**Teaching and its building blocks**

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**ABSTRACT (LONG)**

Educational research and mind and brain sciences have strengthened their cooperation during the last decade, to the extent that a new field of research has been developing. Although progress has been made in dissecting the neurocognitive mechanisms underlying learning, much less is known of those supporting teaching. This has become especially untenable in the light of mounting evidence that teachers have an important, long-lasting impact on their pupils. Moreover, the interest for teaching goes past practical, educational aims. Teaching is a topic of fundamental research susceptible of leading to a better understanding of human culture, cultural evolution, cognitive development, and cognition writ large. A major difficulty in the direction of the understanding of teaching is related to the absence of a shared characterization: teaching is an ambiguous term, used to refer to a diversity of behaviors. It is even doubted whether these behaviors have something in common, cognitively speaking. Educational-cognitive approaches tend to focus on the more complex forms of teaching and to define teaching as an intentional behavior served by computationally demanding cognitive skills – such as metacognitive skills and a theory of mind. Such definitions tend to exclude *in principle* non-human animals from the picture. Quite the opposite, functional-behavioral definitions that have been proposed in the framework of animal and cultural studies of teaching include simple forms of teaching but abandon any reference to the cognitive requirements that are necessary for teaching. While these approaches all use the term 'teaching' it is not clear whether teaching is actually *a thing* or many, and whether the different strands of research can converge for a better understanding of 'teaching'.

In the present paper I advocate that while teaching comes in a multitude of forms (including cognitively simple, pre-wired behaviors), cognitively speaking the capacity of teaching is grounded on a set of functional prerequisites that are necessary for teaching. I call these prerequisites the "building blocks" of teaching. Building blocks can be combined in different ways, thus giving rise to different forms of teaching. They can be implemented by different neurocognitive underpinnings and adaptations, hence are not specific to one particular neurocognitive architecture. The specific building blocks I propose in the course of the paper emerge from the analysis of current theories of teaching, both educational-cognitive and functional-behavioral theories, and from additional evidence gathered from cognitive, developmental, cultural, and animal studies. They belong to three main categories: motivations for sharing and for influencing others' behaviors; capacities related to the sharing of experience in relationship with relevant information; tools for sharing information and for influencing others. Different forms of teaching make use of different building blocks, but they all use some in the three categories. They thus have a common cognitive core based on minimal prerequisites and constitute a specific class of cognitive behaviors.

Compared to existing approaches to teaching, the main advantage of the building blocks' approach is that of being more comprehensive: of permitting to include in the picture simple as well as highly complex forms of teaching without giving away cognition. For this reason, the building blocks approach to teaching has the potential to create common ground for human developmental, cognitive, cultural and animal studies to converge towards a shared understanding.

The building blocks approach also creates favorable ground for empirical studies of teaching. By disambiguating the term ‘teaching’ and by proposing a number of prerequisites for teaching to develop and to evolve, it gives rise to predictions about *who* can teach and *how*. Namely, the building block approach predicts that in the absence of prerequisites from the three categories teaching cannot develop, or evolve. *Vice versa*, that for any form of teaching, building blocks from the three categories should be present. Finally, that different combinations of building blocks from the three categories will produce different forms of teaching.

**ABSTRACT (SHORT)**

Although progress has been made in dissecting the neurocognitive mechanisms underlying learning, much less is known of those supporting teaching. A major difficulty in the direction of the understanding of teaching is related to the absence of a shared characterization: teaching is an ambiguous term, used to refer to a diversity of behaviors. It is even doubted whether these behaviors have something in common, cognitively speaking. In the present paper I advocate that while teaching comes in a multitude of forms (including cognitively simple, pre-wired behaviors), cognitively speaking the capacity of teaching is grounded on a specific set of minimalist, functional prerequisites, that are necessary for teaching. I call these prerequisites the building blocks of teaching. Building blocks can be combined in different ways, thus giving rise to different forms of teaching. They can be implemented by different neurocognitive underpinnings and adaptations, hence are not specific to one particular neurocognitive architecture. They belong to three main categories: motivations for sharing and for influencing others’ behaviors; capacities related to the sharing of experience in relationship with relevant information; tools for sharing information and for influencing others. Different forms of teaching make use of different building blocks, but they all use some in the three categories. Teaching behaviors thus have a common cognitive core based on minimal prerequisites and constitute a specific class of cognitive behaviors. The building blocks approach creates favorable ground for empirical studies of teaching. By disambiguating the term ‘teaching’ and by proposing a number of prerequisites for teaching to evolve and to develop, it gives rise to predictions about *who* can teach and *how*.

**KEYWORDS**

**teaching, social learning, ontogenetic development, evolution, animal studies, developmental research, cognitive science, education**

## INTRODUCTION

*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 practice copying the models on their own. One child is having particular difficulty. The teacher walks over, cups the pupil's hand in hers and molds 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.*** (Byrne & Rapaport, 2011, p. 1207)

