that the notion of teaching should be restricted to the transfer of "skills, concepts, rules and strategies" (Csibra 2007 presents a similar argument). Furthermore, Byrne and Rapaport (2011) argue that Caro and Hauser's criterion is very difficult to apply in many situations and therefore does not work as an operational criterion.

The definitions that fall under Kline's (2015) term "mentalistic" present teaching as behavior with the intent to enhance learning in another (Byrne 1995; Moore 2013; Premack and Premack 1996; Strauss, Ziv, and Stein 2002; Tomasello, Kruger, and Ratner 1993). One example is Moore's (2013:897) definition: "minimal pedagogy would require only the ability to judge the incompetence of an action performed in pursuit of a goal, operating in conjunction with an intention to inform, and the ability to address a demonstrated behaviour to its intended audience." Although such teaching has hardly been observed in nonhuman animals (Boesch 1991 is an exception), Moore suggests that chimpanzees may have this ability.

According to Kline's classification, culture-based definitions of teaching concern activities in classrooms in modern societies, in contrast to informal learning in traditional societies (Lancy 2010; Paradise and Rogoff 2009). From our point of view, classroom teaching is less interesting, since it is a comparatively recent phenomenon and does not give much insight into the evolutionary roots of teaching.

Note that throughout the text we write about teacher and learner in the singular, although we fully acknowledge that teaching forms are embedded in a cultural setting (Sterelny 2012) and that teaching should rather be seen in the context of a "many-to-many" relationship. The evolution of teaching can therefore not be separated from the evolution of culture (Fuentes 2015). Teaching can also be both vertical—between generations—and horizontal—within a generation (d´Errico and Banks 2015).

The different levels of nonintentional and intentional teaching that we present in "Learning without Intentional Teaching" and "Levels of Intentional Teaching" depend on different cognitive and communicative capacities. We next prepare the ground by presenting these prerequisites in some detail.

Mind Reading in Teaching Contexts

One form of cognition that is well developed in humans, compared to other species, is mind reading (also called "theory of mind," e.g., in Premack and Woodruff 1978; Tomasello 1999), which in this context means the sharing and representing of others' mentality. Mind reading is not a unitary ability, however, but it can apply to understanding the emotions, attention, desires, intentions, and beliefs of others (Gärdenfors 2003, 2007).

Several authors have claimed that teaching is linked to mind reading (Frye and Ziv 2005; Kruger and Tomasello 1996; Strauss, Ziv, and Stein 2002; Tomasello, Kruger, and Ratner 1993). In particular, the capacity to understand that somebody else does not know how to do something or does not know a relevant fact is central for intentional teaching. When discussing the intentionality of teaching, it is useful to follow Dennett's (1987) classification. Zero-order intentionality ascribes no intentionality to an individual (the potential teacher). First-order intentionality attributes belief and desires to the individual, in particular a desire to modify the behavior of another individual. This level, however, presumes no understanding of the mind of the other. Second-order intentionality requires an individual to have an understanding of both their own and others' minds and a desire to modify the mind of another (not just their behavior).

Two cooperative forms of mind reading important for teaching are joint attention and joint intention (Tomasello 1999; Tomasello et al. 2005). Joint attention results when the agents have eye contact while sharing attention to a target. The ability to engage in joint attention has not, so far, been established conclusively in nonhuman primates (for a different view, see Gomez 2007; Leavens, Hopkins, and Bard 2005; Leavens, Racine, and Hopkins 2009). As we see in "Levels of Intentional Teaching," joint attention is necessary for our levels 2–5 of intentional teaching. Joint intention requires that the agents share an intention to interact, react to each other's intentions to act, and coordinate their intentions (Tomasello 2014; Tomasello et al. 2005). In typical human teaching situations, the teacher and the learner have the joint intention that the learner learns a particular technique, skill, fact, or rule: the teacher intends to show or inform the learner something, and the learner intends to learn from this interaction. Even young infants are inclined to interpret the behaviors of others as intentional (Csibra and Gergely 2007). This prepares the ground for a human learner to understand the goals of a teacher.

Forms of Communication

Teaching presumes communication between teacher and learner. As we see in "Levels of Intentional Teaching," already our second level, drawing attention, presumes indexicality (Peirce 1932), in the sense that the teacher can indicate, by pointing or some other method, an object or an action that is in focus.

When it comes to more advanced communication, it is useful to distinguish between language and signaling. A decisive difference between these forms is that signals merely indicate what is present in the environment (Gärdenfors 2003; Hockett 1960). However, (iconic) gestures and (symbolic) words make it possible to communicate about things that are absent and may not even exist. (Following Peirce 1932, an icon is taken to be a sign that resembles what it represents, while a symbol is an arbitrary sign.) Hockett (1960) calls this displaced communication. In this function, gestures and words retain meaning in the absence of the referent. Sign languages used by the deaf also have this function. Nonhuman animals mainly communicate by vocal signals, although gestures are sometimes used (Tanner and Byrne 1996; Zlatev, Persson, and Gärdenfors 2005). A word—and in many cases a gesture too—is a convention that one must learn if one is to use it as a communicative tool. Gestures and words have a "communicative sign function" (Zlatev, Persson, and Gärdenfors 2005), which means that the one producing the sign intends it to stand for something else and that the addressee understands this intention. Hence, communication by gestures or words presumes second-order intentionality, according to Dennett's (1987) classification. Gestures and words can be used to off-load the demands of mind-reading cognition: a teacher can communicate emotions, desires, and intentions, so that the learner need not rely only on facial or behavioral cues (that have no communicative sign function). Several researchers have suggested relationships between language evolution and a gradual development in stone tool production over time (Gibson and Ingold 1993; Mahaney 2014; Stout 2010; but see Botha 2015).

Learning without Intentional Teaching

A central question when investigating the evolution of teaching is what skills and what knowledge can be learned by imitation or emulation and what requires some form of teaching (see discussions in Morgan et al. 2015; Shipton and Nielsen 2015). Many human skills, let alone human knowledge systems, are so complicated that they cannot be learned by imitation or emulation only. For example, Tehrani and Riede (2008:318) write about expert weaving and master stone tool making that "if observation and imitation were the major modes of transmission for these skills, we might expect that, over the course of many generations, complex craft and toolmaking traditions would be extremely vulnerable to failings of memory, copying error and inter-individual differences in natural ability." In this section, we focus on social learning in humans and other animals that may occur without intentional teaching being involved. Our purpose is to position our research on teaching within the vast research area on social learning (Högberg, Gärdenfors, and Larsson 2015).

Emulation, Imitation, and Rehearsal

In animal social learning, the learning individual observes the behavior of a second knowledgeable individual (the model), while the model does not adapt its behavior to make it easier for the first individual to learn. An example is the nut-cracking behavior of chimpanzees. It can take up to 4 years for adolescent chimpanzees to learn from adults and become proficient at cracking open palm nuts with stone hammers and anvils. Adults rarely help in correcting hammering techniques or encourage the young (Boesch 1991). Tomasello (1999) distinguishes between learning by emulation, where the learner observes the outcomes of the model's actions and tries to reach the same outcome (goal oriented), and learning by imitation, where the learner observes the sequence of the model's actions and tries to perform the same actions (process-oriented learning; see also Tehrani and Riede 2008).

The "artificial fruit" experiments by Whiten, Horner, and Marshall-Pescini (2005) have been designed to investigate the differences between emulation and imitation. Early results indicated that chimpanzees emulate while children imitate. Later studies by Whiten et al. (2009) suggest, however, that the situation is more complicated: the apes are not confined to emulation but also imitate extensively. It has been shown, for example, that the technology of nut cracking among apes can be transmitted by social learning from one generation to the next (Fragaszy et al. 2013; Wynn et al. 2011). Zentall (2004) also presents evidence that imitation can be found in several bird species.

Apes can be trained to imitate in the so-called do-as-I-do paradigm. In these experiments, the subject (ape) is shown actions on objects and is then encouraged to "do the same thing," and the spontaneous handling of the object is recorded (Toth et al. 1993). The results show a notable increase with age in the ability to manage approximate imitation (Bjorklund and Bering 2003). However, mother-reared chimpanzees seem to do less well, while encultured apes can outperform human children on certain tasks (Tomasello, Savage-Rumbaugh, and Kruger 1993). Bjorklund and Bering (2003) suggest that part of what comprises the enculturation phenomenon is a greater conceptualization of human behavioral programs. However, unlike the case with human children, the imitation does not come spontaneously with the apes but must be extensively trained.

Children not only imitate but they overimitate, in the sense that they copy actions performed by the model that are obviously irrelevant for the success of the task (Whiten et al. 2009; Nielsen 2011). One interpretation of this behavior is that children trust that adults know the right sequence of actions needed to attain a particular goal. Whiten, Horner, and Marshall-Pescini (2005:280) suggest the explanation that "we are such a thorough-going cultural species that it pays children . . . to copy willy-nilly much of the behavioral repertoire they see enacted before them" (see also Boyd and Richerson 2008).

An important difference is that human children, but presumably not apes, can voluntarily rehearse a particular behavior (Donald 2012). This is related to Donald's (1991) "mimesis hypothesis," which proposes that while ape culture is based on associational learning, early *Homo* evolved a new form of cognition. The basis for this is that the body can be used volitionally to do what somebody else is doing and to represent external events for the purpose of communication (mime, gesture). Donald (2012) expands the mimesis hypothesis and emphasizes that a key feature of the human memory system is our ability to voluntarily retrieve a particular memory. The importance of this capacity in relation to our stone tool technology examples presented below is that skilled stone knapping requires rehearsal. Donald's insight is that there can be no rehearsal without voluntary recall of previous performance. The apprenticeship culture that evolved among hominins (Sterelny 2012) presumes a well-established ability to rehearse.

