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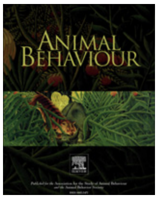

Commentary

What are we learning from teaching?

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A man belonging to the Aché tribe sits down on a long log in the clearing of his forest camp in a Paraguayan Forest Reserve to make a bow. He selects that particular log because it affords a place for another person to sit side-by-side with him. He calls to his son as he begins to work, and his son comes to sit down next to him, watching. Carving a notch into the top of the wooden shaft, the man does not speak but does shift position from time to time so that his son can better observe the process. He methodically wraps the sinew string around the notch in the bow and covers it with a sticky resin. By late afternoon, the father has created a new bow and the son has learned something: the steps involved in making a traditional hunting weapon.

Children in a classroom are learning to write in cursive. The teacher projects the cursive letter models on a Promethean whiteboard and demonstrates how the letters are formed. The students then begin to practise copying the models on their own. One child is having particular difficulty. The teacher walks over, cups the pupil's hand in hers and moulds his actions to the correct form. She only helps this one student; she never had to do so with any of her students during the previous year.

These and similar interactions take place so frequently across the globe as to be unremarkable to the average person. Yet their significance with regard to the evolution and spread of human technological and social culture cannot be overestimated. Our species-wide proclivity to rely on social learning, in particular imitation and teaching, is thought to have first led to the emergence of culture in our hominin ancestors and to support cultural transmission up to the present day (Boyd & Richerson 1996).

Humans have sophisticated cognitive powers that both allow us to imitate a complicated sequence of actions and, in addition, to understand the way each of those actions works towards the final goal, so that the sequence may not only be copied but also improved upon (Boyd & Richerson 1996; Byrne 2006). Few other animals are thought to have these capabilities. What is more, we humans have a psychology that drives us to share our intentions, a psychology that allows us to collaborate with others to an unusual degree (Tomasello et al. 2005). This motivation to share information and to peer into the minds of others has undoubtedly favoured our penchant for social learning, especially teaching (Burkart et al. 2009; van Schaik & Burkart 2010). It is one thing for an animal to gain information from another more informed conspecific, as the more knowledgeable individual goes about his or her normal activities. Social learning of various types is common throughout the animal kingdom. It is quite another for a knowledgeable individual to alter his or her behaviour in such a way as to actively help another to learn what the knowledgeable individual knows: that is, to teach.

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A striking aspect of some forms of teaching in humans is the intentional two-way communication that occurs between teacher and pupil. Teaching can be a very effective means of information transfer when the instructor makes moment-to-moment adjustments, generated by constantly monitoring the knowledge state of the pupil, and offers appropriate assistance when the pupil experiences difficulty or appears to lack the necessary information to complete the task at hand (Strauss et al. 2002; Gergely & Csibra 2006). For instance, when Mayan children teach their younger peers how to do household chores, they rely more on demonstration than on verbal explanation, and they offer encouragement and scaffold the task into component parts when their young pupils do not complete the activity correctly (Maynard 2004). Thus, across cultures, human teachers, even very young ones, not only recognize the skill deficits of others, but also actively work to close the knowledge gap between themselves and their pupils (Wood et al. 1995; Strauss et al. 2002; Hewlett et al. 2011). Of course, human instruction is diverse and not every instance necessarily consists of such back-and-forth assessments. An elementary school teacher who presents information to an entire classroom, as in the cursive letter-writing example at the beginning of our paper, bases the demonstration on the average knowledge of like-aged pupils without attempting to gage the abilities of individual students, at least initially. But assessment of skill deficits and efforts to target specific knowledge gaps are often incorporated into human teaching, and account for its great flexibility.

Early investigators into the evolution of human imitation, teaching and culture discovered that comparative models were surprisingly hard to come by. Although our ape relatives have some aspects of a theory of mind (Call & Tomasello 2008) and can learn new processes by imitating the actions of conspecifics (Whiten 1998; Byrne 1999; Hobaiter & Byrne 2010), they do not regularly engage in teaching. Young wild chimpanzees, *Pan troglodytes*, take years to learn the efficient use of tools for foraging. It can take up to 4 years for adolescent chimpanzees in the forests of western Africa to become proficient at cracking open hard-shelled palm nuts with natural stone hammers and anvils. Nevertheless, adults rarely intervene to correct hammering techniques or to encourage the young, although they regularly allow them to scavenge nutmeat and take over their tool and hammering sites. Only twice has a mother been observed to provide deliberate nut-cracking instruction, in decades of research at multiple western African sites (Boesch 1991). Eastern African chimpanzee populations have shown even less evidence for teaching. One common tool-use technique of wild chimpanzees is to modify thin branches or to strip the midribs of large leaves to insert in termite mounds in order to extract the clinging termites (Goodall 1964; Whiten et al. 1999). In the Gombe National Park, when females fish for termites, their young offspring often sit beside them, paying close attention. However, Lonsdorf (2006) reported that even though mothers do allow their offspring to take tools and termites from them, in 143 days of termite-fishing observation no adult was ever seen to actively guide a youngster's foraging efforts.

