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Introduction: Teaching and its Building Blocks

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This editorial is intended to provide a broad overview of current approaches to teaching as a cognitive ability, as well as a background to the articles of the present special issue. The contributions are from the fields of developmental psychology, archaeology, anthropology, comparative cognition, robotics and artificial intelligence. So broad is the range of disciplines that need to be mobilized in order to characterize and understand human teaching.

1 Aims

The main goal of this introduction to this Special Issue is to suggest what basic building blocks of teaching may be. The route we chose to achieve this goal is to explore several approaches to teaching, and see how they provide insights into these basic building blocks.

But before presenting these approaches, we first justify our choice to seek basic building blocks of teaching. Strauss (2018), without denying the importance of basic building blocks, claimed that a helpful way to come to better understand teaching is to attempt to determine its complexity. That complexity could serve as a map of its components that allows us to do backward engineering to get at teaching's basic building blocks. And that further enables us to reverse course to seek these building blocks' developmental trajectories, as they eventually allow us to describe human teaching's complexity and its fundamental functional units.

All of that having been said, what could basic building blocks give us that is of importance? Several reasons can be offered for their significance. One is that once we

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have determined what they are, we can seek their origins in human infants' cognition and then study their developmental trajectories. Second, we can determine which basic building blocks are common to teaching among humans, nonhuman animals, computers that teach and any other teaching systems. In addition, they have significance for biological evolution in that we could describe which building blocks appear in non-human animals and see which get added on as we move up the phylogenetic ladder. This gets at the phylogenesis of teaching. Yet a fourth reason for their importance is that they can help us define the elusive concept of teaching. That having been said, knowing what teaching's building blocks are doesn't mean we have a definition of what teaching is. We also have to know how these components work and how they produce acts of teaching. But deciding what the building blocks are is a good first step to finding a definition of teaching.

In this introduction, we look at four basic building blocks we believe are fundamental to teaching. They do not exhaust the list but they are central for it to happen. They are *responsiveness*, *relevance*, *information-giving* and *motivation*. We elaborate on them below.

In pursuing a better understanding of teaching, we look at both practical and theoretical aims. On the practical side, research in cognitive science has been valuable in inspiring better practices in education. However, although progress has been made in analyzing, say, the neurocognitive mechanisms underlying learning, much less is known about those supporting teaching (Battro 2010, 2013; Battro et al. 2013; Clark and Lampert 1986; Kane and Staiger 2008; Konstantopoulos 2007; Nye et al. 2004; Olson and Bruner 1996; Pearson 1989; Rivkin et al. 2005; Rodriguez 2012; Strauss 2001, 2005, 2018; Strauss and Ziv 2012; Strauss et al. 2014). This gap has become untenable in the light of increasing evidence that teachers have a long-lasting impact on the socio-economic fate of their pupils (Chetty et al. 2011; Chetty et al. 2014). In that regard, an agreed-upon measure of what counts as good teaching and a good teacher is still missing (Coe et al. 2014, Darling-Hammond 2012, Gordon et al. 2006, Kane et al. 2013, Kane and Staiger 2008, 2010, Rothstein and Mathis 2013, Konstantopoulos 2008, Rothstein 2010).

We take this a step further by stating that in order to know who good teachers are and what good teaching is, we need to know what teaching is. This has eluded scientists and academics so far.

However, interest in teaching goes beyond practical, educational aims. Teaching is a topic of fundamental research that has potential to lead to a better understanding of human culture, cultural evolution, cognitive development, and cognition writ large. Teaching is considered to play a crucial role in the transmission of skills, behaviors, ways of doing, but also norms in the emergence and development of culture among humans (Atran and Sperber 1991; Boyd and Richerson 1995, 1996; Castro and Toro 2014; Csibra and Gergely 2011a, b; Dean et al. 2012; Gergely and Csibra 2006; Laland 2008; Richerson and Boyd 2005; Sperber 1996; Tomasello et al. 1993; Tomasello and Rakoczy 2003; Whiten et al. 2011). Experiments in cognitive archeology show that teaching improves transmission of techniques for the fabrication of clapped stones. They suggest that the emergence of teaching is a favorable factor for the appearance of complex technologies (Morgan et al. 2015; Tehrani and Riede 2008). Developmental studies on babies and children point to the existence of specific mechanisms that facilitate learning from teaching (Csibra 2007; Gergely and Csibra 2006; Csibra and Gergely 2006, 2009; Csibra and Gergely 2011a, b) and of processes that shape children's selective choice of whom to learn from (Corriveau and Harris 2009, Eaves

and Shafto 2012, Gweon et al. 2014, Harris and Corriveau 2011, Shafto et al. 2012, Sperber et al. 2010). Children have also been described as natural teachers, because their motivation and capacity to transmit information and knowledge appears early in life, and follows a developmental path even in the absence of explicit instruction about "how to teach" (Akagi 2012, Ashley and Tomasello 1998, Bonawitz et al. 2011, Calero et al. 2015, Corriveau and Harris 2009, Davis-Unger and Carlson 2008, Eaves and Shafto 2012, Gweon et al. 2014, Harris & Corriveau 2011, Knudsen and Liszkowski 2012, Köymen et al. 2015, Shafto et al. 2012, Sperber et al. 2010, Strauss 2005, 2018, Strauss and Ziv 2012, Strauss et al. 2002, Tomasello 2009). Moreover, growing evidence supports the existence of teaching across cultures and societies, including contemporary traditional societies of hunter-gatherers and agro-pastoralists (Hewlett et al. 2011; Kline 2013, 2015; Kline et al. 2013; Lancy & Grove 2010; Maynard 2002, 2004; Maynard and Greenfield 2005; Paradise & Rogoff 2009).

Not only are the contributions to this special issue representative of this broad range of aspects and forms of teaching, they constitute an attempt toward a productive dialogue between different approaches.

2 Obstacles

A major obstacle in the direction of the understanding of teaching is related to the absence of an agreed-upon characterization of teaching and a shared view of what counts as "teaching behavior".

Educational and cognitive approaches tend to focus on complex forms of teaching. They usually define teaching as an intentional behavior that mobilizes demanding cognitive skills - such as reflexive metacognitive skills and a theory of mind. Animal teaching is thus seen as proto-teaching by some developmental and cognitive researchers (Csibra 2007, Premack 2007). Teaching in young children is sometimes described as proto-teaching because while lacking the necessary ingredients of teaching, they are considered to be precursors of teaching (Strauss 2018; Strauss and Ziv 2012). At the other end of the spectrum, functional-behavioral definitions have been proposed in the framework of animal and cultural studies, which admit the existence of simple forms of teaching but abandon any reference to the cognitive requirements that are necessary for teaching and do so at the risk of throwing away the baby with the bath-water (Byrne and Rapaport 2011; Caro and Hauser 1992; Fogarty et al. 2011; Hoppitt et al. 2008; Thornton & McAuliffe 2012; Thornton & Raihani 2008).

In the absence of a shared characterization of teaching, the very existence of a well-defined object of study can be put into doubt: is "teaching" one thing or many? (Kline 2015; Skerry et al. 2013). Will it be possible to "close the gap" between the different disciplinary approaches and to arrive at a minimalist but still meaningful common sense of teaching?

3 Methodology

We put forward a proposal to bridge the gap between different disciplinary approaches to teaching. In this way, we aim to create a suitable background for the dialogue

between the different contributions to the special issue. More ambitiously, our aim is to help pave the way for the development of new theoretical and empirical studies to teaching that do not suffer from the disciplinary gap.

We proceed by summarizing four prominent approaches to teaching and bring empirical evidence to bear regarding their claims. In this way, it will be possible to extract a small number of functional units that appear to be necessary for teaching to occur. These are the "building blocks" of teaching, which could provide a common ground to the various approaches we discuss.

The building blocks of teaching are quite simple. None of them requires a complex cognitive architecture. Moreover, they are described in terms of functional units that are compatible with human, non-human, and artificial systems' architectures. Compared to existing approaches to teaching, the main advantage of an approach based on "functional building blocks" is that it is intended to be more inclusive. It includes minimal forms of teaching without giving away cognition. Moreover, the building blocks can be combined in different ways, thus giving rise to the different forms of teaching that are described in various literatures.

This having been said, the hypothesis of the existence of a limited number of building blocks of teaching should be tested empirically. For instance, we can use the building blocks as predictors of the presence of teaching behaviors – and even of different forms of teaching behaviors, according to different combinations of prerequisites. They could be tested in different species, at different developmental stages, in relationship with specific neurocognitive deficits, and also by implementing the building blocks approach in artificial systems and by running simulations of the appearance of teaching behaviors.