Enhancement

We next discuss teaching that satisfies Caro and Hauser's functional definition where no intention to teach is ascribed to the teacher. We separate two forms of nonintentional teaching: enhancement and evaluative feedback of a learner's behavior. (Enhancement is sometimes called "scaffolding." We avoid that term, however, since scaffolding often is intentional, at least among humans.) To a large extent, these forms match what Caro and Hauser (1992) call "opportunity teaching" and "coaching," respectively.

A teacher enhances learning by changing the environment so that the learner learns more quickly than it would otherwise have done (Caro and Hauser 1992). Caro (1980) showed, in a laboratory study, that kittens that were exposed to live prey in the presence of their mother became better hunters than kittens who were exposed to prey alone. Meerkats bring back scorpions, often disabled by removal of their sting. As the meerkat pups grow older, the adults modify their behavior, giving the pups increasingly intact prey. However, they do not seem to gauge the skill level of the pup but rely only on changes in pup begging calls with age (Hoppitt et al. 2008; Thornton and McAuliffe 2006). This indicates that the adults do not have any understanding of the competence of the pups.

Nonintentional Evaluative Feedback

The second form of nonintentional teaching is evaluative feedback (mainly approval or disapproval) of the learner's behavior (Castro and Toro 2004). Empirical data on this form of teaching include chimpanzee mothers taking away dangerous food from infants and gorilla as well as chimpanzee and macaque mothers encouraging infants' independent locomotion (Maestripieri 1995, 1996; Whiten 1999). Burton (1992) observed that macaque infants that were encouraged to walk were later better at jumping, climbing, and leaping than their agemates that had not been encouraged. In a study by Humle and Snowdon (2008), captive cottontop tamarin parents were taught two different methods of obtaining food. To some extent their juveniles copied the behavior of their parents, but they also continued begging for food. Interestingly, when a juvenile had learned to retrieve the food, the adults refused begs by their juveniles significantly more than before. This is a form of evaluative feedback that encourages the juvenile to obtain food for itself. Evaluative feedback can be seen as an extension of operant conditioning where the teacher provides (part of) the reinforcement or punishment. It is, however, difficult to verify that the examples presented here really involve nonintentional behavior of part of the animal parents (see the next section).

Teaching by evaluative feedback in the form of disapproval is similar to other kinds of disapprovals of behavior, mainly in the form of aggression, which occurs in territory defense and competition for food. This kind of behavior does not quite satisfy Caro and Hauser's (1992) definition, since it involves an immediate benefit for the aggressor. Nevertheless, the individual toward whom the aggression is directed learns to avoid the contested territory or to avoid competing for food.

Levels of Intentional Teaching

We now turn to our main analysis of levels of teaching. For all five levels it is assumed that the teacher has an intention that the pupil learn something that it would not learn without the intervention of the teacher.

Intentional Evaluative Feedback

Evaluative feedback is ubiquitous in human interactions, but here their expressions are often intentional, the teacher's intention simply being that the learner exhibit correct behavior. Maestripieri (1996:374) suggests that the most parsimonious interpretation of ape and monkey mothers' encouragement behavior is that it is intentional: they want their offspring to behave in a particular manner (a first-order intention, according to Dennett's [1987] classification). Even if we agree that apes and monkey mothers satisfy the criteria of first-order intentionality, the evaluative feedback in nonhuman species seems to be restricted to a limited set of learning situations, while in humans it can be used in almost all circumstances. These uses of evaluative feedback exhibit a more advanced form of mind reading than the nonintentional forms. Furthermore, there is no indication that the ape or monkey mothers have any understanding of how they change the mental states of their learners. This would be a second-order intention in Dennett's (1987) terminology, since the teacher then has an understanding of both its own and the pupil's state of knowledge and a desire to modify the mind of the pupil so that it learns something. On the other hand, the learner need not employ any form of mind reading but need only react to the teacher's signal as a reward or as a punishment.

Castro and Toro (2004:10237) argue that evaluative feedback (disapproval) "allows the offspring to acquire information about behaviors they are self-discovering without having to experience all their negative consequences." We do not find this proposal sufficient, since it does not explain why evaluative feedback is so rare in other species but ubiquitous in humans. Parents in all human cultures frequently react, positively or negatively, to the behavior of their offspring. We suggest that the increased capacity for mind reading is an important part of the explanation. If a potential teacher does not understand that the learner does not have the relevant knowledge, there is no incentive to teach.

On our analysis, intentional teaching comprises several additional levels, apart from intentional evaluative feedback. We distinguish between drawing attention, demonstrating, communicating concepts, and explaining relationships between concepts. Each of these levels represent increasing demands on human intentions, mind reading, and communication, compared to the previous levels. Therefore, we submit that level after level has been added during the evolution of teaching in the order we present them here.

Drawing Attention

The next level of teaching concerns the teacher drawing the learner's attention to something that is relevant in the learning situation. When drawing attention, the teacher's intention is that the learner focus on a particular object, action, or feature. If the learner directs its attention to the intended goal, shared attention is achieved. In order to reach joint attention, the learner must also see that the teacher attends to the same thing, something that involves a form of mind reading on the part of the learner.

Among humans, drawing attention is often achieved by pointing. Bates, Camaioni, and Volterra (1975) introduced the distinction between "imperative" and "declarative" pointing. Imperative pointing is performed in order to make the attendant do something for the pointer, for example, a chimpanzee indicating where on its body it wants to be groomed (Pika and Mitani 2006). Declarative pointing involves directing the attention of the attendant toward a focal object, for example, an infant pointing to an interesting object to obtain its mother's evaluation of the object (Brinck 2004; Tomasello, Carpenter, and Liszkowski 2007). Pointing is naturally combined with evaluative feedback, for example, a parent with a fearful expression on his or her face pointing to a nearby snake. This combination has been called emotive declarative pointing (Brinck 2001; Gärdenfors and Warglien 2013), or expressive declarative pointing (Tomasello, Carpenter, and Liszkowski 2007). The main benefit for the learner of such an exchange is that he or she can learn about the values of objects vicariously.

Nonhuman animals draw attention, in particular via alarm calls. However, in most cases these signals seem to be nonintentional and not dependent on what the conspecifics know and do not know (for an exception among chimpanzees, see Crockford et al. 2012). However, there exist several cases of drawing attention among other species that seem to fulfill the criteria of first-order intentionality. A common attention-getter in many animals is to position oneself within the visual field of the other. Apes also try to get somebody's attention by using nonvocal sound, that is, clapping hands or banging on a resounding object (Call and Tomasello 2008).

Apes that are exposed to human behavior can learn to point imperatively, but pointing is rare in wild populations (Povinelli, Bering, and Giambrone 2003). Pointing declaratively presumes the capacity for joint attention. Leavens and Racine (2009) note that almost all apes that have undergone language training can point declaratively, although such pointing is not as frequent as in human infants. They argue that learning to point declaratively requires an environment where such acts receive positive responses, and encultured apes seldom experience such social contingencies, let alone apes in the wild.

Demonstrating

The next level in our hierarchy is demonstrating that involves intentionality by showing somebody else how to perform a task or solve a problem. Among humans, it is a ubiquitous form of teaching, and children begin to demonstrate at an early age (Strauss, Ziv, and Stein 2002). When demonstrating, the teacher's intention is that the learner exhibit the right actions in the correct sequence. It should be noted that demonstration presumes that the learner will learn by imitation rather than by emulation. Highlighting initial and final states of an action helps the learner to segment the sequence of actions as well as the preconditions for the initiation of the action and the properties of its final result (Rohlfing, Fritsch, and Wrede 2004).

Demonstrating builds on advanced mind reading for both the teacher and the learner. It presumes that the teacher understands the lack of knowledge in the learner and that the learner experiences that there is something to learn. Successful teaching also requires that the teacher and the learner jointly attend to the demonstration. When the learner tries to imitate the demonstrated action, the teacher can also react with evaluative feedback and, if necessary, renewed demonstration. Then the learner rehearses the action sequence until a satisfactory result is achieved. There are rare observations of chimpanzees showing somebody else how to perform an action: a mother can show her infant how to hold a stone in order to crack a nut against an anvil stone (Boesch 1991). We do not consider this to be a good example of demonstration, since the mother only helps the infant to hold the stone correctly but does not show how to hit the nut. Since the chimps have not "socialized" their attention, this form of teaching by demonstration cannot reach very far.

The features of mind reading and communication involved in teaching in the levels presented up to now fit well with Donald's (1991) account of what a prelinguistic mimetic culture might have looked like. Of course, there is no direct evidence for how the early levels of teaching that have been presented so far have evolved. Even though we in no way believe that a direct parallel can be made between the early hominins and extant human societies, it is still of some interest to compare with teaching in modern stone-tool-making societies. One example comes from Stout's (2010) investigation of Langda stone knappers. He notes that when an expert is working with an apprentice, common expressions are: (1) "Do it here" (drawing attention), (2) "Don't do that" (evaluative feedback), (3) "Look here" (drawing attention), and (4) "Wait, you have to do this" (demonstration). These expressions are good illustrations of the levels that we have presented so far. They are, of course, accompanied by gestures, facial expressions, and demonstrating actions.

Communicating Concepts

During our evolution we have relied on concepts for everyday problem solving, for example, learning to recognize edible plant species, distinguishing the tracks of a hyena from those of a leopard, or recognizing a suitable platform in stone tool production. There is a great deal of controversy in the cognitive sciences concerning how to characterize a concept. For our purposes, it is sufficient that having a concept involves the ability to recognize a pattern (Gärdenfors and Lindström 2008). Some of these patterns are perceptual and others—for example, kinship relations—more abstract.