Teaching skills, teachers' training, and teachers' effects on pupils have been studied by scholars in the domain of education for decades; mounting evidence shows that teachers have an important, long-lasting impact on their pupils (Clark & Lampert 1986, Kane & Staiger 2008, Konstantopoulos 2007, Nye et al. 2004, Olson & Bruner 1996, Rivkin et al. 2005, Rodriguez 2012, Strauss 2001). In particular, the quality of teachers correlates with real life indicators of socioeconomic status, including retirement plans, salary, and house ownership (Chetty et al. 2011). Teaching is considered a difficult task, its results uncertain. We still lack a consensual measure of what counts as good teaching and a good teacher in an educational setting (Chetty et al. 2014, Coe et al. 2014, Darling-Hammond 2012, Gordon et al. 2006, Kane et al. 2013, Kane & Steiger 2008, 2010, Rothstein & Mathis 2013, Konstantopoulos 2008, Rothstein 2010). The interest for teaching however goes past practical, educational aims. Teaching is a topic of fundamental research susceptible of leading 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, norms, in the emergence of culture and in cumulative culture among humans (Atran & Sperber 1991, Boyd & Richerson 1995, 1996, Castro & Toro 2014, Csibra & Gergely 2011, Dean et al. 2012, Gergely & Csibra 2006, Laland 2008, Richerson & Boyd 2005, Sperber 1996, Tomasello, Kruger & Ratner 1993, Sterenly 2007, 2012, 2013, Tomasello & Rakoczy 2003, Whiten et al. 2011). Experiments in cognitive archeology show that teaching improves transmission of techniques for the fabrication of clapped stones and suggest that the emergence of teaching is a favorable factor for the appearance of complex technologies (Morgan et al. 2015, Teherani & Riede 2008). Developmental studies on babies and children suggest the existence of specific mechanisms that facilitate learning from teaching (Csibra 2007, Gergely & Csibra 2006, Csibra & Gergely 2006, 2009, 2011) and

of mechanisms that shape children's selective choice of whom to learn from (Corriveau & Harris 2009, Eaves & Shafto 2012, Gweon et al 2014, Harris & Corriveau 2011, Shafto et al. 2012, Sperber et al. 2012). 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 & Tomasello 1998, Bonavitz et al. 2011, Calero et al. 2015, Corriveau & Harris 2009, Davis Unger & Carlson 2008, Eaves & Shafto 2012, Gweon et al 2014, Harris & Corriveau 2012, Knudsen & Liszkowski 2012, Köymen et al. 2015, Shafto et al. 2012, Sperber et al. 2010, Strauss 2005, Strauss & 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, Maynard 2002, 2004, Maynard & Greenfield 2005). It is not the case, then, that teaching is a culture-specific behavior, as it has sometimes been claimed by ethnographers and anthropologists (e.g. Gaskins & Paradise 2010, Lancy & Grove 2010, Paradise & Rogoff 2009; for a review: Kline 2015). Rather, the picture emerging from this recent, pluri-disciplinary literature on teaching suggests that there is something like a 'teaching instinct' – that teaching is, at least in part, an act that comes naturally to human minds, possibly present since childhood (Strauss et al. 2002, Strauss & al 2014). More controversial is the existence of teaching as an adaptive behavior in other species. While observational evidence of teaching exists for several taxa, teaching behaviors have been experimentally studied only in few species. Nonetheless, animal studies propose that teaching facilitates social learning and suggest that teaching behavior might represent an adaptive solution that reduces the costs and risks of individual learning*;* natural selection could then have favored the evolution of teaching at the advantage of offspring and relatives in other species than humans (Fogarty et al 2011, Hoppitt et al 2008, Thornton & McAuliffe 2012, Thornton & Raihani 2008).

**Objectives**

Despite the fact that interest in teaching has been growing recently, especially in the domains of developmental psychology, cultural anthropology and animal studies, few studies have addressed teaching from a neurocognitive point of view and only few cognitive prerequisites that are deemed necessary for teaching have been pointed at for the moment (Battro 2010, 2013, Battro et al. 2013, Strauss 2005, Strauss & Ziv 2012, Strauss et al. 2014). A major difficulty in the direction of the understanding of teaching is related to the absence of a shared characterization (Kline 2015, Skerry et al. 2013). Teaching emerges from current studies as an ambiguous term. Educational and cognitive approaches tend to focus on complex forms of teaching and to define teaching as an intentional behavior that mobilizes computationally demanding cognitive skills considered to be specific to humans - such as reflexive metacognitive skills and a theory of mind. Animal teaching is thus dismissed as proto-teaching by developmental and cognitive researchers on the grounds that the forms of teaching that have been described in the case of non-human animals are limited in scope and lack flexibility (Csibra 2009, Premack 2007, Strauss & Ziv 2012). Quite the opposite, functional-behavioral characterizations of teaching that are current in animal studies, tend to include simple

forms of teaching but to abandon any reference to the cognitive requirements that are necessary for teaching (Byrne & Rapaport 2011, Caro & Hauser 1992, Fogarty et al 2011, Hoppitt et al 2008). While the educational-cognitive approach risks being too restrictive (when plotted against evidence about teaching in young children and in non-human animals) the functional-behavioral is too quick in throwing the baby out with the bathwater (the search for cognitive prerequisites with the idea that higher order cognitive functions are required for teaching). When comparing these approaches it is not even clear whether teaching is actually *a thing* or many, and whether there is common ground for these strands of research to connect.

In the present paper I explore a third option to the study of teaching, mid-way between the level of description adopted by educational-cognitive approaches and the level of description adopted by functional-behavioral ones. The proposed approach is cognitive but minimalist in that it aims at identifying the *minimal prerequisites* that make teaching possible. I call these prerequisites the 'building blocks' of teaching. The level of description of the building blocks is purely functional: the same building blocks can in principle be implemented by different neurocognitive underpinnings and adaptations. Building blocks are thus functional prerequisites that are necessary for carrying out teaching, but do not belong to a neurocognitive architecture in particular.

Through the building block approach I intend to answer the question whether there is sufficient ground for treating teaching as a thing, on the account of its many forms, and to propose a characterisation of teaching that can bridge different strands of research and pave the way to the identification of specific neurocognitives underpinnings and adaptations through which the different forms of teaching are carried on (in different organisms, at different ages, in different situations, in relationship with different contents). The building blocks approach can also help answering the questions of how we teach and of who can teach. By identifying teaching minimal prerequisites we are in fact isolating the ingredients of teaching at a functional level, but these ingredients can be used as frameworks for orienting research on the specific underpinnings and adaptations that put teaching into play in human an non-human animals, at different stages of development, in different systems (including artificial systems), for different contexts and contents. These ingredients are not simple components of teaching, but necessary conditions, in the sense that only the systems presenting the required building blocks are susceptible of developing or of evolving teaching. By isolating the building blocks of teaching it should then be possible to identify the organisms that are more susceptible of developing teaching, or for whom teaching is not an option.