Our introduction explores some aspects of teaching's complexity and gleans from it what we believe are teaching's four basic building blocks: (1) selective responsiveness, (2) relevance signaling, (3) information giving and (4) motivation to influence. We glean them from four approaches to teaching to which we now turn.

4 First Approach. David Premack's Three-Pronged Theory of Teaching

Among the first and most prominent cognitive scientists to have dealt with teaching and its cognitive underpinnings is David Premack who described teaching as a developmental ability, consisting of three main actions (observation, judgment and modification of the learner's behavior) arising from the interweaving of three uniquely human dispositions and abilities. These are: (1) *aesthetics*, (2) *Theory of Mind* (ToM) and (3) *language plus an expertise in gesture modification* (Premack and Premack 2003, 2004). Aesthetics represents a set of standards that define what makes a gesture, product, or conduct appropriate. It is a normative attitude, and constitutes the motivation for correcting others and norming their behavior.

> "*A parent has a conception of a proper act or product and dislikes the appearance of an improper one. The evidence for such standards is twofold. First, humans* "*practice*" *e.g., swing a golf club repeatedly, flip an omelet, sing a song, write a poem, etc., trying to improve their performance of a chosen activity. Second, humans seek to improve their appearance. The mirror is where they*

begin their day, combing their hair, applying makeup, etc. That humans have mental representations of preferred actions or appearances is suggested not only by the demands they make on themselves but by the corrections they make of children when teaching them. Teaching, the attempt to correct others, is the social side of the attempt to correct self." (Premack 2007, 13862).

ToM includes a theory of development, which helps teachers identify children and youngsters as needing to be taught. Language and the capacity of passive guidance are the tools that humans mostly use for teaching - the latter being involved, for instance, in placing the body of others in the desired positions (Premack 1984, 1991, 2010). There is a fourth, hidden ingredient in successful teaching, which rests on the side of the learner: the learner's ability and motivation to imitate models. The human capacity to teach relies not only on the teacher's motivations, theories and tools, but also on those of the learner (Premack 2007). The fact that all these capacities can mesh together makes teaching a *domain-general competence with indeterminately many targets*. This means that human teaching is flexible. At the opposite end, instances of nonhuman teaching are examples, in Premack's view, of rigid adaptations to single goals - in that they are limited to predation, and to specific acts of predation (Premack 2007). Finally, in Premack's view, the disposition to teach constitutes an example of altruistic behavior because the beneficiary is not the teacher himself, but the learner, and the willingness to serve others comes with a cost to oneself.

4.1 From Theory to Evidence: Enforcing Norms and the Motivation for Teaching

There is evidence that the normative attitude described by Premack exists at an early stage of development and follows a developmental path. Children aged 3 years understand norms (e.g. the rules of a game, Rakoczy and Schmidt 2013); tend to correct a puppet violating the rules of a game and may use normative language ("It is not like this" "You have to do like that", see Rakoczy Warneken & Tomasello 2009, Rakoczy et al. 2009, Schmidt and Tomasello 2012). Children 3 to 5 years old use normative language both when enforcing social norms and when teaching others. In the transition from 3 to 5 years, the use of language shifts from specific to generic and law-like (Köymen et al. 2015). Children of that age can extract the norms they successfully enforce both from the adult's pedagogical attitude (the adult explaining the rule of the game) and from the observation of non-pedagogical interactions. For instance, when children observe an adult interacting with an artifact in a confident way, and then observe a puppet interacting with the same artifact, but in a different way, they tend to correct the puppet; however, if the adult seems to ignore the "right use" of the artifact and simply explores its features, children do not feel compelled to correct the puppet whose behavior differs from that of the adult (Schmidt et al. 2011). It is also worth noting that children of that age distinguish between moral norms (such as norms whose violation can produce harm) and simple conventions (or norms related to game-play): moral norms are enforced for everybody with no distinction of group membership, whereas conventional ones are selectively enforced to members of their own group (Schmidt and Tomasello 2012).

In the light of this evidence, it seems plausible to advance that, from an early age, enforcing social norms (conventions, ways of doing, rules of the game, standards,

criteria) represents a motivation for teaching. It is possible that the motivations that sustain teaching to in-group members are slightly different from those of law-enforcing to both in-group and out-group members. Teaching is a normative enterprise, not just intended as a means for the transmission of factual knowledge or skills, but as a means for reducing deviations from social norms and standards, by enforcing them in non-compliant individuals of the in-group (see also Rakoczy et al. 2009). Clearly, the normative dimension of teaching deserves further attention. We claim here that one basic building block of teaching involves its motivational aspects.

4.2 From Theory to Evidence: The Problem with ToM

It is often the case that cognitive approaches to teaching – such as Premack's – invoke the capacity of attributing mental states to others and evoke the notion of Theory of Mind – a theory of others' minds that enables, among other things, false beliefs ascriptions and the identification of lack of knowledge in others (Baron-Cohen et al. 1985; Premack and Woodruff 1978; Wimmer and Perner 1983). However, as explicitly stated by Premack & Premack (1994), the skilled interpretation of others' mental states is most probably a composite function (see also Korkmaz 2011; Call and Tomasello 2008). It is thus not the most promising level of analysis for identifying the simple functional units – the building blocks – of teaching. Moreover, the attribution of mental states is not agreed-upon, as shown by the simultaneous existence of different terminologies for addressing mentalistic capacities ("ToM", "mindreading", "understanding others' minds"). It is not among the objectives of this paper to summarize the disagreements found in the literature. But because a lack of agreement has a potentially negative impact on the understanding of the role of ToM in teaching, it deserves attention.

First, experts disagree on the age at which children succeed at false beliefs tests. With different tests, in fact, the time for achieving this capacity ranges from 4 years old to 2 years old and even to 13 months of age (Baron-Cohen et al. 1985; Wimmer and Perner 1983; Hutto et al. 2011; Southgate et al. 2007; Surian et al. 2007; Scott and Baillargeon 2009). But it isn't so much the age that is of importance here. Rather, it is a methodological and theoretical problem about how we can draw equivalence between verbal tasks used when tapping toddlers' false beliefs and the non-verbal tasks employed with infants.

Second, it has been suggested that, even in the case of false belief tasks, what is being measured, cognitively, is subject to debate. Experts disagree about the conceptual vs non-conceptual nature of such capacities. Some of them consider ToM to be a specifically conceptual capacity – a theory (Gopnik and Meltzoff 1997). Others, such as developmental psychologist and primatologist Daniel Povinelli, posit the existence of both conceptual and purely perceptual (tracking) systems, serving similar purposes. Perceptual systems track "*statistical regularities that exist among certain events and the behaviors, postures, and head movements (for instance) of others*" (Povinelli 2004). Humans could appeal to both perceptual and conceptual systems, while chimpanzees and other primates might lack the second form, thus making the distinction more evident (Povinelli and Vonk 2003; Penn and Povinelli 2007).

In a similar vein, philosopher Ian Apperly and psychologist Stephen Butterfill have also hypothesized the existence of a double system for tracking beliefs. The first system is inflexible, hard-wired, "fast and efficient", cheap (from the point of view of cognitive

computation), evolutionary and ontogenetically ancient. The second system is flexible, effortful, implies the explicit and deliberate attribution of mental states and gradually develops, helped by the maturation of capacities such as language and executive functions, and by experience. The tracking system would not disappear with the development of thoughtful mindreading, but would continue to operate – especially under conditions of stress, cognitive load, time pressure, etc. (Apperly 2012; Apperly and Butterfill 2009; Butterfill and Apperly 2013). It is tricky to decide whether humans are relying upon a tracking system, or a conceptual system, or both.

Finally, experts disagree on the relative role of innate processes (Baron-Cohen et al. 1985; Leslie 1987) vs. socially acquired skills (Heyes 2012, 2014, 2015; Heyes and Frith 2014). A "minimal theory" of mentalizing such as the one proposed by Povinelli, Apperly and Butterfill, which recognizes the game-changing role of conceptual, explicit mentalizing, but does not limit mentalizing to it, seems to represent a suitable solution for dealing with the problem of teaching, because it allows us to take into account occurrences of teaching in young children and in nonhuman animals, and simple forms of teaching, as well.

We conclude this brief discussion by acknowledging that teaching requires some capacity for taking into account others' mental states. But this capacity may possibly be composed of more basic perceptual skills, such as the capacity (or capacities) of tracking intentions, perceptions, knowledge, behaviors and possibly beliefs – with or without the capacity of conceptualizing these mental states and more particularly beliefs.