In modern human societies, the main method to teach a concept is to use a word that represents the concept, together with pointing or some other technique for drawing attention to what is denoted by the concept, in particular the pattern associated with it. Children are well adapted to learning the meaning of words, and often a single example is sufficient (Carey 1978). When they learn the words for new kinds of objects there is a shape bias; that is, the shape pattern of the object is the most important property in determining category membership (Smith and Samuelson 2006).

When communicating a concept, the teacher's intention is that the learner perceive a particular pattern that pertains to an object or an action. For more abstract concepts, the intention is that the learner mentally represent the relevant patterns. In relation to stone tool production, Wynn and Coolidge (2012:70), for example, write about the importance of the distal convexity of a core as a focal point in Levallois technology, "distal core convexity" being a necessary concept to communicate.

As regards requirements of communication, concept teaching builds on a form more advanced than the previous levels. It relies on increased mind reading, since it presumes that the learner understands that the teacher is intentionally using a gesture or a sound as a communicative sign, that is, that the gesture or sound is used to "stand for" something else (Zlatev, Persson, and Gärdenfors 2005). It is not necessary that concepts be communicated by words. Before speech is available (in evolution or in development), an iconic gesture can also be used to convey a concept (an onomatopoetic sound can be seen as a kind of iconic gesture). For example, when finding an animal track, present-day hunter-gatherers mime the animal that made the track, because speech might cause the prey to flee (Liebenberg 1990).

An important type of teaching, based on communicating concepts, is when a learner is taught subgoals in a technological hierarchy. The more complex a technology becomes, the more subgoals are involved (Lombard and Haidle 2012; Mahaney 2014; Moore 2010). Here we define subgoals as necessary production phases that must be completed before the next stage of production can start. In terms of knapping, Stout (2011), inspired by Moore (2010), has discussed this within the frame of hierarchical cognitive structures of increasing complexity. In such a hierarchy, the various phases in the production process are grouped into increasingly nested categories (see fig. 1).

In these action hierarchies, higher levels correspond to more abstract subgoals, while the lowest level corresponds to motor acts ("grasp" or "rotate"). The number of levels involved is called the "planning depth" of the technology. Similar hierarchical analyses have been proposed by Haidle (2009, 2010) and Perrault et al. (2013; see also Greenfield 1991, which Moore 2010 builds on). An increased planning depth demands more developed working memory and executive functions. It has been

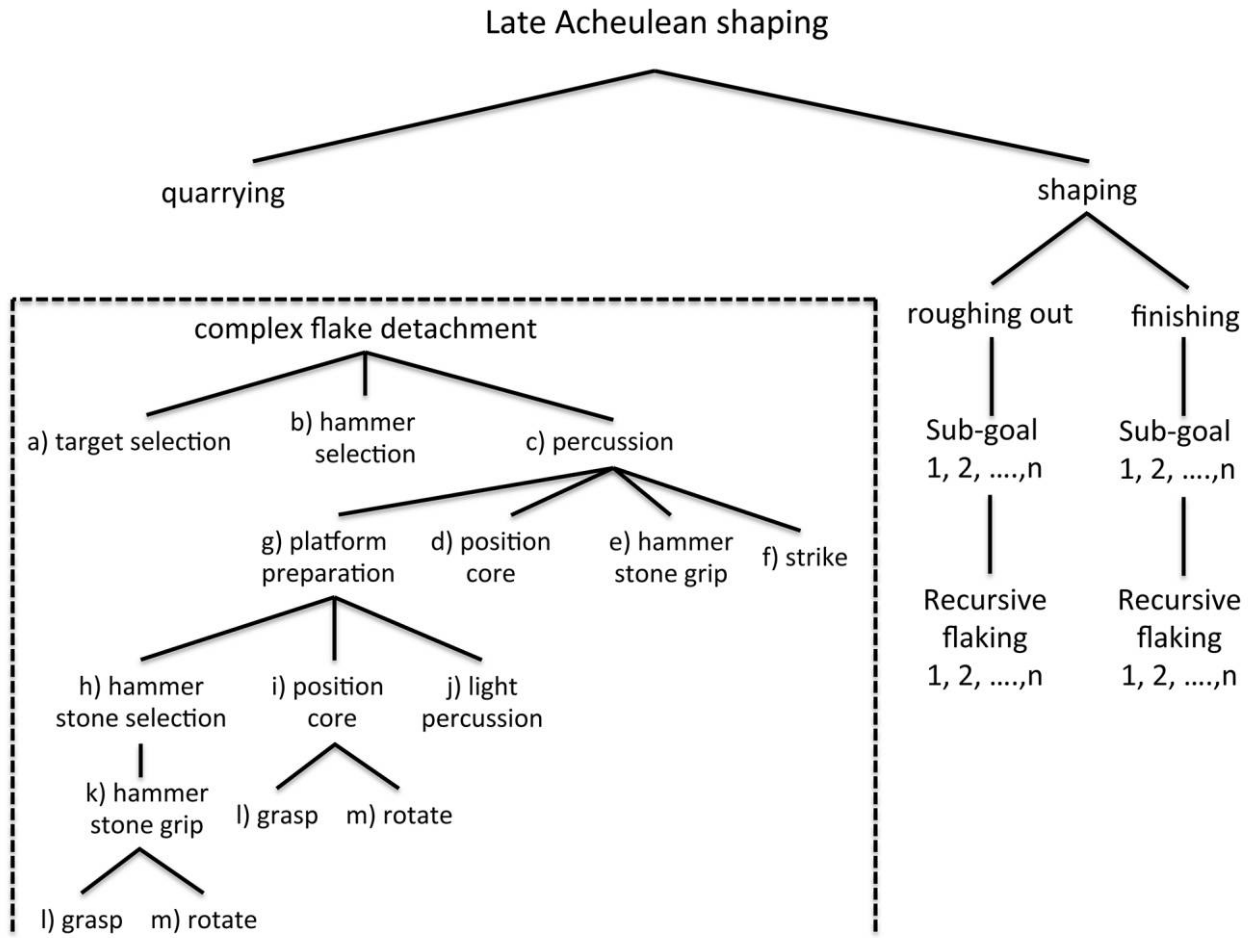

Figure 1. Illustration of subgoal hierarchy in stone knapping. The figure illustrates the planning depth involved in shaping a late Acheulean hand-axe. Complete flake detachment relies on several subgoals. If a flake is to be detached, target selection (a), hammer selection (b), and percussion (c) are performed. Percussion (c) includes how to position the core (d), how to grip the hammer stone (e), and how to strike (f). If percussion involves platform preparation (g), more subgoals are involved: that is, hammer stone selection (h), positioning the core (i), and light percussion (j). Again, these subgoals include more subgoals: that is, hammer stone grip (k) and grasping (l) and rotating (m) the object. Figure reworked from Stout (2011:1052).

suggested that during human evolution, the working memory span has gradually increased (Coolidge and Wynn 2005; Nowell 2010), with an estimated span of 2 ± 1 units for chimpanzees and pre-*Homo* and 7 ± 2 units for modern humans (Read and van der Leeuw 2008). Furthermore, Stuart-Fox (2014) argues that increased working memory is involved in understanding causal relations (see "Explaining Relationships between Concepts").

The main point in relation to teaching is that the subgoals cannot be perceived directly from the action sequence and are therefore very difficult, or impossible, to learn via imitation (sensu Moore 2010). The subgoal features can therefore not be introduced by drawing attention or demonstration. They must be taught via concepts. In "Teaching Late Acheulean Hand-Axe Technology," we argue that learning the late Acheulean hand-axe technology is made possible by the teacher, who assists the learner in understanding the structure of the subgoals by teaching how to perceive patterns. As you become a more skilled stone toolmaker, you focus less and less on the lower-level actions and more on the properties of the subgoals that you are working on (cf. Greenfield 1991:535). It is, however, not only the quantity of subgoals involved that determines complexity. A production process may involve only a few subgoals, but if one of them is difficult to learn, it will take in-depth teaching and hard practice over a long period to acquire the knowledge needed.

Explaining Relationships between Concepts

Words or gestures can be used to teach concepts, but linguistic communication mainly involves relationships between concepts. Relations between concepts are, for example, that mushrooms that look like champignons but have white gills are poisonous and that wet wood is difficult to use to light a fire. The next level of teaching concerns conveying such relationships. Here we consider teaching causal relationships.

Human reasoning about causal relationships is different from that of other species, in particular reasoning about causes that cannot be directly perceived (Penn and Povinelli 2007). For example, monkeys have difficulties interpreting signs indicating that there are predators in the vicinity. Cheney and Seyfarth (1990) made a false python track in the sand for a flock of vervet monkeys. They did not react to this, even though pythons are highly dangerous to vervets. Nor did the monkeys react when a dead antelope was hung up in a tree, despite the fact that this was a clear sign that there might be a leopard in the vicinity.

As regards causal learning, Woodward (2011) distinguishes between three learner forms: (1) the "egocentric causal learner," who is able to learn causal relationships linking its own actions to outcomes; (2) the "agent causal learner," who also learns about causal relationships from the actions of others; and (3) the "observation causal learner," who also learns from patterns of covariation in nature that are not produced by any agent. Tomasello and Call (1997) suggest that apes are not observation causal learners (see also Povinelli 2000). They are egocentric causal learners, and to some extent, via imitation or emulation, they become agent causal learners. Children are avid agent causal learners (see, e.g., Meltzoff 1995). Human infants learn basic causal connections from their experiences. In particular, explorative play is helpful here. Children are also observation causal learners, but only to a limited extent: they fail to perceive many contingencies, for example, that lack of food leads to a bad temper. Furthermore, they often think that they see causal relations where there are none (as do human adults), and they tend to have animist conceptions of causes in the world.