Ewer (1973) offered preliminary evidence for teaching in wild carnivores, but for years controversy reigned as to whether nonhuman animals, particularly nonprimates, could understand what other individuals did or did not know and thereby teach in the sense that humans teach, especially with regard to the process of assessing the knowledge state of a pupil and then aiming to fill the specific informational gap (Premack & Premack 1996; Strauss et al. 2002). Caro & Hauser (1992) circumvented this problem by developing an operational definition for teaching; teaching then could be measured by what one could observe, rather than first having to tackle the tricky question of the mental attributes of the study subjects. The criteria of Caro & Hauser's (1992) definition are: (1) a knowledgeable individual A alters its behaviour only in the presence of an inexperienced individual B, (2) A incurs a cost, or at least no immediate benefit, (3) the demonstrator's action encourages or punishes B or provides B with appropriate experience, and (4) as a result, B either learns more quickly or efficiently or acquires knowledge that it might not otherwise learn. The utility of this functional definition is that teaching can be said to occur when a tutor effectively modifies its behaviour so that an inexperienced pupil learns something new, whether we understand the tutor's intentions or not. In other words, the definition permits the question of whether teaching occurs to be separated from the issue of what mechanisms are used to support it. Caro & Hauser's (1992) article launched the modern field of animal teaching. None the less, we believe that the ensuing single-minded attention to the functional definition, to the virtual exclusion of the cognitive processes that drive the behaviours, now may be hindering our understanding of the phenomenon.

Recent reviews show that teaching, as defined by the four criteria, occurs only rarely but in diverse taxa and thus the behaviour must have evolved independently several times (Hoppitt et al. 2008; Thornton & Raihani 2008). Examples of teaching include species for which complex cognitive mechanisms are highly improbable. All of Caro & Hauser's (1992) criteria for teaching are satisfied by a species of ant, *Temnothorax albipennis*, when informed individuals run in tandem to guide naïve followers to a new food source (Franks & Richardson 2006). What is more, the ant leaders slow down and the followers speed up when the distance between leader and follower gets too great, which indicates that not only do leaders encourage the naïve individuals to follow (criterion three), but that two-way communication is occurring, reminiscent of the feedback typical in human teaching. Tandem running shows the impressive power of natural selection to mould even very intricate fitness-enhancing behaviour and thus helps us to understand the contexts under which teaching may evolve: but the ants do not shed light on the evolution of the capacity for the deep social understanding that is common in human teaching (Leadbeater & Chittka 2007).

Likewise, Thornton & McAuliffe's (2006) study regarding the development of hunting in wild meerkats, *Suricata suricatta*, convincingly demonstrated that all of Caro & Hauser's (1992) criteria are met by adult meerkats, which first bring dead or disabled scorpions to young pups and then later offer live scorpions with stingers intact to older pups. Furthermore, adults often nudge prey repeatedly when pups do not attempt to interact with the proffered food, and even further disable it if a pup has difficulty with the live prey item. As a result of the experience, the pups more quickly learn to kill dangerous prey. Field experiments revealed, though, that pup age was the determinant for whether adults would provide live or dead scorpions; adults did not assess the foraging competencies of individual pups to tailor their provisioning behaviour accordingly (Thornton & McAuliffe 2006).

Strong evidence for animal teaching, such as these studies provide, can help us to understand the ecological underpinnings of assisted social-information transfer (Thornton & Raihani 2008); but they describe phenomena that are not necessarily equivalent, even nominally, to most human teaching. What is more, even unambiguous cases of teaching in humans do not always meet Caro & Hauser's (1992) criteria. Take the first example in this article's opening paragraph. The bow-maker chooses his place to sit because it will allow his son to observe the process. He also frequently shifts his position during bow construction to accommodate his son. Thus, Caro & Hauser's (1992) first criterion, that the behaviour shall occur only in the presence of a naïve individual, is met; that is, as long as the behaviour of interest is defined as the entire suite of behaviours and not just the bow-making process. The man invites