5 Second Approach. Teaching as a Natural Ability

In his research on education and developmental psychology, Sidney Strauss – one of the two co-editors of this special issue – has proposed a characterization of human teaching as a "natural cognitive ability", i.e. it is universal, developmentally reliable, found in our ancient hominin ancestors, has a phylogenetic history and specific neurocognitive underpinnings (Strauss 2005, 2018, Strauss & Ziv 2012, Strauss et al. 2002).

Strauss (2018) posits that although teaching involves information giving, complex human teaching encompasses more than that. It includes stage-setting with emotion-, motivation- and mind-reading, organizing teaching sessions, scaffolding, detecting knowledge gaps and reducing them via teaching strategies such as demonstrations and verbal explanations. In addition to teaching's mind-to-mind coupling, it also includes heart-to-heart coupling. Teaching is prosocial in its very essence, and it is also part of its complexity. Teaching is a form of helping behaviour but is not altruistic because altruism involves the voluntary giving another something of value to another person where what has been given is no longer in the possession of the giver. When teaching, the teacher gives knowledge to another, the learner. But because the teacher doesn't lose her knowledge when passing it on to the learner, teaching is not considered to be altruistic.

This complexity of human teaching can serve as a map for teaching's basic building blocks.

Adult human teaching aims to reduce the knowledge gap between the one who knows (the teacher) and the one who doesn't (the learner). Teaching is

thus (1) *an intentional act*, motivated by (2) a *prosocial stance* and involving (3) *information giving*. To achieve this, teachers build upon (4) their *understanding of other people's minds*, that is, ToM, which we discussed in critical terms in relationship with Premack's theory.

The development of ToM introduces a distinction between precursors and more advanced forms of teaching. ToM is also the hallmark of advanced human teaching as it permits adapting to the learner's developmental level and knowledge gaps. But Strauss claims that aspects of teaching are preceded by two kinds of precursors that do not require ToM. The first kind is proto-teaching, i.e. information giving not involving the transmission of generalizable knowledge. The second kind is early teaching, e.g. solicited information-giving or unsolicited mistakes correction shown by infants. The first form of information-giving does not require ToM and is also present in nonhuman animals (Strauss and Ziv 2012). At the opposite end of the spectrum, contingent teaching – teaching during which the teacher responds to the learner, and vice versa – is based on a more sophisticated form of ToM: "on-line ToM", which implies monitoring (a form of metacognition) and executive function (working memory, flexible planning, focused attention) (Strauss 2005, Strauss et al. 2002).

Teaching behaviors thus follow a trajectory of evolutionary and ontogenetic development, which go from teaching without ToM to teaching with ToM and eventually teaching with on-line ToM.

Based on Strauss' and colleagues' studies on professional teachers (Strauss and Shilony 1994), however, none of these natural forms is enough for efficient professional teaching. Whilst grounded on natural bases, sophisticated and mature teaching is a learnt ability. Professional teachers are required to develop their mastery of subject matter knowledge and their pedagogical content knowledge, eventually modifying their implicit mental models of children's mind and learning (their folk psychology and pedagogy: Strauss 2001, Strauss and Shilony 1994, Strauss and Ziv 2012).

5.1 From Theory to Evidence: Information Giving during Ontogenetic Development

There is some evidence that giving information appears relatively early in ontogenesis, follows a developmental trajectory, and is preceded by precursors that involve the solicited transmission of information and the correction of others' mistakes (Calero et al. 2015; Strauss 2005; Strauss et al. 2014). For instance, as has been described in previous paragraphs, children aged 3–5 protest when norms are not respected and try to enforce them by demonstrating actions and stating rules (Köymen et al. 2015). There is an ontogenetic trend in solicited peer-teaching with coordination. When engaged in a collaborative problem-solving task requiring joint and coordinated actions, children aged 3.5 years have been observed to engage significantly more in explicit teaching actions than their peers aged 2, 2.5 and 3 years (each "knowledgeable" child being paired with a naïve peer and asked to teach the necessary actions to solve a task; Ashley and Tomasello 1998). Children aged 3 years still coordinate poorly with the behaviors of the other child and do not engage much in verbal teaching. Younger children do not even master the task alone. Other studies have confirmed the existence of an ontogenetic path, especially in relationship with the engagement of children in verbal interaction, in collaboration with and sensitivity to the learner's states of mind as compared to simple demonstration of actions to be taught (Astington & Pelletier 1996, Davis-

Unger and Carlson 2008, Wood et al. 1995). For instance, when taught to play a board game, 3-year-old children spontaneously show other children how to play. They do so with little or no explanation and without systematically correcting others' errors. Children age 5, on the other hand, demonstrate *and* explain by reminding the rules of the game, thus correcting the mistakes of the co-player. They also engage more in feedback and mistake diagnosis. For a review of this literature, see Strauss and Ziv (2012).

At least two explanations are possible for the development from simple to more sophisticated information-giving behavior: first, younger children are more *motivated* to win the game than to explain it; second, older children have developed the necessary *skills* for monitoring and reacting on-line to the errors of their co-players (they display more sophisticated forms of ToM, as suggested by Davis-Unger and Carlson 2008).

Spontaneous engagement in teaching younger siblings has also been observed among Zinacantec Maya populations in Chiapas, with children teaching skills such as how to prepare tortillas and how to take care of dolls in the context of everyday chores (Maynard 2002, 2004). Changes have been observed in the modalities of teaching (but not in time spent at teaching), with children aged 3 to 5 years mostly sitting side by side and providing the younger sibling a task to perform, and older children giving more feedback, engaging more in explanations, commands, guidance of the learner's body, etc.. A significant difference is observed between children aged 5 to 7 years and children aged 8 to 11 years, the latter but not the former engaging significantly more in talk with demonstration than the 3–5-year-old group (Maynard 2002).

Information-giving strategies thus seem to become progressively more varied and flexible starting from 3 to 5 years with children aged 7 years being capable to engage in the kind of adjustment to the learner, which is described by Strauss and Ziv as contingent teaching and as requiring on-line ToM (Strauss et al. 2002; Strauss and Ziv 2012).

5.2 From Theory to Evidence: Teaching Has Precursors in Ontogenetic Development

There is evidence that information-giving behavior is preceded by precursors that involve: a. the solicited transmission of information that is needed by another and b. the non-systematic but spontaneous correction of others' mistakes. For instance, when exposed to an adult who is inefficiently looking for a lost object - the object being in full sight for the child but not the adult - infants aged 1-year point at the object so as to provide information, if pressed to (Liszkowski et al. 2006, 2008). At about the same age, children engage spontaneously in the correction of mistakes when the experimenter suddenly pretends not to be able to put the right shape – pyramid, cube, ball – in the right hole. This attitude also follows a developmental path: infants 12 to 19 months tend to act in the place of the experimenter and to put the shape in the appropriate hole; children aged 20–23 months, stop replacing the adult and start pointing at the right solution, or utter sounds in relationship with the task. The correction of mistakes perceived in others thus progressively includes actions, deictic gestures (pointing) and proto-language as tools (Akagi 2012) It has been noticed that mental retardation but not autism with mild mental retardation has a negative impact of this behavior: children with autism do display active correction of mistakes once they attain 40 months

of developmental age, Akagi 2012). Considering the correction of mistakes as a precursor of teaching is coherent with the hypothesis – suggested by Premack, and discussed above – that teaching has a normative dimension.

5.3 Challenging Evidence: Information Giving and Alliances

At least one strand of evidence hints at the possibility that information-giving is not limited to filling in a knowledge gap. In four experiments, Kim et al. have shown that, when teaching adults, children aged between 3 and 6 years do not systematically choose to teach those who are more in need (Kim et al. 2014). It seems, however, that children of this age do recognize the difference between adults who know more and adults who are less knowledgeable, and treat the former as better informants than the latter (for the capacity of children aged 5–7 years of identifying informants who omit information, see Gweon et al. 2014). Somewhat unexpectedly, though, the children who have taken part in Kim et al.'s experiments show a preference for giving information to adults who have demonstrated to be *more knowledgeable than others*, even when the knowledgeable adult tells the child that she already knows what the child wants to share. In the cited experiments, children never choose to inform adults who have a record of ignorance (Kim et al. 2014). While limited, this kind of evidence is supportive of the hypothesis that the emergence of teaching behaviors is related to different motivations: in addition to fulfilling a prosocial motive, sharing information might help establish fruitful collaborations and alliances with knowledgeable ones (or be a form of reciprocal prosociality related to the sharing of information), thus fulfilling a self-serving interest.