Experience is not sufficient for learning about the causal relationships that are required for a successful life, in particular in an extreme environment. Boyd, Richerson, and Henrich (2011) present a list of examples from Inuit knowledge about causal relationships that are necessary for survival in the environment and are impossible for Inuit children to learn from personal experience. Here a teacher who presents explanations about, for example, the connection between the breathing holes of seals in the ice and their behavior or what causes the soot from a seal fat lamp will dramatically increase the learning speed. Another example is the relationship between various species of plants and their medical effects, which, again, cannot be learned from experience alone. In general, causal relationships can be seen as a special kind of "patterns"—patterns in time: if cause C is present, then effect E will follow, where C and E are concepts.

The teacher's intention in explaining is that the learner understand the causal relationship between two concepts. Teaching by explaining also presumes that the learner understands that the teacher is using gestures or words as a communicative sign. Furthermore, explaining often involves displacement of the referents. Teaching facts and causal relationships involves using combinations of concepts. It is possible that such combinations can be achieved with iconic gestures, but a symbolic language would enhance the communication.

Another example of an area for teaching about causal relationships is tracking (Lombard and Gärdenfors, forthcoming; Shaw-Williams 2014; Stuart-Fox 2014). Liebenberg (1990) calls tracking "the origin of science." As mentioned above, nonhuman animals do not understand tracks as effects of an animal or human causing the tracks (Cheney and Seyfarth 1990; Shaw-Williams 2014). In terms of Woodward's (2011) classification, one has to be at least an agent causal learner to achieve this. When a learner observes a track, the teacher can explain the track as the effect of an animal or human passing by and perhaps add other inferences about the behavior of the individual. It would be beyond the capacity of a single learner to pick up all this knowledge from his or her personal experience.

Stuart-Fox (2014) notes that ideas about causal connections that an individual can form—for example, concerning the relationship between a track and the animal that caused the track—are prone to errors. So how can efficient causal cognition evolve? Stuart-Fox argues that in a social species there are two means of confirming a causal hypothesis. One is the endorsement of expert others. In our terminology, this amounts to a version of evaluative feedback, albeit what is approved represents a relationship between concepts, rather than the behavior of the learner. The second means is coherence within a structure of previously shared beliefs. Shared beliefs develop through the activities of the group, and coherence of beliefs reflects the experience of the group. In other words, learning causal beliefs mainly consists of social learning (see also Liebenberg 1990).

Table 1 summarizes our discussion concerning different forms of teaching. The levels are presented in terms of increasing demands on the intention of the teacher, increased demands on mind reading in the teacher and in the learner, and increasing demands on the underlying communication system. It should be noted that the order of the forms of mind reading fits with the evolutionary (and developmental) order proposed by Gärdenfors (2007).

Archaeological Applications: Teaching Oldowan and Late Acheulean Technologies

Teaching Oldowan Stone Tool Making

We next turn to our first thesis, that for stable cultural transmission learning core maintenance in Oldowan technology required at least teaching by demonstration. The Oldowan is generally associated with *Homo habilis* and early *Homo erectus*, but other hominin species might have used it as well (Toth et al. 1993). Oldowan technology is based on flake production from simple cores. Flakes and, more contingent, cores (Toth and Schick 1993) were used as tools for butchery and possibly plant processing (Lemorini et al. 2014; Torre 2011; Wynn et al. 2011) as well as for nonsubsistence tasks such as woodworking (Lemorini et al. 2014). Oldowan has previously been re-

Table 1. Summary of forms of teaching

Type of teaching	Intention of teacher	Mind reading of learner and teacher	Communicative requirements
Nonintentional teaching:			
Enhancement	None	None	None
Nonintentional evaluative feedback	None	None, but empathy helps	Evaluative expression
Intentional teaching:			
1. Intentional evaluative feedback	Correct behavior	None, but empathy helps	Evaluative expression
2. Drawing attention	Joint attention	Joint attention	Pointing (or gaze direction)
3. Demonstrating	Learn action sequence	Joint attention and joint intention	Demonstration
4. Communicating concepts	Perceive pattern	Understand sign function	Iconic gesture or spoken word
5. Explaining relationships between concepts	Learn factual or causal relation	Understand sign function	Displaced communication

garded as the earliest evidence of flaked-stone technology. However, a recent study provides evidence that flaked tools predate Oldowan (Harmand et al. 2015).

The technology is limited to two techniques—knapping with a hammer stone using direct percussion and bipolar percussion with an anvil (Braun et al. 2008)—and a few tasks—raw material acquisition, finding a suitable hammer stone or anvil, finding a place to knap, splitting up a nodule, detaching a flake, twisting the core to detach another flake, and repeating this until the core is exhausted (Stout et al. 2009; Toth and Schick 1993).

Toth and Schick (1993:349) have demonstrated that the ability to recognize acute angles on cores to serve as striking platforms and good hand-eye coordination are important principles necessary to master Oldowan stone tool making. Drawing on these results, we bring out the principle of core maintenance as an important quality to master. Core maintenance is achieved by detaching flakes from the core in a way that makes it possible to strike further flakes from it later (see fig. 2). The principle is that a flake is detached in a way that allows for a second flake to be detached. This second flake is then detached in a way that allows for a third flake to be detached, and so on. This is repeated until the core is exhausted, that is, until it is no longer possible to detach flakes. It keeps the core active in a toolkit without immediately exhausting it and, hence, extends

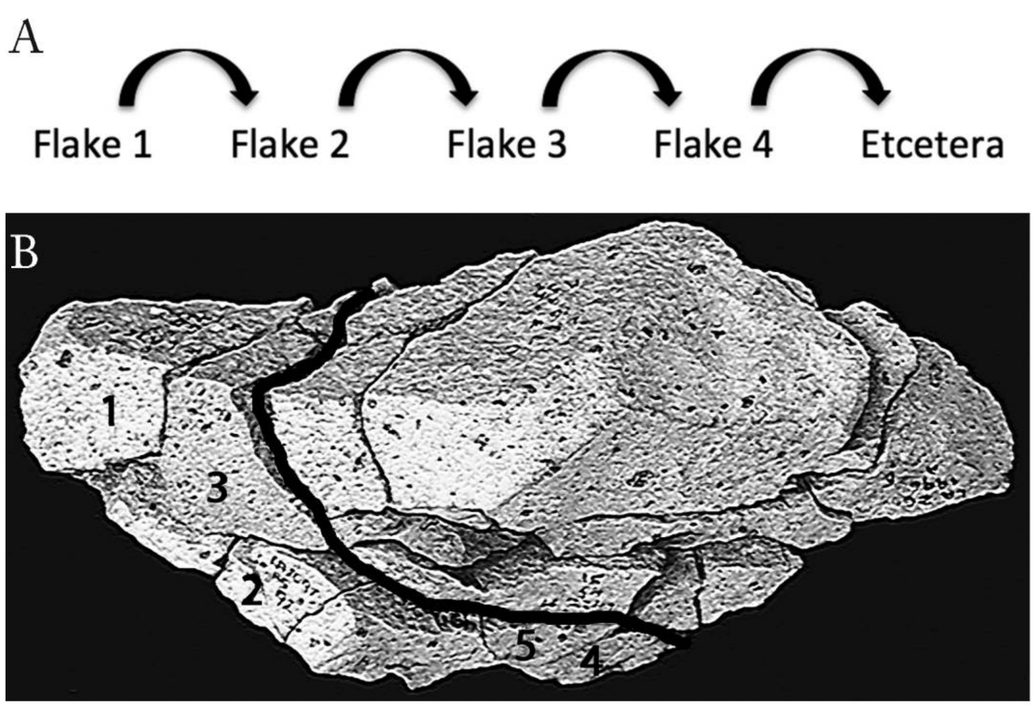

Figure 2. Oldowan core maintenance. *A*, Oldowan core maintenance: flake 1 is detached in a way that allows for flake 2 to be detached. Flake 2 is detached in a way that allows for flake 3 to be detached, and so on. *B*, A refitted Oldowan core viewed from the platform. Several flakes have been detached in a sequence. The numbers 1–5 indicate the first five flakes. The thick black line marks the platform edge at the core front after these five flakes were detached (revised from Steele 1999). The core is approximately 15 cm from left to right.

the use-life of cores and increases the reduction intensity (Braun et al. 2008). Extensive refitting analyses demonstrate that core maintenance was practiced in Oldowan stone knapping. Delagnes and Roche (2005) have reported on cores from which up to 20 flakes have been knapped in this way.

For core maintenance to be achieved, the flakes must be detached from a core with a platform using a correct angle between platform and core front, a front that allows for the flake to be detached without fracturing in a way that causes irregularities on the core front, and a distal core end that allows flakes to detach without errors. To set up a core that matches these criteria is, however, not enough to achieve core maintenance. Experimental studies have shown that core maintenance, as described here, requires planning. It is an intentionally applied strategy and does not automatically or randomly follow from any type of knapping (Sternke and Sørensen 2009). The teacher must demonstrate a setup that allows a flake to be detached in a way that facilitates the detachment of another flake, which in turn facilitates the detachment of the next flake, and so on. And the learner must practice to master this setup. It should be noted, however, that core maintenance does not presume any planning depth, that is, an understanding that the first flake in the sequence will result in the whole coming series of flakes. Since the technology builds on repetition, one would need only to have been taught, first, how to set up a core and knap a correct flake one at a time and, second, to understand how the detachment of a flake alters the core and in doing so facilitates the detachment of another flake.

The way we lay out core maintenance here is similar to how Moore (2010:18ff.) describes stone knapping built up by single basic flake units carried out sequentially. However, while Moore suggests that this can be achieved as a nonintentional result from static core morphology—and consequently views it as a nonintentional part of knapping—we see core morphology as dynamic and something that is intentionally maintained. As Harmand et al. (2015) have demonstrated, basic intentional stone knapping that predates Oldowan technology was performed without core maintenance being developed as part of the knapping principles. This implies that the geometrical relationships underpinning the basic flake unit can be understood and practiced without the knapping resulting in core maintenance, something we also see in later prehistoric stone knapping from different parts of the world (e.g., Högberg 2009; Knarrström 2001; Nishiaki 2000; Rosen 1997). Consequently, we see core maintenance as an intentional strategy that must be demonstrated for stable cultural transmission.