In bulk of the paper I proceed at the analysis of current theories of teaching and of relevant evidence that can lead to the identification of minimal requirements of teaching. In the discussion, I proceed at proposing a limited number of building blocks that constitute the minimal requirements for different forms of teaching and I divide them into three categories - motivations, capacities and tools; different combinations of building blocks from the three categories can give rise to different forms of teaching. Finally, in the conclusions, I propose a definition of teaching that goes past the opposition between educational-cognitive and functional-behavioral approaches.

## METHODS

In order to identify the building blocks of teaching, I have selected four theories, which characterise teaching in different ways. Each theory deals with motivations, capacities and tools for teaching. In the bulk of the paper I progressively extract the prerequisites of teaching from these theories and I correct them in the light of empirical evidence that I draw from developmental, cultural and animal studies.

The first theory has been proposed by cognitive scientist David Premark, who considers teaching as a specifically human capacity (a. Premack's Theory of human teaching). Premack puts the accent on normative aspects of teaching and on the role of mentalizing capacities in the form of a theory of mind, plus linguistic tools and gestural modification. The theory thus puts high demands in cognitive terms on the teacher. It is however possible, in the light of additional evidence and of the comparison with the other theories, to reduce this demands to minimalist requirements. The second theory discussed below has been advanced by psychologist of education Sidney Strauss in relationship with teaching in children. It presents teaching across the life span as an altruistic intention to fill-in a knowledge gap, based on information giving mechanisms (b. Strauss' Theory of teaching as filling-in a knowledge gap). Evidence shows that information giving mechanisms are present early in development, as it is the case for the normative attitudes proposed by Premack, and thus constitute good candidates for the building blocks of teaching. The third theory emerges from a more general theory of learning and cooperation proposed by developmental psychologist Michael Tomasello and colleagues (c. Tomasello's Theory of instructed learning). Tomasello and colleagues stress the role of social motivations in teaching (the motivation for sharing common ground, including through conformity to a model), the importance of mechanisms for gathering and orienting the attention of the learner so as to signal the relevance of a certain object or event, and the role of particular classes of gestures for singling the pedagogical nature of the interaction. Relevant evidence is discussed in relationship to these proposals, and further lines of research are proposed. The fourth selected theory corresponds to the view embraced by animal and cultural studies on teaching and social learning, following the seminal article by Tim Caro and Marc Hauser published in 1992 (d. Caro's and Hauser's Functional-behavioral theory of teaching). While the first three (cognitive) theories offer different but reciprocally compatible characterizations, they all conflict with the functional-behavioral approach to teaching.

### A rationale for comparative studies, and a vision

A pivotal strategy for the identification of minimal prerequisites for teaching or building blocks is represented by the comparison between human and animal studies, cognitive and functional-behavioural approaches. This strategy is still rather uncommon in relationship with teaching. Both cognitive and functional-behavioral 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. From this consideration 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 non-human animals, analogous to those identified in the human cognitive architecture, on the ground that the respective (teaching) behaviors share functional similarities. This objection is not specific to teaching, of course: 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 & Wynne 2009) (see also Bolhuis et al. 2011, Hemelrijk & Bolhuis 2010). Nonetheless, we shouldn't 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. Combining studies of human and animal teaching allows making abstraction from the constraints and possibilities that each type of cognitive architecture imposes. Limiting oneself to human studies, on the contrary, is susceptible of hiding categories of skills and motivations that can be carried out by less complex neurocognitive underpinnings, at a lesser 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. This claim goes on par 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, which consists in looking for human-like capacities in non-human animals, and of starting searching for simple and unconscious mechanisms, triggered by behavioral cues in humans, similar to those that have been identified in the case of non-human animals. In her opinion, 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 vision is similar to the one purported by (de Waal & Ferrari 2010) and 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 vision is also at the basis of the building blocks approach proposed in this paper for the study of teaching.

*TABLE 1. Theories of teaching, their characterizations and their prerequisites*

| **a. Premack's Theory of human teaching** | **b. Strauss' Theory of teaching as filling-in a knowledge gap** | **c. Tomasello's Theory of instructed learning** | **d. Caro's and Hauser's Functional-behavioral theory of teaching** |
|---|---|---|---|
| Teaching is a developmental ability, consisting of three main *actions* and arising from the interweaving of three uniquely human *dispositions and abilities*. | Teaching is an *intentional act*, motivated by an *altruistic* stance to fill in he knowledge gap in someone else's mind. Teachers build on their ToM. Proto-teaching and early teaching exists in the absence of full-fledged ToM. | Instructed learning is a form of social learning in which the learner imitates a demonstrator's actions and gestures. | Teaching is any modification of the teacher's behavior in the presence and only in the presence of naive observers that produces better learning outcomes for the learner, with no immediate benefit for the teacher. |
| Prerequisites *i. Aesthetics (normative attitude) ii. ToM iii. Language and gesture modification* | Prerequisites *i. Altruistic intention to fill-in a knowledge gap ii. ToM iii. Information giving mechanisms and tools* | Prerequisites *i. Social motivations to share, cooperate and conform ii. Perspective taking iii. Pedagogical and performing gestures* | Prerequisites *i. Altruism ii. Sensitivity to the learner's states iii. Capacity of action and of altering one's behavior in response to the learner's states* |