5.4 More Challenging Evidence: Self-Serving Motivations for Teaching (Cognitive Advantages)

A second strand of evidence hints at the possibility that teaching behavior has immediate self-serving benefits for the teacher, in this case that teaching others enhances *the teacher's* capacity to learn. One study has shown that preparing oneself for teaching promotes better retention of verbal material as compared to preparing oneself as a learner; in the framework of this study, actually teaching others – as compared to verbalizing aloud alone and to working alone – does not seem to make a difference (Barg & Schul 1980). This result seems to be confirmed by another study in which self-explanation is shown to produce the same effects as engaging in tutoring when dealing with rote learning and better effects when dealing with deep learning (Roscoe & Chi 2008). It has thus been proposed that preparation for teaching mobilizes metacognition and favors a better organization of the learning material (Annis, 1983, Benware & Deci 1984). For what concerns the expectancy to teach, (Renkl 1995) found both negative effects (anxiety) and positive effects on the time spent studying a specific problem, but no positive effects on actual learning. However, a more recent study suggests that actual teaching might have a positive impact on retention: (Fiorella & Mayer 2013) assessed the relative benefits of preparing to teach and of actual teaching; the specificity of their study consists in joining immediate and delayed assessment of the learning outcomes of the different conditions (learning for learning, leaning by

preparing for teaching, learning by preparing for teaching and actually teaching). In immediate assessments, teaching gives better learning outcomes than preparing for learning, and actual teaching does not provide additional advantages. In delayed assessments the advantage of preparing for teaching disappears, but participants who have actually taught maintain their advantage. The authors extrapolate that preparing to teach and actually teaching promote different cognitive processing relative to memorization. However promising, existing studies on the cognitive (learning) advantages of teaching are still limited. Moreover, the cognitive mechanisms involved in the presumed advantages of teaching are not clear, the effect size appears to be small if compared to studying for oneself and the measured effects present a high degree of inter-individual variability (Cohen et al. 1982, Rohrbeck et al. 2003, Roscoe & Chi, 2008, Fiorella & Mayer 2013).

More research is required to evaluate the cognitive benefits of teaching for the teacher, and to identify the mediating mechanisms. Likewise, more work is needed to identify the potential immediate benefits of teaching for the teacher, and to assess the hypothesis that teaching is not (or at least not only) an altruistic behavior.

6 Third Approach. Michael Tomasello's Theory of Instructed Learning

The third and last cognitive characterization of teaching discussed here is instructed learning. Instructed learning is defined as a form of social learning in which the learner imitates a demonstrator's actions and gestures (Tomasello 2016, Tomasello & Carpenter 2007, Tomasello et al. 1993). The characterization thus focuses on mechanisms that are relevant for social learning. It is proposed that engaging in social learning is not limited to epistemic motives (information gathering/giving) but also extends to social motivations of different kinds (Carpenter 2006, Tomasello & Carpenter 2007). Over & Carpenter (2012), in particular, proposed that, due to their dependence on the group, humans have evolved a social motivation to imitate and that imitation has the function of a social glue. Children imitating adults or other children might thus be trying to make themselves more similar to the model or to the group *independent* of the goal of learning new behaviors. They might copy adults for communicating with them and sending them a message (of empathy, of affiliation and similarity), for strategically buying their place in the group, and possibly for complying with social pressure and with norms that are more or less explicitly enforced. Conformity can in fact promote "peace" and minimize conflict by reducing dissimilarities within the group and at the same time enhance social acceptability via the adherence to shared social norms (Over & Carpenter 2012). Cohesion and conformity are thus important aspects in instructed learning.

Instructed learning also includes responsiveness, on the part of the learner, to a special class of communicative acts that the instructor performs while demonstrating a target action. Skills and motivations that are deemed relevant for instructed learning are: a. mechanisms related to the attitude of taking the perspective of someone else, which stems from the possibility of sharing attention (of bringing attention on a shared target) and of sharing intentions (of doing something together with the same intention, not just in parallel, but cooperating) and b. social motivations to cooperate and to conform; c. the capacity of imitating intentional behaviors with both fidelity and

rationality – where fidelity refers to the fact that the learner copies the details of the model's actions, i.e., the specific gestures employed by the model in order to achieve the outcome; and rationality refers to the understanding of the goals behind the action (see Gergely et al. 2002, Lyons et al. 2007, Meltzoff 1988, Whiten et al. 2009). Evidence related to the three groups of requirements is discussed in what follows.

6.1 From Theory to Evidence: Perspective-Taking Evolves

There is evidence that capacities related to perspective-taking and cooperation follow a developmental trajectory, which includes: i. Gaze-following and ii. flexible and intentional attention-reading/attraction relative to a third party. Gaze-following is present at birth and can be considered a precursor of full-fledged attention-reading. At around 9–12 months of age infants reliably follow the gaze of an adult, but she also intentionally performs gestures that attract the attention of the adult toward an external object or event, e.g. through pointing. At the same age, infants infer an intention (e.g. a goal) in relationship with a shared framework or common ground (Call 2009).

Cooperation also follows a developmental trajectory. Skills and motivations for coordinating actions around a common goal start to appear around 14 months of age. However, at this stage, children are more proficient in helping others than in cooperating with them. This observation suggests that helping and cooperating differ significantly from a cognitive point of view, the latter probably requiring more than perspective-taking of others' goals. Children aged 18 months perform cooperative actions with adults by coordinating gestures around a common goal. They have acquired the ability to form shared plans and to coordinate actions in a timely manner (Warneken & Tomasello 2007). Nonhuman animals, and in particular chimpanzees, which are often compared with children in studies, do not show shared intentionality, not because of an incapacity to read attention or intentions, but because they lack the intrinsic motivation to do so (Tomasello & Carpenter 2007). This can be a partial explanation for why some nonhuman animals do not teach (Call 2009).

6.2 From Theory to Evidence: The Role of Social Motivations in Social Learning and Teaching (Conformity)

There is evidence that preschool children can be quite strategic when imitating their peers: in the situation in which one child receives information at odds with that received by a group of peers, and is asked to express his or her opinion publicly, in a majority of cases he or she will conform to the opinion of the group; however, when asked to silently – not publicly – express his or her views, the tendency to conform to the group is reduced (Haun & Tomasello 2011). There is also evidence that – starting from 5 years of age – prosocial behavior (e.g. unsolicited helping, collaboration) attracts more "followers" than coercive behavior or coercive behavior alone (Hawley 1999, 2002). Since having more "followers" is considered to be a sign of prestige (Boyd and Richerson 1995, Henrich & Gil-White 2001, Richerson and Boyd 2005; van de Waal et al 2013), it is possible that prosocial behaviors, such as teaching, bring teachers prestige, with relative advantages in terms of social position (for the social advantages brought about by prestige, see Cheng et al. 2013).

Teaching might then represent a means for the end of gaining social status without engaging in dominance-related, aggressive behaviors, which imply a risk for the dominance-seeking individual (for the evolution and psychology of prestige vs. dominance, see Henrich & Gil-White 2001). Fusaro & Harris (2008) show that 4-year-old children selectively choose to learn from individuals who are "popular", having received manifest assent to their assertions from other individuals. Chudek et al. (2012) extended these data by substituting manifest assent or dissent with attention paid to the "teacher" (time of gaze); they showed that children are twice as likely to learn from an adult who has been accorded 10 s of attention from another adult than from an adult who has received no attention.

Children thus seem to respond to simple cues that identify others as being popular, and to defer to them in a way that attracts popular teachers more followers/learners. By gaining more followers, these individuals achieve greater prestige and are more likely to be copied, i.e., to be adopted as teachers. With regard to these data, some (Boyd and Richerson 1995, Henrich & Gil-White 2001, Richerson and Boyd 2005) have advanced the hypothesis that prestige mechanisms have evolved because they help choose the "best teachers" via proxies that can be easily and rapidly assessed. Because of the social advantages of prestige, it is plausible that teaching is a way of gaining prestige. That is, individuals become proactive in attracting their followers by displaying prosocial behaviors, by advertising their skills and knowledge, and by actively teaching others, rather than waiting to be copied. This hypothesis requires more evidence in order to be supported.