We conclude that transmitting Oldowan technology requires imitation, including rehearsal, together with active teaching in the form of evaluative feedback, drawing attention, and, most importantly, demonstration. Through imitation and evaluative feedback, the learner can learn to choose a suitable raw material or hammer stone. The teacher will scaffold the learning by enhancing an appropriate knapping place. Core maintenance requires the teacher to draw attention to a suitable striking platform area on the core. Drawing attention and demonstrating facilitate the learning of an appropriate way to hold the core and the correct movement of the arm and hand holding a hammer stone when detaching a flake. The upshot is that Oldowan technology could not be transmitted between generations without intentional teaching, involving drawing attention and demonstration.

It should be noted that when we claim that demonstration is necessary for transmitting the Oldowan technology, we do not exclude that single skilled individuals could discover the practice of core maintenance by themselves. In fact, somebody must have made such a discovery before the technology could be taught. Our claim is rather that demonstration is needed for transmitting the technology to other individuals, without which it is not possible to reliably maintain the technology within a culture. (Henrich [2004] argues that, apart from teaching capacity, another factor involved in transmission success is population size.)

Some researchers have claimed that the behavior of Oldowan tool-producing hominins can be accommodated within the ape adaptive grade (Wynn et al. 2011). Wynn et al. (2011:195) write, "Apes had been very successful and very varied for millions of years before the advent of flaked stone technology, and it is likely that several were tool users. It is within this context that the Oldowan should be understood." Their main supporting evidence for the claim is the knapping behavior of the bonobos Kanzi and Panbanisha, both trained to knap by human knappers.

However, Toth et al. (1993) show that Kanzi did not achieve the skill level of Oldowan knappers. Acknowledging differences in anatomy and motor control (Key and Dunmore 2015; Williams, Gordon, and Richmond 2014), we submit that there is a more fundamental difference between the apes and the hominins. The bonobos never voluntarily rehearsed knapping as it had been demonstrated to them. Donald's (2012) thesis concerning the apes' lack of voluntary retrieval of memories entails that they cannot rehearse. Kanzi engaged in the kind of knapping demonstrated to him only when encouraged by his teachers or when the reward box was loaded. When knapping alone, he invented his own techniques; for example, he preferred throwing the core on the cement floor, rather than knapping, to create sharp flakes (Toth et al. 1993). Hence, Kanzi emulated the human knapper. He did not rehearse the teacher's actions by repeating the demonstrations that were provided. In particular, no signs of core maintenance are visible in Kanzi's knapping.

There is also a fundamental difference between Oldowan and ape stone tool use in relation to the intentions involved. Apes' use of their stone toolkit gives an immediate food reward: a nut to eat. In Oldowan knapping, a hammer stone is used to hit a core to produce a tool that might be kept and transported for later use (Braun et al. 2008). This is a case of planning for future goals (Gärdenfors and Osvath 2010; Osvath and Gärdenfors 2005), also called prospective planning or mental time travel (Suddendorf and Corballis 2007).

The evolution of autocuing, in the sense of Donald (2012), is presumably a gradual process, but already for Oldowan tools, modern humans need practice to master their manufacture (Nonaka, Bril, and Rein 2010). Kanzi is conditioned to knap, yet he does not exhibit any signs of autocued memories. Such memories postulate a skill system embedded in a social network of toolmaking practices in which adaptation for learning to refine skill has evolved (Donald 2012:280). Therefore, we disagree with Wynn et al. (2011) and view Oldowan technology as being beyond the reach of extant apes but presumably within the reach of extinct hominin species other than *Homo* (see Hecht et al. 2015 for a similar conclusion).

It has been suggested that early hominins discovered the mechanisms of stone flaking as a result of flakes that unintentionally fractured from anvils used for nut or bone cracking (Marchant and McGrew 2005). How this unintentional flaking was transformed into basic intentional tool production, as reported by Harmand et al. (2015), and more elaborate tool production with accompanied teaching is not known. In a large-scale experimental study, Morgan et al. (2015) tested how different social-learning mechanisms could be used to transmit Oldowan stone-knapping techniques. They conclude that cultural reliance on Oldowan tools generated a selection mechanism that favored teaching (Morgan et al. 2015:3). The levels of intentional teaching we have relied on here—drawing attention and demonstrating—and their interaction with autocued memory increase our understanding of how this system might have worked.

Teaching Late Acheulean Hand-Axe Technology

We now turn to our second thesis, that learning late Acheulean hand-axe technology requires communicating concepts. Hand-axes are found in Africa, Asia, and Europe and are associated with *H. erectus*, *Homo heidelbergensis*, and late Middle Paleolithic classic Neanderthals (Hodgson 2015; Li et al. 2014; Lycett and Gowlett 2008; Ruebens 2013; Shipton 2013). In terms of morphology (an oval bifacial shape), hand-axes show extraordinary stability over time, even if variation in symmetry is reported (Cole 2015). At the same time, one finds distinct refinement through the long time span of the Acheulean; late hand-axes are generally thinner and more elaborately knapped than earlier ones (Diez-Martín et al. 2015; Shipton 2013; Stout et al. 2009). A comparison made over large geographical areas indicates noteworthy differences (Davidson and Noble 1993; Li et al. 2014), in particular between late Acheulean hand-axes from Europe (Stout et al. 2014), eastern Asia (Li et al. 2014), and Africa (Beyene et al. 2013). Our discussion here mainly concerns European examples (Stout et al. 2014).

Late Acheulean hand-axe technology requires advanced levels of intragenerational transmission of skills and knowledge (Shipton 2013). Beyond basic tasks such as accessing proper raw material and being accustomed to a range of working tools and positions, the production process builds on entangled sequences of techniques and methods that, in part, repose on knowledge of specific concepts. These concepts cannot be learned by attempts to copy the sequences of techniques and methods used (Mahaney 2014) or solely by individual (trial-and-error) learning (Lycett et al. 2015).

A number of theoretical models have been suggested for the cognitive capacities necessary to perform this technology, typically dealing with variation and complexity of techniques and methods involved (Rugg 2011) or with aspects of symmetry and the ability to cognitively visualize and process a three-dimensional image (Lycett et al. 2015; also see Hodgson 2015 for a recent review). We recognize the importance of these models and expand on them by focusing on the techniques and methods necessary to perform platform preparation in particularly crucial phases of the production process (for other relevant concepts, see Read and van der Leeuw 2008). This means that we go beyond analysis of morphology and symmetry (Cole 2015; Lycett et al. 2015) to discuss a specific technological high-level subgoal (see "Communicating Concepts"; fig. 1).

Platform preparation is systematic flaking (beveling) and abrading (grinding, rubbing, shearing) applied to the tool with the intention to shape the platform and alter the platform angle to support "on-edge" marginal percussion (Mahaney 2014). It is the key technological innovation necessary to produce the thinner late Acheulean hand-axes (Stout et al. 2014). The concept of a platform is central for the subgoal structure of the technology (fig. 3). However, as a high-level subgoal in action hierarchies, platform preparation is difficult to perceive without having this concept (Stout et al. 2014).

It must be explained to the learner how platform preparation isolates and alters the platform angle on the area from which a flake is to be detached. The learner must therefore be able to envisage the pattern that constitutes an appropriate platform before it exists. When the importance of the angle is understood by the learner, this must be supplemented with showing how to prepare the platform to get it right and how to apply force to the piece in relation to the angle, so that the intended type of flake can be detached. The teacher must also be able to explain why the learner needs to detach that particular kind of flake (a so-called thinning flake), enabled by platform preparation. This requires that the teacher be able to break down the sequences into low- and high-level subgoals and to highlight these in order to convey the specific concepts the learner needs to master the technology. To achieve this, the idea of how to make the artifact has to be deconstructed (Gowlett 2011). Then the teacher must help the learner to put the production process together again, so that it may be internalized as his/her own knowledge. The teacher must adopt a holistic view of the complete production process and be able to teach the process in such a way (Malafouris 2010). This includes explaining the concept of a platform as well as the temporal patterns involved in the action hierarchies necessary to prepare it. And, since the production process is a multivariate construct (Gowlett 2011), different phases in the tool production require different approaches to set up a platform. Technological variation requires teaching how the production process is materialized in a variety of opportunities and con-