*TABLE 2. Relevant evidence*

| **a. Premack's Theory of human teaching** | **b. Strauss' Theory of teaching as filling-in a knowledge gap** | **c. Tomasello's Theory of instructed learning** | **d. Caro's and Hauser's Functional-behavioral theory of teaching** |
|---|---|---|---|
| A normative attitude appears early in development. | Information giving and mistakes' correction appears early. | Social motive for teaching include sharing and conformity. | There's experimental evidence of animal teaching that does not require human higher-order skills. |
| Minimal mentalizing suffices for teaching. | Information giving and teaching are not limited to altruistic intentions. | Perspective taking and cooperation appear early in development. | Minimalist forms of teaching exist among adult humans. |
| | | When imitating, children respond to pedagogical gestures, not only actions. | |

*TABLE 3. Building blocks of teaching, organized in three categories*

| **1. Motives for sharing information and altering others' behaviors** | **2. Conditions and capacities that make information relevant in a shared experience** | **3. Tools for sharing, giving, altering** |
|---|---|---|
| (1a) the promotion of conformity to standards, and the relative motivation to correct deviations from them. | (2a) Responding to or tracking others' mental states, so as to be able to react to them in a sufficiently specific way, according to the circumstances. | (3a) Communicative signals: verbal, vocal, gestural, … |
| (1b) Disposition to share and give information, that can be itself motivated by altruistic or by self-serving motivations. | (2b) Attracting attention upon an opportunity, stimulus, place or association, the teacher's actions, feedback, reward, punishment, demonstration or instruction that the learner should attend to. | (3b) Indexing, attracting, enhancing gestures. |
| (1c) Motivation to create common ground, that can lead to cooperation as much as to conformity. | (2c) Space and/or time synchrony | (3c) Performing gestures that enable the teacher to act in the place of the learner, provide opportunities, enhance stimuli and places for the learner, show actions, correct and reward the learner's actions. |

## ANALYSIS AND RESULTS

**(a) Premack's Theory of human teaching**

Within the first theory, teaching is a developmental ability, consisting of three main *actions* and arising from the interweaving of three uniquely human *dispositions and abilities*. First, the teacher observes the potential learner (observation); then the teacher assesses the learner's actions and products against norms and standards (judgment); and finally, the teacher alters the learner's behavior to make it more compliant with the standards (modification). Correspondingly, the three cognitive components that are necessary for teaching and that characterize human teaching according to Premark are: *(i) aesthetics, (ii) ToM, and (iii) language plus expertise in gesture modification* (Premack & Premack 2004, 2003). Aesthetics represents a set of standards that define what makes a gesture, product, conduct appropriate. It is a normative attitude, and it constitutes the motivation for correcting others and norming their behavior, as expressed by this citation: "*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).

In Premack's characterization, possessing a theory of others' minds (ToM) is a necessary condition for determining whom and what needs to be taught. ToM includes a theory of development, which helps teachers identifying children and youngsters as susceptible of needing to be taught. Language and the capacity of passive guidance are the tools that humans mostly use for teaching - the latter being involved in placing the body of others in the desired positions (Premack 1984, 1991, 2010). There's 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 thus relies not only on the teacher's motivations, theories and tools, but also on those of the learner. 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, cases of non-human teaching – e.g. meerkats and cats, which Premack considers the only two ascertained cases of animal teaching and that we will discuss later in this paper - are examples, in Premack's view, of rigid adaptions 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 for oneself. Since children have been observed to help other children at large, their disposition to teach cannot be attributed to kin or reciprocal altruism, but to the evolution of dispositions to help the group.

In the following sections, I analyze evidence related to the normative dimension of teaching and introduce evidence about motivations for teaching that go past altruism. I also discuss ToM and the problems that a view of teaching based on ToM entails for identifying the minimal prerequisites for teaching. I suggest a possible solution based on

minimal mentalistic abilities.

***From theory to evidence (1): A normative attitude is present early in development***

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-old understand norms (e.g. the rules of a game, Rakoczy & Schmidt 2013) and object to a puppet violating the rules of a game: they tend to correct the puppet and may use normative language ("It is not like this" "You have to do like that") (Rakoczy Warneken & Tomasello 2008, Rakoczy et al. 2009, Schmidt & Tomasello 2012). Children aged 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-old, the use of language shifts from specific to generic and law-like (Koÿmen et al. 2015). It is worth noting that children of this age can extract the norms they successively 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 successively 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 Rakoczy & Tomasello 2011). It is also worth noting that children of this age distinguish between moral norms (norms whose violation can produce harm) and simple conventions (or norms related to game-play): moral norms are enforced to everybody with no distinction of group belonging, conventional ones are selectively enforced to members of their own group, (Schmidt & Tomasello 2012). In the light of this kind of 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 within one's group, and that the motivations that sustain teaching to in-group members are slightly different from those of law enforcing moral norms that can be indifferently directed to in-group and out-group members. In the light of this brief review of children's understanding and enforcing of norms, it is a plausible hypothesis that 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 Warneken & Tomasello, 2009). The normative dimension of teaching thus deserves further attention if we are to unlock the motivational building blocks of teaching.

***From theory to evidence (2): Minimal mentalizing suffices for teaching***

As Premack's theory of teaching, the two other cognitive approaches to teaching that will be discussed below revolve around the capacity of attributing mental states to others and evoke the notion of Theory of Mind. However, this notion is problematic within a minimalist approach and thus requires a preliminary discussion to disambiguate its role in teaching. As explicitly stated by Premack (1994), the skilled interpretation of others' mental states is most probably a composite function (see also Korkmaz 2011). Moreover,

the attribution of mental states is not consensual ground, as shown by the different terminologies for addressing mentalizing capacities ("ToM", "mindreading", "understanding others' minds"), by contradictory interpretations of the evidence about the ontogenetic development of the attribution of false beliefs, and by conflicting views on the conceptual vs non-conceptual nature of such capacities in humans and non-human animals (Apperly 2012, Baron-Cohen Leslie & Frith 1985, Heyes 2012, 2015, Heyes & Frith 2014, Gopnik & Meltzoff 1987, Leslie 1987, Premack & Woordroof 1978). It is not among the objectives of this paper to present all the possible alternatives that have been proposed for explaining the evidence concerning mentalizing capacities in adults, infants, and non-human animals. But because a lack of agreement has potentially a negative impact on the understanding of the role of ToM in teaching, it deserves attention. In what follows I describe the major points of disagreement and a temporary solution *as far as the building of a theory of teaching is concerned*.