6.3 From Theory to Evidence: Responsiveness to Pedagogical Cues

Multiple experimental results indicate that when ostensive acts (eye-contact, addressing a person by name, etc.) are addressed to children and even infants, they react differently than when demonstrations are proposed without ostensive cues. For instance, when adults perform demonstrations in combination with ostensive communicative cues, children as young as 14 months of age respond by imitating with fidelity the specific gestures performed by the adult. When these cues are absent, children tend to copy "rationally", that is, they copy the result of the action. Also, in the presence, but not in the absence of ostensive communication with eye-contact, infants 14 to 18 months old tend to generalize the moral reactions of an adult to the class of objects they are directed towards. For instance, rather than assuming that the adult does not like the particular item that lies in front of him, they assume that the class the item belongs to is not likable. In the absence of eye-contact the generalization is not made and the child attributes the reaction to a particularity of the demonstrator (Csibra and Gergely 2009, Egyed et al. 2013, Gergely et al. 2002).

Based on the receptivity of learners to this particular class of cues – which includes linguistic utterances and prosody (namely: motherese) in addition to eye-contact and ostensive gestures – Csibra and Gergely have developed a theory of cultural transmission of knowledge called "natural pedagogy" (Csibra and Gergely 2006, 2009, 2011, Gergely and Csibra 2006). Natural pedagogy is hypothesized to represent an adaptation related to the growth of artifacts in hominin societies, and thus to constitute a solution to a learning problem of acquiring knowledge that is "opaque" – in the sense that it cannot be easily extracted via experience and/or imitation of social models (e.g. how to

use or produce a particular tool with a specific technique) – and it is general (i.e., valid beyond the current situation and specific content) (see also Morgan et al. 2015).

Pedagogical protocols of the kind described as natural pedagogy might thus constitute adaptations that signal to the learner that the information transmitted has a particular relevance and should be learnt and generalized. Experimental studies by Csibra, Gergely and colleagues also support the hypothesis that there is more to teaching than demonstration and explicit, verbalized instruction. Eye-contact, gaze direction, manual, vocal, bodily attitudes and gestures directed towards external events and objects (ostensive gestures) modify the receptivity of the learner, convey signals about the relevance and generalizability of the contents of communication, and are understood by the learner without requiring linguistic exchange. This class of communicative acts thus deserves further attention and empirical studies in order to better characterize the palette of "teaching tools" that are involved in initiating pedagogical interactions.

6.4 From Evidence to Research Questions: Teachers' Actions and Gestures

Despite the term "natural pedagogy", Csibra's and Gergely's work has been aimed mostly at the learner, e.g., how do learners respond to ostensive versus non-ostensive cues? Given this, it would be useful were researchers to develop the theory of natural pedagogy in the direction of identifying the relevant actions that are put in place by teachers and that make one apt to convey a pedagogical intention. Useful insights into the cognitive processes underlying teaching and the capacity of teachers of conveying pedagogical intents to learners might come from the implication of participants for which one or the other of these capacities is selectively impaired. One could also understand teaching better from the study of non-verbal behaviors – e.g., communicative, iconic, deictic and ostensive gestures – put in place by children while teaching.

This particular line of research has been recently investigated by Calero and colleagues (Calero in preparation, Calero et al. 2015, Strauss et al. 2014). They have been able to show that children aged 3 to 8 years use gestures, namely ostensive gestures and referential signals, while providing explanations to adults. They do so more than during other communicative acts. Children aged 3 to 5 years use ostensive gestures at both the onset and offset of pedagogical acts aimed at conveying information about how to play a game, whereas children aged 6 to 8 years use ostensive cues such as eye-contact only at the offset. This suggests a developmental pattern: older children make use of referential signals especially at the onset of teaching episodes, while these are almost absent in the gestural repertoire of younger children. Also, in Calero et al.'s experiments children, that included children age 7, on average do so "rationally" – by tuning the receptivity of the learner to their ostensive gestures – and "intuitively", i.e., not as a form of imitation of adult's behavior. Ostensive gestures emitted by children during pedagogical episodes are reduced if the adult learner does not pay attention to them; they increase after having been exposed to a teacher who minimizes the use of ostensive gestures.

From these studies children emerge not just as the receptive participants of the pedagogical protocol, but as emitters, too (Calero et al. 2015). These studies do more than confirm that teaching is a natural behavior, which develops from childhood. They hint at the possibility that teaching is anchored in gestural, pre-verbal cues, to which

infants are tuned and that children put in place when they are on the emitter, teacher, side of pedagogical events. These cues need not be reflective or intentional. It is possible that they are part of an automatic cue-response system.

7 Fourth Approach. Non Cognitive, but Cultural and Evolutionary

> "*An individual actor A can be said to teach if it modifies its behaviors only in the presence of a naïf 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, or that it would not learn at all.*" (Caro and Hauser 1992).

Animal studies and comparative cultural studies indicate that minimalist forms of teaching exist, which do not require complex computations to be carried out (evidence is reported below). These studies rely on a characterization of teaching that makes no reference to cognitive requirements. The characterization, originally proposed by biologists Caro and Hauser (1992), focus on teaching behaviors and their effects on the learner (function), and in this way avoids any reference to complex and even basic cognitive requisites. Teaching is: *any modification of the teacher's behavior in the presence and only in the presence of naïve observers that produces better learning outcomes on the side of the learner, with no immediate benefit for the teacher.*

Within this minimalist approach to teaching, it is not necessary for the teacher to possess a special form of sensitivity to the learner's mental states in order to modify his or her own behavior (a Theory of Mind). Nonetheless, the definition implies that teaching takes place in the presence of learners that are "naïve" and not experts, which – Caro and Hauser concede – requires *some form* of sensitivity to conspecifics' behaviors. The solution proposed by Caro and Hauser is that the teacher's sensitivity is on a continuum ranging from time-locked adaptations (a stereotyped time-course for teaching, unlocked by specific behavioral patterns on the side of the learner) to highly-sensitive mechanisms capable of tracing minimal changes in the learner's mental states, and to react by choosing the most appropriate course of action rather than stereotyped responses. The difference between low-sensitive and high-sensitive mechanisms is not represented by their efficiency, but by the ecological and social circumstances that favor one or the other, and by their costs in terms of processing. For instance, in a stable environment a stereotyped teaching behavior can be both efficient and low-cost, and so can be favored by evolutionary processes (Caro and Hauser 1992). Chazan (2018, this volume) makes a similar argument for teaching among hominins. The "sensitivity to the learner's state" that emerges from this view may be analogous to the minimalist form of mentalizing discussed above in relation to ToM, and used as a system for recognizing individuals-susceptible-to-be-taught.

The second mental capacity the behavioral-functionalist account of teaching does without, is the intention to teach (Caro and Hauser 1992; Hoppitt et al. 2008). However,

even in this case, the circumstantial modification of the teacher's behavior can be considered as *some form* of intentionality, in that the teacher – in specific circumstances – modifies its own behavior and acts *in such a way as* to pass on some information or knowledge or norms. There is then a functional similarity with the intention to teach, but this form of minimalistic intentionality does not require metacognition. It is implemented in patterns of behavior that express themselves in specific circumstances and only in those circumstances.

This approach has been productive, in that it has favored the burgeoning of a strand of evolutionary research on animal teaching (Hoppitt et al. 2008; Byrne and Rapaport 2011; Fogarty et al. 2011).

7.1 From Theory to Evidence: Animal Teaching

There is limited but solid evidence, gathered in natural and controlled experimental conditions, that some form of teaching exists even in taxa that are not considered to display complex mentalistic capacities, namely: meerkats (Thornton 2008; Thornton and Clutton-Brock 2011; Thornton and McAuliffe 2006), ants (Franks and Richardson 2006; Leadbeater et al. 2006; Richardson et al. 2007) and pied babblers (Raihani and Ridley 2008).

Experimental research on meerkats has shown that a relatively inflexible, hard-wired, pre-adapted mechanism can explain the capacity of these animals to tune their behavior to the behavioral state of learners. Adult meerkats provide young meerkats prey – scorpions – in various ways that have the consequence of sharpening pups' predatory skills. Adults provide unarmed or armed preys, depending on the age of the learner: younger learners are assigned unarmed preys, easier and less dangerous to deal with; older ones have to deal with the risk of being stung.