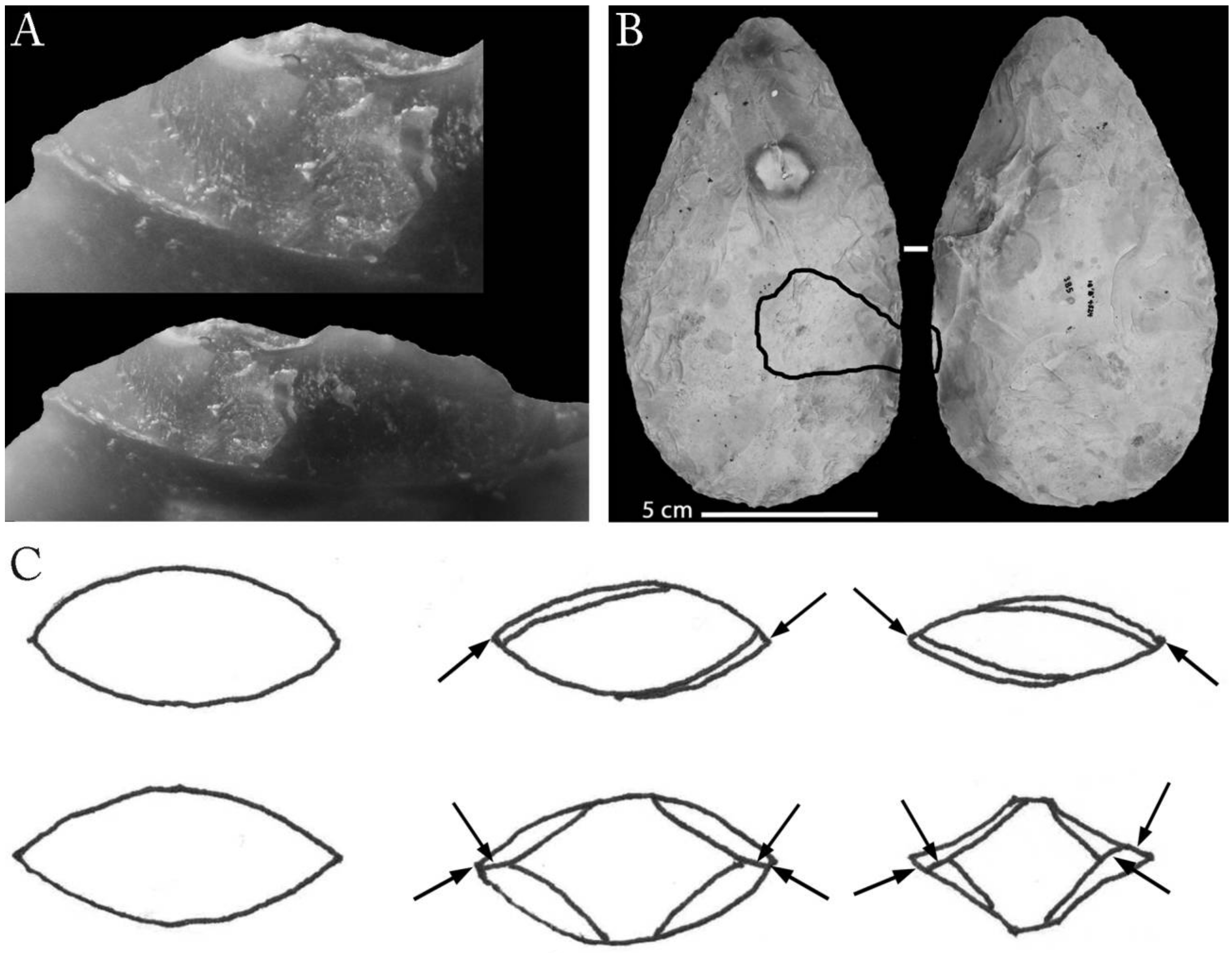

Figure 3. Late Acheulean platform preparation, techniques, and production sequence. *A*, A prepared platform on a flake from Boxgrove. The platform is prepared by detaching small flakes at the edge of the tool preform. The negative scars of these flakes can be seen on the platform in the photo (revised from Stout et al. 2014). *B*, An imaginary thinning flake has been drawn onto a hand-axe from Boxgrove (to the left), and on the opposite side of the hand-axe the placement of the platform of that thinning flake is drawn (to the right). It is on this side that platform preparation has to be applied (photo revised from Stout et al. 2014). *C*, Using on-edge percussion allows the knapper to reduce thickness while simultaneously keeping the length and width of the tool, resulting in a tool with a lenticular cross section. This makes it possible to produce a late Acheulean hand-axe with substantially less body and weight and a more regular and coherent working edge than early Acheulean hand-axes. With off-edge percussion, the thickness is not reduced in the same way, and the length and width of the tool change significantly throughout the production sequence, resulting in a diamond-shaped cross section. Arrows mark where the hammer hits the edge. A color version of this figure is available online.

straints provided and enforced by the size, shape, and quality of raw material used and the knapper's ability to meet these opportunities and constraints.

To demonstrate the importance of understanding the concept of a platform, we here expand on results presented by Putt, Woods, and Franciscus (2014). In an experimental study, they show that the overall shape of a bifacial stone tool and the concept of symmetry during stone tool reduction can be learned by both verbal and nonverbal teaching. In the experiment, two groups of novices were instructed to produce a rough bifacial tool resembling an early Acheulean hand-axe. One group was instructed by demonstration and verbal instruction and the other by demonstration only (also see Toth and Schick 1993:357).

The verbally instructed group tried to copy the teacher's actions. Since they had been verbally instructed about the importance of platform preparation, they devoted time to setting up striking platforms. This indicates that they had perceived the temporal patterns, subgoals, and hierarchies in the technology. During this group's early stage of learning, however, setting up platforms was difficult. Lacking sufficient practice, they were not able to fully convert their knowledge into successful knapping. The nonverbal group did not understand the concept of a platform. Therefore, this group aimed to make their product resemble those produced by the teacher. Hence, rather than trying to conceptualize the particular subgoals that pertained to the sequences of the actions the teacher performed, this group showed evidence of emulation.

The variation in teaching influenced the learning of the two groups. The nonverbally instructed group did not fully understand the necessary planning hierarchy involved in the technology. The verbally instructed group, however, understood the concept of a platform and its relevance to the technology. They could implement it, at least partially, in their knapping strategies.

These results are important for understanding the teaching that is necessary to produce a late Acheulean hand-axe. By gaining experience through practice, the verbally instructed group will improve their skills, relying on their knowledge of the high-level subgoal of platform preparation. Further instructed, they will be able to transform the rough bifacial tool they were taught to produce into a more elaborate shape. In contrast, the nonverbal group will have a hard time improving their knapping skills, since they do not sufficiently understand the relevant concepts. The conclusion is that to teach late Acheulean hand-axe production, the teacher must communicate displaced concepts (Hockett 1960). In contrast, the previous levels of intentional teaching we have presented require only teaching based on communication about perceivable entities. In support of our statement that the Acheulean technology is cognitively more demanding than the Oldowan, an experimental study by Stout et al. (2015) shows that late Acheulean toolmaking affects neural activity and functional connectivity in the dorsal prefrontal cortex to a significantly higher degree than Oldowan toolmaking.

It has been suggested that late Acheulean hand-axes acquired their shape "as luck would have it," through the sequencing of core reduction. On the basis of a critical discussion of shape variability, Dibble (1989) speculates that the regular shape of Acheulean hand-axes may be a result of technological constraints as well as archaeological methods of classification, hence having "nothing to do with mental templates of the hominids who made them" (Dibble 1989:424). In his study of "grammars of action," Moore (2010) also argues that complicated knapping sequences can be performed by applying simple flake units in long chains of actions, referred to as "mindless flaking" (Moore 2010:34). In contrast to this, we view platform preparation as a high-level subgoal in action hierarchies. This goes beyond a discussion of shape as presented by Dibble (1989). Platform preparation is close to Moore´s (2010) elaborate flake units but differs in one significant way. While Moore (2010) sees stone tool production as a result of mechanically adding actions together, we claim that this is not sufficient, since it does not account for the subgoal structure that must be followed in the production.

Platform preparation is present in the late Acheulean findings from Boxgrove (Stout et al. 2014), dated to about 500,000 years ago, associated with *H. heidelbergensis*. In an analysis of Late Middle Paleolithic hand-axes, Ruebens (2013) has presented specimens from about 100,000 years ago associated with classic Neanderthals, knapped in a way that indicates the use of platform preparation. One of the earliest findings of elaborately knapped Acheulean hand-axes comes from the Konso Formation in Ethiopia. These are dated to about 850,000 years ago, are associated with *H. erectus* (Beyene et al. 2013), and are knapped in a way that indicates the use of platform preparation. However, no technological study of the hand-axes described by Ruebens (2013) and Beyene et al. (2013) has yet been performed. If our analysis is correct, teaching by communicating concepts, via words or gestures, was practiced in periods that predate *Homo sapiens*. This does not entail that a full linguistic capacity was in place, but at least that the late Acheulean or late Middle Paleolithic toolmaker could refer to nonpresent entities.

Conclusion

The evolution of *Homo docens* can be discussed as something that emerges gradually, as a behavioral development shaped through the interaction between nature and nurture (Donald 2001; Högberg and Larsson 2011; Lombard 2012; Zilhão 2007). Sterelny (2012:8) describes this as "positive feedback loops" between social complexity and individual cognitive capacity. In line with Sterelny (2012:xii), our starting point is that human evolution must be thought of as multifactorial, that a diverse set of coevolutionary factors over a long time has resulted in the evolved *H. docens*, as we see ourselves today (Langbroek 2012). Here we have investigated one factor—teaching.

The key theoretical contribution of this article is the analysis of a number of levels of intentional teaching and their cognitive and communicative requirements, as summarized in table 1. By breaking down teaching into several levels and discussing them in the context of selected archaeological finds, we have been able to demonstrate how different technologies depend on increasing sophistication in the levels of cognition and communication required for teaching them.

Our analysis also has implications for the evolution of language. Evaluative feedback can be given without any iconic or symbolic communication systems. Attention drawing and demonstration rely on the use of intentional gestures but not on iconic or symbolic communication. Transmitting concepts, however, requires detached communication, at least by iconic means, but a symbolic system would be more efficient. If our analysis of the late Acheulean technology is correct, it follows that detached communication was in place among the hominins at least 500,000 years ago. Similarly, explaining relations between concepts requires detached communication, and here a symbolic system would be even more efficient.

The general effect of teaching is that it speeds up and improves individual learning. Following the levels we have presented, *Homo sapiens* exhibits more advanced forms of teaching than other species. The ordering of the levels of mind reading corresponding to different levels of teaching presented here fits well with the evolutionary ordering proposed in Gärdenfors (2007) and with developmental progress in human children. Nonhuman species, to varying degrees, display evidence of copying (emulation and imitation), enhancement, and evaluative feedback, and a few primate species may exhibit intentional evaluative feedback. The evidence for teaching by drawing attention or demonstration is, in nonhuman animals, so far meager.