First, experts disagree on the development of mentalizing, namely on the role and timing of succeeding at false beliefs tests that measure the capacity of projecting oneself in another's mind while taking distance from reality. With different tests, the time for achieving this capacity ranges from 4-years-old to 2-years-old and even to 13 months of age (Baron-Cohen Leslie & Frith 1985, Wimmer & Perner 1983, Hutto, Herschbach, Southgate 2011, Southgate Senju & Csibra 2007, Surian Caldi & Sperber 2007, Scott & Baillargeon 2009). Second, experts disagree on the 'crosscutting points' that distinguish full-fledged forms of mentalism from precursors and component processes. In the domain of comparative psychology (Call & Tomasello 2008) distinguish between: understanding or reading goals and intentions, reading perception, reading knowledge, and reserve "ToM" to the attribution of false beliefs. (ToM, construed as the attribution to others of false beliefs, represents for these authors a special ability set apart from other forms of mindreading because, while chimpanzees and young children can detect ignorance as opposed to knowledge, only the latter seem to be able to detect errors based on false beliefs. Call & Tomasello 2008). The capacities listed above can however be implemented in different ways, and the same behaviors can be the product of different neurocognitive processes. Developmental psychologist and primatologist Daniel Povinelli, for instance, distinguishes between the capacity of tracking "*statistical regularities that exist among certain events and the behaviors, postures, and head movements (for instance) of others*" (Povinelli, 2004) and conceptual abilities that serve the same purposes. While chimpanzees are limited to the first, humans can combine behavioral tracking systems and concepts (Povinelli & Vonk 2003, Penn & Povinelli 2007). Psychologist Ian Apperly and philosopher 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), but efficient, evolutionary and ontogenetically ancient (that is, it is supposedly present since early development and probably shared with other taxa). 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 (and might possibly be trained). The tracking system does not disappear with the development of thoughtful mind reading, but continues to operate especially in particular conditions of stress, cognitive load, time pressure (Apperly & Butterfill 2009, Butterfill & Apperly 2013). Thus, while teasing

apart the presence of mentalizing abilities in chimpanzees might be relatively easy given the appropriate experimental setting, it might be trickier to decide whether humans are relying upon a tracking system or a conceptual system when teaching - whether human teachers rely on mechanisms that require great amounts of complex computations in order to pick whom to teach and how; or if they rather employ behavioral rules that dispense them from complex computations and conceptualizations; or both.
A 'minimal theory' of mentalizing such as the one proposed by Povinelli, Apperly and Butterfill recognizes the game changing role of conceptual, explicit, flexible mentalizing but does not limit mentalizing to it (Heyes 2014, 2014, Heyes & Frith 2014). For these reasons, it seems to represent a suitable solution for dealing with mentalizing capacities in relationship with teaching, because it allows to take into account occurrences of teaching in young children and in non-human animals, and simple forms of teaching as well. We can conclude this brief discussion by acknowledging that *teaching requires some capacity for taking into account others' mental states but that this capacity is possibly composed of more basic skills*: the capacity (or capacities) of tracking intentions, perceptions, knowledge, possibly beliefs, and the capacity of conceptualizing these mental states and more particularly beliefs.

**(b) Strauss' Theory of teaching as filling-in a knowledge gap**

"*When faced with the question of determining whether an action is a teaching action, as opposed to some other actions such as reciting, talking or acting in a play, it is the intention of bringing about learning that is the basis for distinguishing teaching from other activities."* (Pearson 1989, p. 66)

Cognitive scientist and educational psychologist Sidney Strauss has been the first to propose considering teaching as a natural cognitive ability, i.e. a universal behavior with an evolutionary history and specific neurocognitive underpinnings (Strauss 2002, 2005). Following a classical definition of teaching - put forward by educational philosopher Allen Pearson - Strauss' characterization of teaching delves with the (i) altruistic intention to reduce the knowledge gap between the one who knows (the teacher) and the one who doesn't (the learner). For fulfilling this intention, teachers build upon their understanding of other people's minds, that is: (ii) ToM, but also on other (iii) information giving mechanisms and tools that do not require ToM. As for Premack, ToM is in fact one of the key cognitive features of Strauss' characterization of human, adult teaching. The definition of ToM adopted by Strauss is moreover a direct emanation of Premack's, in that ToM here invoked as the capacity of recognizing the lack of knowledge and eventually the presence of false beliefs in others (Baron-Cohen Leslie Frith 1985, Premack & Woodroof 1978, Wimmer & Perner 1983). However, Strauss' theory enlarges Premark' view of teaching by adding the dimension of teaching precursors that do not require ToM. In Strauss' theory, proper teaching is in fact preceded by precursor forms of teaching-without-ToM: *proto-teaching*, i.e. information giving not involving the transmission of generalizable knowledge (it has been pointed at by Ashley & Tomasello 1998 that for children younger than 2-years-old the information given is only episodic and not generalizable) and *early teaching* (e.g. solicited information giving or unsolicited mistakes' correction shown by infants). Both forms of teaching precursors are also present in non-human animals (Strauss & Ziv 2012). More advanced forms of

teaching all use ToM, and some require even more sophisticated forms of ToM that 'basic' teaching. It is the case of contingent teaching, during which the teacher responds to the learner and the learners to the teacher. In this case teaching requires 'on-line ToM', which implies *monitoring* (a form of metacognition) and *executive function* (working memory, flexible planning, focused attention) (Strauss, 2002, 2005). Teaching behaviors thus follow a trajectory of evolutionary and ontogenetic development, which goes from teaching without ToM (inclusive of proto and early teaching) to teaching with ToM and eventually teaching with on-line ToM. The further steps towards efficient teaching do not necessarily develop naturally: whilst grounded on natural bases, sophisticated and mature teaching is a learnt ability (see the difference between teachers' folk pedagogy and efficient pedagogy: Strauss 2001, Strauss & Ziv 2012). In the following sections I consider evidence on early precursors of the development of information giving and relative prerequisites. I also discuss the reference to teaching and more generally to information giving as an altruistic behavior.