Experimental manipulations have allowed researchers to identify the mechanisms at play in this form of elementary "behavior-reading". Adult meerkats have been exposed to voice records of young meerkats while in the presence of pups of different ages. Adult meerkats do not appear to react to the physical aspect of the pups, but rather to the pitch of the voice that is played for them. If the pitch corresponds to a younger animal, the potential learner is assigned an unarmed prey; if the pitch corresponds to an older animal, the learner is assigned an armed prey, independent of its real age. The pitch thus represents a proxy of the developmental stage of the young animal. Meerkats do not need elaborate complex computations in order to interpret the behavioral state of the learner and to choose the most appropriate teaching behavior.

Tandem running behavior in ants (*Temnothorax albipennis*) also fits the behavioral-functional definition of teaching provided by Caro and Hauser. In the process of colonizing a new nest, tandem running leaders recruit a nest-mate and guide their companion to the new site. The companion taps the leader's abdomen with its antennae and the leader adapts to the companion's velocity. During the process, the teacher evaluates the necessity of pursuing the tandem runs and adapts to the learner, which in turn gives feedback to the leader.

This behavior is costly in terms of time spent, slowing down the leader, even when compared to other forms of transfer from an old to a new nest (carrying). However, such teaching behaviors might have the advantage of permitting transfer, in that the pupil ant learns the route and can subsequently become a tutor (carried ants do not learn

the route) (Franks and Richardson 2006). The case of tandem running ants provides an example of how apparently complex forms of teaching, such as teaching through evaluative feedback and contingent responses to the actions of the learner (a form described as advanced teaching by Strauss 2005) can be carried out through simple mechanisms. This having been said, though, we do not want to claim that human teaching, with language, gestures, etc. is equivalent to that of tandem-running ants.

While this example does not explain the variety of situations in which humans teach by adapting to the learner, it suggests that simple mechanisms can suffice in the case of specific behaviors in specific circumstances. Contingent teaching is thus not specific to humans, even if the mechanisms used by our species for contingent teaching might be in large part human-specific – e.g. relying on language and other symbolic systems. The same consideration applies to the case of associative teaching in pied babblers.

Pied babblers emit purr calls during food delivery in a way that produces associative learning in their offspring. The manipulation of purr calls during and after the learning phase shows that only the pairing of purr calls with actual food delivery produces learning and that once the association is learnt, recorded purr calls with no delivery activate the paired response in the offspring (Raihani and Ridley 2008).

Once more, these examples suggest that it is possible to teach without mobilizing the symbolic, linguistic, explanatory, conceptual tools that are available to the human mind. It is however difficult, in our case, to establish which is the part of similar low-cost pre-adapted mechanisms in human teaching. A parsimonious stance suggests that whenever simpler mechanisms are sufficient for granting an efficient behavior, there is a good reason to look for less complex calculations.

7.2 Some Methodological Issues about Teaching in Humans and Non-human Animals

Evolutionary approaches to teaching generally espouse the view that the relevant resemblance between teaching in humans and in non-human animals is in the effects, with no proper equivalence in the (neurocognitive) mechanisms at stake (Caro and Hauser 1992; Fogarty et al. 2011; Hoppitt et al. 2008). From this assumption, they draw the conclusion that the study of non-human teaching cannot bring any contribution to the identification of the neurocognitive underpinnings of human teaching. "*Any functional similarities should not obscure the fact that mechanistically, cases of animal teaching are entirely different from human teaching, and are not reliant on homologous characters*" (Fogarty et al. 2011, p. 2).

It is the conclusion and not the premise that is challenged here. It is certainly desirable to avoid the pitfalls of anthropomorphism, namely attributing complex mental states to nonhuman animals, analogous to those identified in the human cognitive architecture, on the ground that the respective (teaching) behaviors share functional similarities. And, similarly, convergent patterns of evolution should not be confounded with common descent and common origin of similar mechanisms. Mechanisms identified for one species might be irrelevant for another despite the similarity of the respective behaviors because "*evolutionary convergence may be more important than common descent in accounting for similar cognitive outcomes in different animal groups*" (Bolhuis and Wynne 2009) (see also Bolhuis et al. 2011, Hemelrijk and Bolhuis 2011).

Nonetheless, the evolutionary approach might be too quick at dismissing the possibility that animal studies and their functionalist guiding principle can be productive for advancing the understanding of human teaching. Quite the opposite, by abstracting from the constraints that each type of cognitive architecture imposes, and by avoiding any reference to complex cognitive mechanisms, they are especially suited for identifying *functional units* that are necessary for teaching but are not unique to the most complex forms of teaching, e.g., comparative animal studies provide several examples that complex solutions can arise from simple mechanisms (Emery and Clayton 2004; Gunturkun 2012; Mueller and Gerardo 2002).

In addition, limiting oneself to human studies is susceptible to hiding functional units that can be carried out by less complex neurocognitive underpinnings or at a lesser (cognitive) cost. Even in the case of humans, some forms and some aspects or components of teaching might in fact be carried out by "a less complex mental calculator", that is, in the form of pre-adapted, cue-response mechanisms or of low-cost processes that do not require conceptualization – such as the tracking of behavioral cues described above in the framework of the discussion about mentalizing capacities.

This claim is consistent with a more general approach to the comparative study of cognition. Psychologist and zoologist Sara Shettleworth, in particular, has insisted on the necessity of reversing the trend in comparative cognitive studies, where there is a search for human-like capacities in nonhuman animals, and of searching for simple and unconscious mechanisms, triggered by behavioral cues in humans, similar to those that have been identified in the case of nonhuman animals. It is her opinion that the de-anthropomorphization of explanations for complex cognitive functions might benefit the understanding of human behavior no less than that of other animals: "*dissecting broad abilities into elements, some of which are phylogenetically widespread, others confined to species with specific ecologies or evolutionary histories, and some perhaps unique to humans.*" (Shettleworth 2010). Her view is similar to the one put forward by de Waal and Ferrari (2010) regarding what they call a bottom-up approach to cognition, in that it restates the continuity between species and the necessity of adopting a Darwinist point of view on the study of cognitive skills and motivations. This view motivates the "building blocks approach" proposed here to foster the understanding of teaching and to bridge gaps between disciplinary approaches.

Moreover, human teaching itself is not limited to complex forms of teaching. Rather, evidence (described below) indicates that human teaching comes in a variety of forms, some of which are minimalist and do not require teachers to engage in complex computations and some of which are complex requiring mind-reading, language, etc.. In this view, the functionalist approach proposed in the framework of animal and comparative studies may be no less suitable to study the varieties of human teaching than cognitive approaches. The latter could limit us to the consideration of only complex forms of teaching with ToM and explicit intentionality. The functionalist approach has potential to make a relevant contribution to the understanding of forms of human teaching as well as that of nonhuman ones. Along with that, though, using only the functionalist approach to teaching has the potential to eliminate what is unique to human teaching (Strauss and Ziv 2011). In our view, neither approach should have hegemony. Each helps us gain an understanding of teaching in ways different from the other.

7.3 From Theory to Evidence: Minimalist Forms of Teaching among Adult Humans

Several forms of teaching behavior have been described in the framework of different human societies, ranging from tolerance to observation, to scaffolding and simplification, to stimulus enhancement, to teaching with feedback and, finally, to explanations and demonstrations.[1] Some of these forms are minimalist, requiring only a certain degree of acceptance of the learner's attention, with no specific modification of the teacher's behavior and with no need for mentalization. For example, in Fijian agro-pastoral societies, women tolerate children who observe them while cooking; men and women simplify daily tasks so that children can participate; they point and use motherese in ways that enhances the salience of the stimulus to be attended to; adults and children scold other children when they violate social taboos; parents teach through verbal explanations and gestures or gestural demonstrations alone, i.e. how to weave a basket (Kline 2015).