In contrast, the hominin line shows, already at 2.6 Mya, clear signs of intentional teaching. Our first empirical thesis has been that teaching by demonstration (level 3) is necessary to maintain core-maintenance Oldowan technology. The second thesis is that late Acheulean hand-axe technology requires communication of concepts (level 4), for example, the concept of a platform on a tool preform as part of a high-level subgoal hierarchy in the production sequence. Teaching, as we have discussed it here, allows for stable transmission of technology between generations. If teaching by demonstration or communication of concepts is accepted as a criterion for intentional teaching, it follows from our analyses that *H. docens* clearly preceded *H. sapiens*.

Acknowledgments

We gratefully acknowledge support from Stellenbosch Institute for Advanced Studies; the Swedish Research Council, for support for the project "The Materiality of Education and Social Learning within the Evolution of Mankind" (dnr 721-2014-2100); and the Linnaeus environment "Thinking in Time: Cognition, Communication and Learning." We also want to thank the participants in the workshop "How Did *Homo sapiens* Become *Homo docens*? On the Evolution of Social Learning and Teaching" and the seminar at Lund University Cognitive Science, where earlier versions of this material were presented. Furthermore, Rudie Botha, Francesco d'Errico, Ivo Jacobs, Arne Jarrick, Lars Larsson, Marlize Lombard, Deborah Olausson, Mathias Osvath, John Parkington, Tomas Persson, Mats Rosengren, Björn Sjödén, Slawomir Wacewicz, and Thomas Wynn have generously commented on earlier versions of the manuscript. We also thank Jan Apel and Dietrich Stout for kindly letting us use their photos. Finally, we thank three anonymous reviewers for very helpful comments on earlier versions of the article.

Comments

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Is There an Evolutionary Hierarchy of Intentional Pedagogy?

The authors have performed a valuable service in providing this comprehensive review, and I am in agreement with much of what they say. My brief comments concern their objective of developing an evolutionary hierarchy of teaching, in which each successive level of mastery represents a hypothetical evolutionary step in the direction of fully modern *Homo docens*.

Their core hypothesis is that primates do not have "intentional" pedagogy, whereas humans do, and that this capacity first emerged in archaic human ancestors long before the evolution of *Homo sapiens*. This seems a solid conclusion; primates do not teach one another by accommodating their actions to the learner, whereas humans actively influence one another and rely heavily on a sophisticated pedagogical environment that guides learning at every opportunity. Sometimes this dependency is greater than we might expect; recent evidence reviewed by the authors suggests a counterintuitive conclusion: that highly educated, anatomically modern humans cannot learn to make Oldowan tools without deliberate and significant pedagogical guidance. Primates are not able to achieve this level of teaching at all, but evidently *Australopithecus afarensis* was already able to do it several million years ago; Oldowan stone tools were used in butchering game as early as 3.4 Mya (McPherron et al. 2010). So we, along with our ancestral species, have been teachers for quite a while.

One of the authors' key assertions is that teaching evolved in several stages, or "levels," before the emergence of language and that the more advanced skills needed for Acheulean tool manufacture indicated the presence of an even higher level of pedagogical skill in *Homo erectus* than earlier hominins had mastered in transmitting Oldowan toolmaking skills. The reason for this conclusion is that teaching how to make the more complex Acheulean tools entailed not only a capacity for demonstrating a specific set of steps but also the effective communication of abstract concepts—in the case of making handaxes, the concept of preparing a core.

However, in my view this assertion is not entirely convincing. The teaching of Acheulean toolmaking may in fact require a higher pedagogical capacity than the lower one supposedly needed for teaching Oldowan skills, but it might also simply reflect a bit more of the same, in both teacher and learner, rather than a qualitatively new stage of pedagogy. A general improvement in key executive functions such as working memory, multifocal attention, and temporal integration might suffice, and the authors acknowledge this possibility. They also concede that language would probably not be necessary to communicate a concept such as preparing a core, but in that case the necessity of their second stage is left somewhat unresolved.

It is also questionable whether teaching how to prepare a core can properly be called a "concept" in the sense normally used in cognitive psychology. Preparing a core is a complex motor schema, no doubt. But is preparing a core any more abstract as a motor schema than, for example, the complex sequence of operations Byrne and Russon (1998) observed in gorillas as they were learning how to safely eat nettles? The gorillas learned this complex pattern by what Byrne and

Russon called "program-level" imitation. Granted that preparing a core is a tangible intermediary goal in a complex sequence of actions that are not telegraphed either by the raw material (stone) or by the shape of the final product, such a sequence does not appear to be qualitatively different from the program-level sequences demonstrated in gorillas. In the latter case, since active pedagogy was virtually absent, the onus was more on the learner than on the teacher-demonstrator.

This is the nub of the shift from the traditional emphasis on the learner to the more recent emphasis on the teacher: the responsibility for learning is now shifted, perhaps too much, to the teaching environment and away from the learning process. There is a danger inherent in this shift of emphasis, the same danger inherent in learning research but in the opposite direction: that the other element in the teaching-learning dyad is deemphasized too much. It also raises a real possibility that the learners in these experimental demonstrations of stone toolmaking, who are usually a highly educated group, have been trained out of the habit of observational learning and have developed a stronger habit of depending too much on explicit instruction. Perhaps subjects can learn not to learn in certain ways, and, unless liberated from their pedagogical expectations, they are locked into a teaching paradigm. Until this possibility is tested, we cannot be sure that Acheulean toolmaking skill really demands such a qualitative improvement in teaching methods.

This reservation reflects a key challenge facing any evolutionary theory that tries to fill in the finer gradations of human cognitive evolution. We do not have enough information on intervening species to make such fine distinctions, and archaeology alone will never provide the kind of detail we would need to thoroughly test such proposals. We can establish mimesis as one very basic level of representation that must have existed very far back in time; and spoken language, clearly on another level, seems identified with the much later evolution of sapient humans. But the finer shades of the transitions between the first and second stages are still very hard to establish with any certainty. Perhaps at some point paleogenetics will provide us with better tools.

One closing point: modern humans are speakers, used to settling communicative issues verbally as well as mimetically. The authors do not claim that *H. erectus* had language, but then what does their proposal for a higher "communication of concepts" level amount to? Is it a loose combination of demonstrations, pointing, eye contact, and approving/disapproving grunts, all driven by the teacher's grasp of the student's growing mastery? Seen from the teacher's standpoint, that is primarily a significant challenge in evaluating the student's performance and in mind reading, but it does not seem very different from the first level in terms of the activity of teaching, except that the sequence being learned is a bit more removed from the properties inherent in the raw material and requires finer guidance of attention and possibly a more effective grasp of the student's working memory capacity.

Or are they implicitly postulating that some form of language must have existed at this early date? I have suggested (Donald 1993) that *H. erectus* might have had the lexical equivalent of home signs—protowords—essentially still a mimetic skill but far short of narrative, which relies on being able to tell an original story based on personal experience. However, the presence of home signs or protowords alone would not justify postulating a qualitatively new stage, in my opinion.

A final point: did pedagogy evolve directly in its own right, or did it come as part of a more general expansion of hominin cognitive skill? The authors conclude that the latter may well have been the case, and I heartily agree with that conclusion. The major cognitive innovation of humanity is our capacity for group learning and remembering, and pedagogy is an essential factor in guiding young learners into the labyrinthine complexities of human cultural networks.

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How Teaching Performance Develops

Gärdenfors and Högberg depict in a comprehensive way a plausible course of the evolution of teaching. In my comment, I draw attention to the developmental process of this characteristic human phenomenon.

Teaching is an intersubjective performance that comprises physical, mental, and behavioral aspects of two subjects, A and B, within a shared environmental or resource space (fig. 4*C*). While individual learning of subject A can take place in a nonsocial context (fig. 4*A*), simple forms of social learning by stimulus enhancement, nonintentional evaluative feedback, emulation, and probably simple imitation require a unidirectional social setting (fig. 4*B*), with learner A including the performance of model B into his/her learning environment. The different forms of teaching sensu stricto, however, require a mutual social situation (fig. 4*C*). In the ideal form, the naïve individual A perceives the expert individual B as a resource as well as a target of information; the expert delivers information about the new performance to be learned but also receives information about the needs of the naïve learner. The intersubjective performance of learning with teaching is a process that both subjects A and B have to train for individually, but they do so with the mutual assistance of teaching: the performance is self-enhancing.