***From theory to evidence (1): Solicited and unsolicited information giving and mistakes' correction appear early in development***

There's some evidence that information giving appears relatively early in ontogenesis, follows a developmental trajectory, and is grounded on prerequisites that involve the solicited transmission of information and the correction of others' mistakes (Calero et al. 2015, Strauss et al. 2014, Strauss 2005). Current evidence indicates that children engage in teaching as unsolicited norms and information giving starting from around age 3-years-old. For instance, as it has been described in the previous paragraphs, children aged 3-5-years old protest when norms are not respected and try to enforce them by demonstrating actions and stating rules (Köymen et al. 2015). Ashley and Tomasello have presented children aged 2,5-3 and 3,5-years-old with a collaborative problem-solving task requiring joint and coordinated actions. They have successively paired each "expert" child with a naïve peer and asked the expert child to teach the necessary actions. Children aged 3,5-years-old have been observed to engage more in explicit teaching actions (Ashley & Tomasello 1998). Maynard has observed children teaching skills such as how to prepare tortillas and how to take care of dolls in the context of everyday assisting of siblings among Zinacantec Maya populations in Chiapas (Maynard 2002, 2004). Spontaneous engagement in younger siblings teaching has been observed from age 3-4-years-old, with no significant change in *time spent* at teaching between children aged 3-4-years-old and children aged 11-years-old. Changes have been observed in the *modalities* of teaching, however, with children aged 3-5-years-old mostly sitting side by side and providing the younger sibling a task to perform and older children giving more feedback, engaging more and more in explanations, commands, guidance of the learner's body. A significant difference is observed between children aged 5-7-years-old and children aged 8-11-years-old, the latter but not the former engaging significantly more in talk with demonstration than the 3-5-years-old group (Maynard 2002). Other studies have confirmed the existence of an evolutionary path, especially in relationship with the engagement of children in verbal interaction, in collaboration and in sensitivity to the learner states of mind as compared to simple demonstration of actions to be taught (Astington & Pelletier 1996, Davis-Unger & Carlson 2008, Wood et al. 2005). For instance, when taught to play a

board game, 3-years-old children spontaneously demonstrate other children how to play. They do so with little or no explanation and without systematically correcting others' errors. Children aged 5-years-old, on the other side, 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. Information giving strategies are thus more varied and flexible among 4-5-years-old children than among 3-years-olds (Strauss et al. 2002, Strauss & Ziv 2012). Finally, children aged 7-years-old 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 & Ziv 2012). At least two explanations are possible for the development from simple and early to later and more sophisticated information giving behavior: first, that younger children are more *motivated* to win the game than to explain it; second, that older children have developed the necessary *skills* for monitoring and reacting on-line to the errors of their co-players (that is, more sophisticated forms of ToM, as suggested by Davis-Unger & Carlson 2008). Whatever the explanation, available evidence supports the idea that *information giving mechanisms are present early in development and are susceptible of constituting prerequisites for teaching behaviors to develop*.

There's also evidence that information giving behavior is preceded by precursors that involve the solicited transmission of information that is needed by another and 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 both the child and the adult - infants aged 1 year old point at the object so as to provide information, if required to (Liswkowsky et al. 2006, Liswkowsky Carpenter & Tomasello 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 12-19-months-old 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 that can be considered a prerequisites of certain forms of teaching*. 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 prerequisite of teaching is coherent with the hypothesis – emitted by Premack, and discussed above - that teaching has a normative dimension.

### *From theory to evidence (2): Information giving and teaching are not limited to altruistic intentions*

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 to adults, children aged between 3 and 6 years old 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 first as better informants than the latter (for the capacity of children aged 5-7 years old of identifying informants who omit information, see: Gweon et al. 2014). Somehow unexpectedly, then, the children who have taken part to 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 an altruistic motive, *sharing information* might help *establish fruitful collaborations and alliances with knowledgeable ones* (or be a form of reciprocal altruism related to the sharing of information), thus fulfilling a self-serving interest. The discussion of the instructed learning theory of teaching will add further support to this hypothesis.

Additional support to the self-serving view of teaching, comes from a strand of evidence that hints at the possibility that teaching to others enhances the teacher's capacity to learn, that is, that *teaching brings cognitive (and not only social) benefits to the teacher.* One study has shown that preparing oneself for teaching promotes better retention of a verbal material as compared to preparing oneself as a learner; in the framework of this study, actually teaching to others - as compared to verbalizing aloud alone and to working alone - does not seem to make a difference (Bargh & Schul 1980). This result seems to be confirmed by another study in which self-explanation is shown to produce the same effects than 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). As for what concerns the expectancy to teach, (Renkl 1995) has found both negative effects (anxiety) and positive effects on 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: (Logan & Mayer 2013) have 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 actual 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 actual 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, Logan & Mayer 2013). More research is then required in order to evaluate the cognitive benefits of teaching for the teacher, and identify the mediating mechanisms. More in general, to identify potential immediate benefits of teaching for the

teacher, and to dispassionately assess the hypothesis that teaching is not (or at least not only) an altruistic behavior.