Anthropologist Barry Hewlett (Boyette & Hewlett 2018 this volume) presents evidence that hunter-gatherers/foragers of the Congo Basin (Aka and Bofi) teach their children, mostly vertically (parent to child) before 5 years of age, and obliquely (adult to child) and horizontally (child to child or adult to adult) between 5 and 12 years of age (Hewlett et al. 2011). Aka life is based on egalitarianism, autonomy, and sharing. On the autonomy side, children and even infants are generally free to play with machetes and other cutting devices. However, if they do not share, others (including other children) react by gesturing at them or teasing. Also, "*Young children often hear stories about how*

[1] (Caro and Hauser 1992) have proposed to organize teaching behaviors in three major categories: a. opportunity provisioning (giving young animals the opportunity to learn), b. coaching, and c. the invitation and encouragement to imitate a demonstrator. Opportunity provisioning can be enhanced through various forms of facilitation, e.g., reducing the complexity of the task, or helping the learner to deal with it. Coaching consists of encouragement and punishment techniques and happens in response to the learner's acts, rather than in preparation to them (as it is the case for opportunity provisioning). Invitation to imitate is accompanied by various forms of demonstrations and is considered as typically human. This basic classification as served as a basis for two others. (Hoppitt et al. 2008) have proposed 5 categories of teaching, each corresponding to a specific, observed form of social learning: 1. teaching through local enhancement - e.g. by attracting the learner to a particular spot, as it happens in the case described above of tandem running ants; 2. teaching by exposing the learner to the association between two stimuli - e.g. babblers conditioning the association between a particular call and food; 3. teaching through demonstration - e.g. humans demonstrating gestures and actions; 4. teaching by structuring the task for the learner so as to make it easier to learn - e.g. the case of meerkats simplifying the task for the younger learners; 5. teaching by encouraging and discouraging behaviors. The theory behind this kind of classification is that teaching has evolved to increase the likelihood of social learning, and that each form of teaching represents a superstimulus for facilitating that particular form of learning. Based on her ethnographic work in the Fiji Islands, and on an extensive review of the literature, anthropologist Michelle-Ann Kline has proposed a slightly different taxonomy of teaching types, which we have adopted here, ranging from very minimalistic to very demanding forms of teaching (in terms of the teacher's effort). In Kline's taxonomy, different forms of teaching represent the selected answer to different forms of learning problems, in given ecological conditions. The taxonomy proposed by Kline includes: a. teaching by social tolerance (in which the teacher simply accepts the presence and observation of another individual, beyond what she would do in "normal circumstances", but without altering her behavior relative to the task); b. opportunity provisioning, c. stimulus and local enhancement (the teacher creates opportunities for practicing, eventually simplifies the task for the learner; or the teacher "guides" learners towards relevant objects, puts them in situations where they have opportunities for learning specific skills or acquiring specific knowledge; more generally: the teacher manipulates the learner's attention); d. teaching by evaluative feedback (when the teacher rewards or punishes certain actions or their outcomes); e. directed active teaching (not just in the more developed forms of explicit formal teaching but also in communicative natural interactions, such as natural pedagogy) (Kline 2015).

people who do not share properly face sanctions (e.g. illness, death, death of a child)." (Hewlett et al. 2011), In addition, children declare that they learned how to share food and what to consider edible food from their parents, mainly same-sex parents.

These examples can be seen as complex forms of teaching, which include correction of behavior by peers and elders, and direct, explicit, verbal teaching about the values and norms that pervade the Aka way of life. At the same time, Aka show other, less cognitively demanding forms of teaching. First, they tolerate observation – even when observation is intrusive, e.g. sitting on one's lap while one is doing a chore ("*Forager children's high motivation to learn occurs early and often. Infants climb into their parents' laps to watch them cook, play an instrument or make a net. Children want to learn more than what parents and others want to give, but forager parents seldom refuse the intrusions of a child, because of their egalitarian and autonomy ethos*", Hewlett et al. 2011). Second, they provide children with "toys" (axes, spears, digging tools, baskets) that have the features of adult tools, but are child-sized and are accompanied by a pedagogical stance, which consists of encouraging, commenting on the use of such pedagogical artifacts and in guiding the gestures of the child ("*The infants chop, dig, etc., and the parents watch, laugh, make sounds and sometimes physically take the infants' hands to show them how to use the implement.*"). Another example of pedagogy in the form of scaffolding (demonstration and correction) of a naïve individual consists in an adult and young (12-year-old) Aka women teaching B. L. Hewlett how to weave a basket. Finally, there is evidence of horizontal instruction among children while at play, and namely while imitating productive activities. Note that (Wiessner 1982) and (Konner 2010) confirm the importance of teaching social norms of sharing among other populations of hunter-gatherers, namely the! Kung Of South Africa:

> "*Wiessner described how parents removed beads from infants' necklaces and had them give the beads to appropriate kin relations so they could learn about sharing networks. Konner also indicated that !Kung learn to share early: '!Kung value sharing very highly, and from the time their infants are six months of age mothers and other adults frequently say 'Na' meaning 'Give' when a bit of food is in the infant's hand and on the way to its mouth. The criterion is that they should inhibit the very strong impulse to eat and reliably turn the morsel over to the adult making the demand'.* (Hewlett et al. 2011).

Not only do various pedagogical techniques exist among farming and hunter-gathering/foraging societies, which require different amounts of cognitive computation, but teaching in these societies is not limited to tool-making and food provisioning skills, also investing in values and norms that are relevant for that particular society.

8 Discussion

8.1 Characterizing Teaching in Terms of Elementary, Functional Units (Basic Building Blocks)

The extent of teaching behaviors is vast, ranging from very minimalist to the very complex and demanding. It is unlikely that these behaviors are all served by a unique

set of neurocognitive mechanisms and processes, especially a set made of demanding, complex neurocognitive underpinnings. Given our analysis of the four approaches and of the evidence gathered to date, we believe that it might be the case that teaching behaviors are underpinned by a finite group of *functional units* or *building blocks*. These functional units are common to minimalist and less minimalist forms of (human) teaching, and are also shared by documented forms of nonhuman animal teaching. They are neutral to the specific neurocognitive architecture that implements them.

From our review, we detected four basic building blocks, and it is to them that we now turn.

1. *Selective-Responsiveness Block*. Each form of teaching requires some form of sensitivity to the learner and of selective responsiveness to him/her/it. Educational-cognitive approaches to teaching tend to invoke high-order capacities (ToM) to fulfill the task, but it has become evident from the discussion of ToM - as well as from examples of animal teaching and of minimalist forms of teaching in humans – that simple tracking systems and pre-wired adaptations may do the job – at least when simple forms of teaching are involved. Sensitivity to the learner might be required even in the case of tolerance to observation in order to decide who will be tolerated as an observant learner and who will be treated as a disturbance.
2. *Relevance-Signaling Block*. Each form of teaching requires some mechanisms for attracting – eventually focusing – the attention of the learner upon an object, action, location, feedback, demonstration or explanation. Some mechanisms for synchronizing with the learner around a shared object or task are described in the case of human instructed learning, and more generally in the case of cooperative tasks. Ostensive gestures and other "tools" employed in natural pedagogy interaction have been described as communicating the fact that we are communicating something and, in so doing, we are intentionally preparing the L for the content of the message. When doing this, we are communicating ostensively having the effect of making the information relevant to the learner (and eliciting specific behaviors on the side of very young learners). However, in more minimalist forms of teaching, the time-lockedness of the interaction[2] and the sensitivity of the learner to the presence of a teacher can be sufficient for obtaining this effect (e.g., in the case of tolerance to observation). In the case of stimulus enhancement, for instance, the very presence of a social model (teacher) represents a cue that enhances certain physical stimuli in the learner's environment, and drives the learner's attention to them. The Relevance-Signaling building block can thus be implemented differently according to the teacher's (and learner's) neurocognitive architecture, but it does not require particular forms of metacognitive activity on the side of the teacher. Moreover, even natural pedagogy tools consist of reflexive, prewired mechanisms that human teachers employ without even knowing that they will make a difference for the learner. Such tools can thus be considered as simple functional units that do not require higher-order cognitive architectures.

[2] Current researches in brain-to-brain coupling are susceptible of shedding new light on the neural processes that underpin the creation of this kind of synchronicity, how it affects learning and its role in creating a shared experience between individuals (Hasson et al. 2012).

3. *Information-Giving Block.* Some form of information-giving is involved in all the categories of teaching. However, these forms vary considerably from one kind of teaching to another. Cognitive approaches to teaching cite both language (or other symbolic tools) and gestures (iconic gestures, gestures for demonstrating, gestures for repositioning the body of the learner, giving feedback …). Animal studies provide examples of signals and cues, such as birdsongs. But even other forms of action – the simplification and structuring of a task (acting in the place of the learner, as in carrying ants toward a new nest or in disarming a scorpion), the provisioning of an opportunity to learn – can be considered as forms of information-giving. Sometimes a simple cue-response system is sufficient to indicate that the information given is appropriate for the learner, other times the transmission of information implies a finer matching of the task to the learner's state of knowledge, thus implying some form of metacognition relative to the task in addition to the capacity of tracking the knowledge state of the learner. But these are not necessary to define teaching, and may only intervene in some of its complex forms. The variety of possible implementations is huge and this diversity can easily justify the impression that teaching hardly looks like "one thing". However, the form through which the information-giving functional unit is implemented (an adaptation or a specific neurocognitive function) is not essential to its definition.
4. *Motivation-To-Influence Block.* Teaching is an activity that requires some form of explicit or implicit motivation, such as: the motivation to encourage certain behaviors (e.g. predatory behaviors) and to discourage others (e.g., not eating a poisonous leaf, violating a taboo) to influence others and modify their actions according to norms, standards, accepted rules (e.g. in games) and to accept (tolerate) becoming a model for imitation/observation. All these, and more, are forms of influence that promote some conformity to the teacher. In one way or another, the teacher is then motivated to influence the learner and to modify the learner's behavior according to the teachers' own knowledge, beliefs, ways of doing, norms etc. However, the motivation to influence need not be represented metacognitively. The teacher and the learner can act as if they had this motivation. The motivation can simply be the function the behavior responds to, the selective force behind the existence of the behavior. The compliance of the learner to the teacher can be to the learner's advantage. This aspect is captured by the behavioral-functional definition of teaching, according to which, in virtue of teaching interactions, the learner's skills are enhanced.