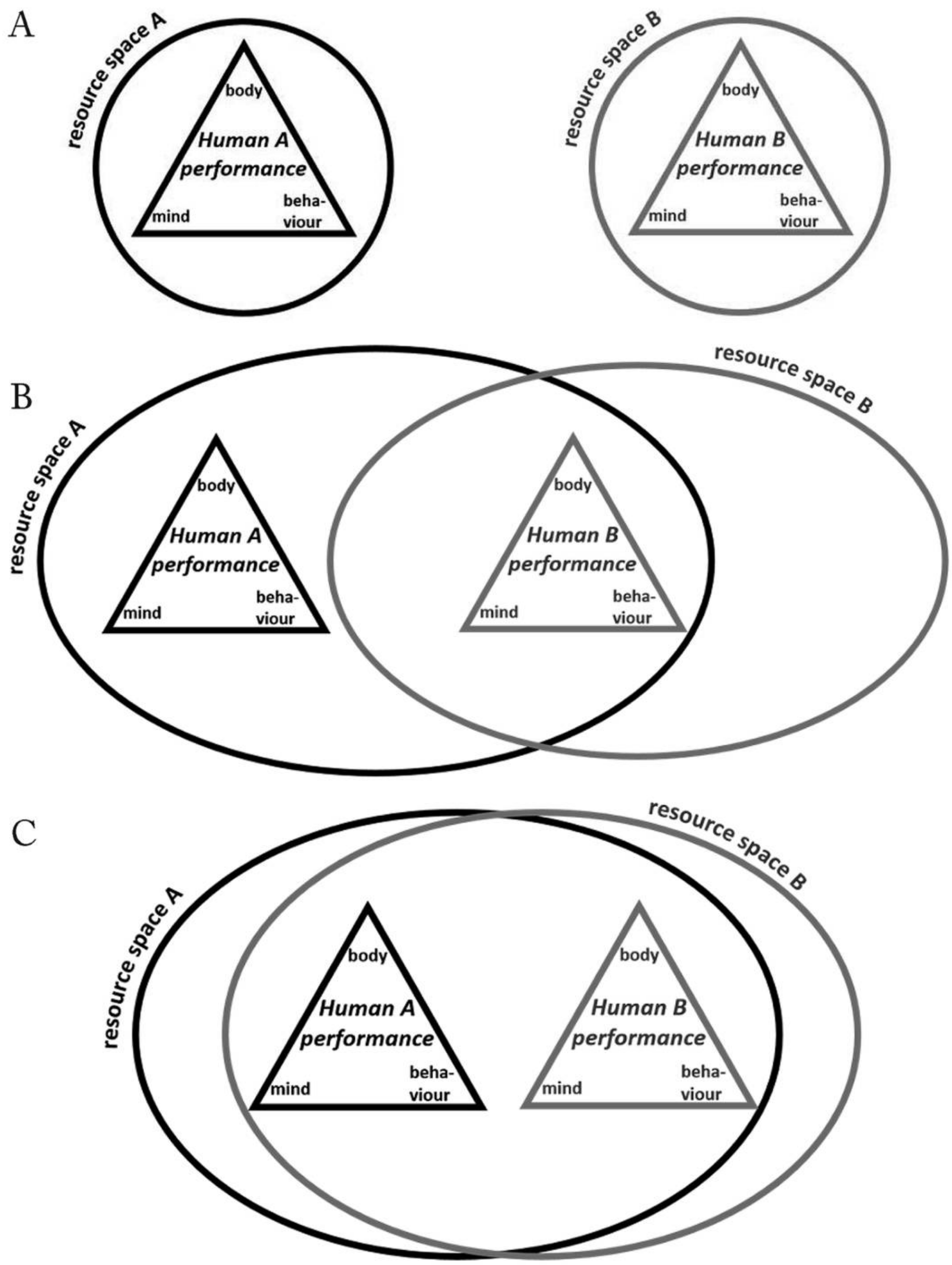

Figure 4. Different learning situations: nonsocial performance (*A*); unidirectional social performance (*B*), and mutual social performance (*C*).

A prerequisite of mutual-social performances is joint attention. In humans, joint attention is trained permanently from the beginning of individual life, by visual eye contact, by audiovocal interactions, and later including objects by give-and-take play and in combination with visual and audiovocal exchanges. The first directed initiative generally comes from older individuals, raising the attention of the newborn. Undirected gestural, mimic, or vocal utterances of the baby are answered; after some time the baby starts more or less directed utterances to provoke an answer. The greater the response that is provided, the more the baby will take social initiative. From very early on in life, human babies learn to refer to other individuals and include objects or other elements of the environment into the context of social exchange.

Advanced forms of imitation in human children, as in apes, probably do not come spontaneously but are a learned result of mutual repetition of behavior, which is also a training for the human ability to rehearse.

The intersubjective performance of learning with teaching comprehends different subperformances of the naïve and the experienced individual, including observation, reference to another individual's performance, and repetition. Natural pedagogy (Csibra and Gergely 2011) and theory of mind (Frith and Frith 2005) are undoubtedly beneficial to the teaching performance. Yet they are probably not prerequisites of the developmental process but rather outcomes. The teaching performance—that is, the subperformances—possesses three dimensions of development (see Haidle et al. 2015). In the evolutionary-biological dimension (A), the general anatomical and physiological range for physical, mental, and behavioral aspects of a certain performance has been formed by gene replication, mutation, natural and sexual selection, and genetic drift, among other aspects. Regarding the intersubjective performance of learning with teaching, humans developed in this dimension into curious and socially tolerant beings with many qualities fostering performances of material and social engagement. Through the ontogenetic-individual dimension (B) of development, the general range of the different physical, mental, and behavioral aspects of a performance are shaped individually by positive or negative experience. In individual lifeways, the subjects learn to cope with their environment, avoid harmful settings, or seek beneficial situations. They gain individual sets of experiences in encounters with elements of the specific resource space and with conspecifics, as well as other agents and objects.

If we consider the teaching performance, individuals experience, for example, joint attention initiated by one or several models with different frequency, intensity, and feedback of their own initiative. Some situations will be rewarding in physical, emotional/mental, or behavioral ways; others may cause distress. The individuals train their relationships and individual ways of interactions in this special form of encounter with conspecifics. The historical-social dimension (C) determines the way in which performances are focused; it marks the cultural range of a performance set in the historical-social context. The historical-social dimension narrows the range of variability given by the evolutionary-biological dimension but may broaden an individual's potential by relying on the additional experiences of other individuals within a specific time and group framework. Important for the teaching performance is, for example, the group-specific way of handling babies and young children. This provides the setting for early experiences of joint attention, or preferred forms of interaction, such as classroom and ex cathedra teaching.

The evolutionary-biological dimension (A) forms the basis of the ontogenetic-individual dimension (B) and the historical-social dimension (C), but the specifications of B and C within a group contribute to shaping the selective environment of further development in A. Thus, the foundations of forms of social engagement, such as joint attention, lie in the evolutionary-biological dimension, but their application creates an environment that fosters adaptations toward natural pedagogy and mind reading. Parallel to material engagement (Malafouris 2013), which shapes the physical, mental, behavioral, and environmental aspects of our exposure to the nonsocial world, social engagement is a catalyst and driving factor of the evolution of human social performances, with reference to *Homo docens* as delineated by Gärdenfors and Högberg. A characteristic of the development of human teaching is the combination of material and social engagement with active teaching as a new relationship to conspecifics. This broadens the learning environment and focuses the path of experiences.

Reply

We thank Merlin Donald and Miriam Haidle for their constructive comments. Donald questions our interpretation of the teaching involved in late Acheulean toolmaking. He asks whether platform preparation (Donald calls this "core preparation") is more abstract as a motor schema than the "program-level" imitations performed by gorillas in their preparation of plant food. Following Byrne and Russon's (1998) interpretation of the gorillas' behavior, he argues that if gorillas can learn such food-collecting schemas by imitation, then late Acheulean toolmaking can also be learned by imitation and our conclusion would be invalid.

Donald's challenge is interesting and worthy of a detailed analysis. Byrne and Russon's interpretation has been questioned by several commentators. Bauer (1998) points out that the food-preparing techniques show little variation and pass through a few bottlenecks: collecting whorl of leaves, collecting whorl of stemless leaves, folding nettle parcel, and putting the parcel into mouth. This sequence of intermediate states is the only one that gives a satisfactory result, and it can be learned by priming, without invoking imitation (Bauer 1998).

But even if the gorillas do not imitate at the program level, the question whether late Acheulean platform preparation could be learned by imitation remains. First of all, someone must have discovered how to do it. For this to happen, no direct teaching but experimentation was involved. The important question, however, is how the technology can be maintained in a culture over several generations without substantial drift. In our paper, we report on the experiment by Putt, Woods, and Franciscus (2014), where two groups of novice knappers were instructed to produce a tool resembling an Acheulean hand-axe, one group by demonstration, the other by demonstration and verbal instruction. The result was that those instructed by demonstration alone tried to make hand-axes that were as similar as possible to the models, but they never understood the concept of a platform nor its importance in the process as a high-level subgoal. Those instructed by demonstration and verbal explanations learned the concept of a platform and tried to perform accurate platform preparation as a subgoal in their knapping. Platform preparation is, however, difficult to master, and since the practice time was limited, the end results were not better than those of the other group. Our conclusion is that the group that has been taught the concept of a platform has a higher potential for developing their expertise in the late Acheulean hand-axe production and that imitation alone is not sufficient to learn platform preparation. An important factor from an evolutionary point of view is also that learning becomes more efficient when the learners are taught the relevant concepts.

We find Haidle's distinctions between nonsocial, unidirectional social, and mutual social learning situations helpful. Her claim that successful learning depends on establishing rich social relations between teacher and learner is an important addition to our analysis. Donald asks whether pedagogy evolved directly or is part of a more general expansion of human skills. In our paper, the focus is on the role of the teacher and the teacher's intentions, but we agree that the interactive dynamics between the teacher and the learner is also central and should be further investigated.

We agree entirely with Haidle's emphasis on the centrality of theory of mind in mutual social learning. In particular, she correctly points out that achieving joint attention is a prerequisite for the mutual social situation. In addition to joint attention, Csibra and Gergely (2009:149) argue that "human communication is often preceded, or accompanied, by ostensive signals that (i) disambiguate that the subsequent action (for example, a tool-use demonstration) is intended to be communicative and (ii) specify the addressee to whom the communication is addressed." Gergely, Egyed, and Király (2007) provide experimental evidence for the importance of the ostensive nature of the teacher's behavior. In brief, extensions of mind-reading capacities are crucial for the evolution of pedagogy.

Donald also asks what is involved in the communication of concepts. We emphasize that communicating concepts is fundamentally making the learner see relevant patterns, for example, the shape of a platform in knapping. Also, learning categorizations of plants or spoors of animals involves recognizing new patterns. Symbolic language need not be involved in this process, but forms of gesturing are often sufficient. One point we did not make in the article is that the teacher can check that the learner has grasped the relevant patterns if the learner exhibits the right categorizations when faced with practical problems. As Haidle points out, this feedback to the teacher is an important element of a teaching culture.

—Peter Gärdenfors and Anders Högberg

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