**(c) Tomasello's Theory of instructed learning**

Focusing on the learner can provide useful insights on the teacher's processes. Michael Tomasello's and Malinda Carpenter's 'instructed learning' is a form of social learning in which the learner imitates a demonstrator's actions and gestures (Tomasello & Carpenter 2007, see also: Tomasello 1996, Tomasello Kruger & Ratner 1993). Instructed learning is thus characterized in the terms of the learner's reactions to the instructor's actions, but implies a reciprocal attitude on the side of the teacher: (i) social motivations to cooperate and to conform; (ii) 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, of cooperating); (iii) 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 and rationality refers to the understanding of the goals behind the action; on the side of the teacher, performing specific gestures in order to achieve the outcome (see Gergely et al. 2002, Lions Young Keil 2007, Meltzoff 1988, Whiten et al. 2009). Evidence related to the three groups of requirements is discussed below.

Tomasello and colleagues insist that whatever drives social learning is not limited to epistemic motives (information gathering/giving) but extends to social motivations of different kinds (Carpenter 2006, Tomasello & Carpenter 2007). (Over & Carpenter 2012) in particular have proposed that, due to their dependence from the group, humans have evolved a social motivation to imitate and that imitation has the function of social glue. Children imitating adults or other children might thus be trying to make themselves more similar to the model or to the group *independently* from 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, for complying with social pressure and norms that are more or less explicitly enforced. Conformity can in fact promote 'peace' and reduce 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).

***From theory to evidence (1): Social motives for teaching include sharing and conformity***

There's evidence that preschool children can be quite strategic when imitating their peers: in the situation in which one child receives information that is 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's also evidence that - starting from 5-years of age - pro-social 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 & Richerson 1995, Henrich & Gil-White 2001, Richerson & Boyd 2005), one can advance that pro-social 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 Heinrich & Gil-White 2001). (Fusarol & Harris 2008) have shown that 4 years old children selectively choose to learn from individuals who are "popular", having received manifest assent to their assertions form other individuals. (Chudeck et al. 2012) have extended these data by substituting manifest assent or dissent with attention paid to the "teacher" (time of gaze); they have shown that children are twice as likely to learn from an adult who has been accorded 10 seconds 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 a greater prestige and are more likely to be copied, i.e., to be adopted as teachers. In relationship with these data, (Boyd & Richerson 1995, Heinrich & Gil-White 2001, Richerson & Boyd 2005) have advanced the hypothesis that prestige mechanisms have evolved because they help choosing the "best teachers" via proxies that can be easily and rapidly assessed. *Because of the social advantages of prestige, it is however also plausible that teaching is a way of gaining prestige.* That is, that individuals become proactive in attracting their followers by displaying pro-social behaviors, by advertising their skills and knowledge, and by actively teaching to others, rather than waiting for being copied. This hypothesis requires more evidence in order to be supported.

***From theory to evidence (2): Perspective taking and cooperation appear early in development***

The capacities related to perspective taking and cooperation are present early in human development and follow a developmental trajectory, which includes: gaze following and flexible and intentional attention reading/attraction relative to a third party. Gaze following is present since birth and can be considered as a precursor of full-fledged attention reading (which we have discussed in relationship with the first cognitive characterization of teaching). At around 9-12 months of age the infant reliably follows 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. By the same age, the child infers 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 at 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 on others' goals. Children aged 18-months-old perform cooperative actions with adults by coordinating gestures around a common goal. They have thus acquired the ability to form shared plans and to coordinate actions in a spacy and timely

manner (Warneken & Tomasello 2007).
It is worth noting that according to Tomasello and colleagues, chimpanzees do not seem to 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, Call 2009). If this is confirmed, it can be inferred that they do not teach in the same way human children and adults do, but not that they don't teach. As it will emerge in the discussion of the functional-behavioral approach to teaching, in fact, non-human animals demonstrate the capacity of "tuning" to the learner and to coordinate actions in virtue of mechanisms that include sensitivity to the learner's states (e.g. meerkats) and adaptation to the learner's behavior (e;g. tandem running ants). *Perspective taking and coordination are thus prerequisites that can be put into play differently by different neurocognitive architectures, but seems necessary functional building blocks of teaching*.

***From theory to evidence (3): When imitating, children respond to pedagogical cues, not only actions***

In addition to social skills and motivations that are common to social learning in general, instructed learning includes specific requirements, namely the responsiveness - on the side of the learner - to a special class of communicative acts that the instructor performs while demonstrating a target action. Multiple experimental results indicate that when ostensive acts (eye contact) are addressed to children and even infants, the latter 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, to copy the result of the action. Also, in the presence but not in the absence of ostensive communication with eye-contact, infants 14-18-months-old tend to generalize the moral reactions of an adult to the class of objects they are directed to: 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 unlikable. In the absence of eye-contact the generalization is not made and the child attributes the reaction to a particularity of the demonstrator (Csibra & Gergely 2009, Egyed Kiraly & Gergely 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 & Gergely 2006, Gergely & Csibra 2006, 2009, 2011). 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 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's 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.

It seems especially desirable that researchers develop the theory of natural pedagogy in the direction of identifying the relevant actions that are put in place *by teachers* and that make apt at conveying a pedagogical intention. Useful insights on 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. Also, 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 invested by Calero and colleagues (Calero in preparation, Calero et al. 2015, Strauss Calero Sigman 2014). Calero and colleagues have been able to show that children aged 3-8-years-old use gestures, namely ostensive gestures and referential signals, while providing explanations to adults. They do so more than during other communicative acts (children aged 3-5-years-old use ostensive gestures at the onset and at the offset of pedagogical episodes aimed at conveying information about how to play a game, while children aged 6-8-years-old use ostensive cues such as eye contact only at the offset, thus suggesting 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. experiments children 7-years-old on average do so 'rationally' – by tuning on the receptivity of the learner to their ostensive gestures - and 'intuitively' – not as a form of imitation of adult's behavior: ostensive gestures emitted by children during pedagogical episodes are reduced if the adult learner manifests not to pay attention to them; but the quantity of ostensive gestures emitted when teaching to an adult does not depend on the quantity of ostensive gestures emitted by the same adult when he or she was in the teacher's position. From these studies children emerge not just as the receptive parts of the pedagogical protocol, but as emitters too (Calero et al. 2015). However, these studies do more than confirming that teaching is a natural behavior, which develops since childhood. They hint at the possibility that teaching is anchored in gestural, pre-verbal cues, to which infants are tuned and that children instinctively put in place when they are on the emitter side of pedagogical events. These cues need not be reflexive or intentional. It is impossible to exclude, at this stage, that they are part of a pre-wire cue-response system.