   Typical examples of this are represented by teaching and learning opaque knowledge and by teaching and learning dangerous skills (such as predation of poisonous scorpions). However, this does not seem to be the only motivation for teaching, not even for learning (imitating) from models, e.g., conformity to teachers can be promoted because it lowers conflict, to the advantage of both the learner and the teacher. Or because it promotes collaboration, as when teaching someone else how to play a game (together) and how to solve a problem (in a cooperative task). Or even because it creates common ground, e.g. for establishing alliances, for communication and sharing, for bonding, etc. One of the effects of teaching is the reduction of distance and the creation of a shared perspective between the teacher and the learner. After the process

of teaching-learning has taken place, the mental states of the learner and of the teacher are more similar - the learner having "adopted", by learning them, those of the teacher.

To summarize, despite their diversity, teaching behaviors may require only a small number of functional units to be in place: they may have a common core. First, teaching implies certain forms of responsiveness to learners (and to teachers). Second, during teaching interactions some information is made relevant and, third, given. Fourth, teaching responds to a motivation to influence and create compliance to the teacher. The common core of teaching is not exclusive to (adult) humans. The specific mechanisms that implement these functional units (building blocks) can vary considerably. The fact that each building block can be implemented in different ways – depending on the cognitive architecture and on the circumstances of teaching – might explain why observed forms of teaching vary widely and look very different in human adults, in children, and in meerkats.

This leaves the door open for greater latitude in the search for the mechanisms that put teaching into play in different species, under different circumstances, in relationship with different neurocognitive architectures. Various domains of research (animal studies, behavioral ecology, cultural studies, developmental, cognitive, evolutionary psychology, artificial systems research) can use this characterization and the building blocks approach as a framework for specifying the mechanisms at stake, case by case.

Many other questions remain open: about the self-serving advantages of teaching, its evolutionary path in different species, the possibility of reproducing teaching artifacts from the study of natural teachers, that of "empowering" natural teachers via a better understanding of teaching behaviors and more. Nothing less than a large, multidisciplinary effort is required in order to advance our knowledge about teaching, how we teach and why.

Another open issue is that these four basic building blocks are not unique to teaching. All four appear in behaviors other than teaching. For example, the Motivation to Influence Block can be seen in, say, alpha males of baboon tribes asserting their dominance so as to influence the other males' behaviors towards females in the tribe. What this could mean for the thesis we have been proposing on these pages is that all four may be co-opted when teaching occurs. What makes teaching unique is a topic that needs discussion.

9 The Special Issue's Content

The contributions included in the present special issue offer a multi-disciplinary overview of teaching as a cognitive ability (or as a sum of cognitive abilities with specific properties and functions). They can be divided into two main groups.

The first group of contributions deals with the evolution of teaching as a strategy related to cultural evolution.

Christine Caldwell, Elizabeth Renner, Mark Atkinson investigate the roles of teaching in terms of the transmission of knowledge and know-how that is particularly difficult to acquire individually or via social learning (imitation, emulation). They provide a comprehensive review of positions taken regarding the places of teaching

in cumulative culture. Teaching thus might have played a role in the accumulation of culture, especially in human beings.

There is disagreement among social anthropologists as to whether or not there is teaching among hunter and gatherers (HGs). This can be framed in a larger question about teaching being universal among humans. Within this controversy, Adam H. Boyette and Barry Hewlett claim that teaching occurs in HG bands. Along with that, though, they add nuance to what teaching looks like there and cast it within the cultural emphases on autonomy and egalitarianism found among HG societies. The authors posit that HG societies offer multiple and varied examples of teaching, discuss how teaching has both co-evolved with culture and contributes to the construction of our particular cultural niche.

Michael Chazan contributes to the understanding of the evolution of teaching among hominins with a review of the literature in cognitive archaeology. He deals mostly with the "life cycle" of stone tool production (making the tool, using it, maintaining it and, eventually, discarding it) at different points in the Paleolithic era. Chazan takes into account constraints and characteristics of hominin evolution such as the variability of the dynamics of the environment, the adaptive advantage of social learning and the progressive development of technology and opaque knowledge. For example, he argues that at times of dynamic paleoclimate changes, there was more of a need for trial and error learning as opposed to periods when there was relative paleoclimate stability where there was more of a need for transmission of cultural knowledge. He believes that it is plausible that all these characteristics have influenced the specificities of human teaching, including its flexibility as compared to teaching among other animals.

Along these lines, Emily R. R. Burdett, Lewis G. Dean, and Samuel Ronfard suggest that teaching in humans is more flexible, diverse and complex than in other species. One of the balancing acts they present is the tension between the production of innovations that lead to changes in the culture and the preservation of these very cultural innovations. The former is achieved through low-fidelity transmission mechanisms, whereas the latter happens via high-fidelity transmission (including teaching). The balancing act between innovation and preservation is maintained by what they term a teaching tool-kit found among humans. Because humans are thought to have the ability to teach using both high- and low-fidelity transfer mechanisms, they can fit the kind of mechanisms they choose to the demand characteristics of the tasks at hand.

The second group of contributions deals with teaching in children as an instinct that progressively exploits different cognitive abilities.

The existence of teaching before cognitive maturity reinforces the image of a cognitive ability that is grounded into more basic functions that are present from early childhood and are possibly based on natural predispositions. Cecilia I. Calero, Andrea P. Goldin and Mariano Sigman have studied teaching in pre-school children and shown that when teaching others, they use the same tools that have been previously identified in adults who assume a pedagogical position. Rather than study the roles of ostensive cues among the receivers of teaching, learners, they tested whether or not children who are the emitters, i.e., teachers, produce ostensive cues. Their findings show that youngsters do teach using ostensive cues. In addition, they suggest that human teaching does not necessarily involve ToM. The authors also reverse the traditional relations between teaching and metacognition. They suggest that instead of teaching requiring metacognition, teaching might be the catalyst for metacognition's development.

Teaching behaviors and capacities develop. This is further evidence that human teaching is grounded on more elementary skills and tools that develop with age, some of which do not require reflexive metacognitive capacities, but are eventually enhanced and modified by their development. In their respective contributions, Kathleen Corriveau, Samuel Ronfard & Yixin K. Cul, and Samuel Ronfard & Paul Harris show that children can teach selectively, that is, they adapt their teaching to the target learner, and namely to what the learner knows or ignores. Corriveau points out that flexible teaching of this kind depends on the development of the ability to represent others' mental states, in real time, and on executive functions, as well. Ronfard and Harris propose that children are more susceptible to teach norms, generic knowledge and knowledge that is difficult to acquire. This differential susceptibility indicates that teaching might respond to motivations that go beyond the fact of "filling-in a knowledge gap", and that teaching has a normative value as well as the function of transmitting knowledge that the learner might not acquire on its own and that the teachers "wants" to impinge in the learner.

The final contribution opens up new perspectives on the study of teaching and its building blocks. Anne-Lisa Vollmer and Lars Schillingmann reverse the usual teaching situations where robots teach humans. They use robots as learners, and to modify the learner properties so as to induce different teaching on the part of human teachers. In this way it is possible to study the teacher's attitudes in response to learners in controlled settings.

The different contributions presented are compatible with the theory proposed in this editorial, that teaching is a natural cognitive ability grounded on building blocks that are present from childhood and have an evolutionary history, that are all combined together in an adaptive complex function that both responds and fosters cultural evolution. Since the basic building blocks develop with age, teaching abilities and behaviors develop, too. The specificities of human teaching are thus explained when both human cultural evolution is taken into account and human cognitive architecture is considered.

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