**(d) Functional-behavioural approach to teaching**

"*An individual actor A can be said to teach if it modifies its behaviors only in the presence of a naive 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 & Hauser 1992).

Functional-behavioral approaches to teaching rely on the functional characterization of teaching proposed by biologists Tim Caro and Marc Hauser (1992). According to the definition, teaching is any modification of the teacher's behavior in the presence and only in the presence of naive observers that produces better learning outcomes on the side of the learner, with no immediate benefit for the teacher. The functional-beahavisoral approach to teaching thus adopts the view, discussed in the sections dedicated to the gap-filling theory, that teaching is a uniquely altruistic behavior. Evidence about self-serving motives and direct advantages for teachers shake this view and deserves more attention from animal a well as from human studies of teaching. The most interesting features of the behavioural-functional approach - from a building blocks point of view - reside however in its capacity of building a theory of teaching without making reference to complex cognitive capacities, i.e. to ToM and intentionality.

First, the definition implies that teaching takes place in the presence of a certain category of potential learners that are naive and not experts, which - Caro and Hauser concede – requires some form of sensitivity. The solution proposed by Caro and Hauser is that the teacher's sensitivity is a continuum that ranges 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 that are capable of tracing minimal changes in the learner's mental states, and to react by choosing the most appropriate course of action rather than stereotypes 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 be favored by evolutionary processes (Caro and Hauser 1992). The sensitivity-to-the-learner-state that emerges from this vision as one of the prerequisites for teaching is analogous to the system for recognizing individuals-susceptible-to-be-taught (minimal mentalizing) that has been discussed in the framework of the human teaching theory of teaching. Animal studies confirm that this system can be present in non-human animals and in minimal forms of teaching. Also, that it can be implemented in different ways - from stereotyped triggering mechanisms to high-sensitive process of mentalizing capable of tracking the smallest variations in the learner's mental states - thus giving rise to different types of teaching – from low to high-sensitive to changes in the learner's behavior, from stereotyped to flexible responses to the learner's mental states. These forms of teaching do not differ in in terms of their functional requisites but in terms of the cognitive architecture that form the substrate of the specific solution.

The second mental capacity the functionalist account of teaching does without is intentionality. Whatever the motivational or intentional state of the teacher, alteration of behavior that favors learning in naive individuals and is not common in the absence of naive individuals, represents a sign of teaching according to the functional definition (Caro & Hauser 1992, Hoppitt et al. 2008). No mental state is evoked. However, the very possibility of selectively altering its own behavior depends on the capacity, on the side of the teacher, of responding to particular cues with an appropriate behavior. The capacity of selectively altering one's behavior in response to specific cues (behaviors, mental states) can thus be considered a prerequisite for teaching, which adds up to the capacity

of detecting such cues. This particular prerequisite can be implemented by simple cue-response mechanisms that trigger the behavioral modification. In other cases, more flexible choices and modulated behaviors can be achieved, for instance in the case of cognitive architectures that take into account multiple factors and modulate their response in accord to them, or that anticipate outcomes of one's actions on others' mental states. In a building blocks approach to teaching, the circumstantial modification of the teacher's behavior can be considered as a minimalist form of intentionality, in that the teacher does not attend to the naive individual as it does with another individual and acts *as if* it had the intention to pass some information or knowledge or norms, or to favor the acquisition of a skill in the naïve individual. In this way, the functionalist approach contributes with two prerequisites to a minimalist theory of teaching: *the capacity of being sensitive to the learner's states and the capacity of responding to these states by altering the teacher's own behavior*. Both capacities can be implemented by less to more costly cognitive processes (Caro & Hauser 1992, Fogarty et al. 2011, Hoppitt et al. 2008).
The functional definition of teaching has also been productive, in the sense that it has favored the burgeoning of a strand of evolutionary research on animal teaching (Hoppitt et al. 2008, Byrne & Rapaport 2011, Fogarty et al. 2011).

***From theory to evidence (1): Animal teaching shows that teaching does not require human higher-order skills***

Several studies in the domain of social learning and cultural transmission in animals affirm that different forms of teaching exist, which do not require complex computations to be carried out, but simple cue-response mechanisms and other hard-wired, biologically preprogrammed adaptations. These forms of teaching include: I. opportunity provisioning (giving young animals the opportunity to learn, and eventually facilitating their task, e.g. by reducing the complexity of the task, or by helping the learner to deal with it, structuring the task for the learner so as to make it easier to learn); II. teaching through local enhancement (e.g. by attracting the learner to particular spot); III. teaching by exposing the learner to the association between stimuli; IV. coaching (i.e., encouraging and discouraging behaviors that happen in response to the learner's acts); V. the invitation and encouragement to imitate a demonstrator - eventually accompanied by various forms of demonstrations of gestures and acts, which would make this form of teaching more typically human (see Caro & Hauser 1992 and Hoppitt et al. 2008).
There's limited but solid evidence, gathered in natural and controlled conditions, that simple cue-response mechanisms and other adaptations exist at least in few taxa and lead to the aforementioned forms of teaching: meerkats (Thornton 2008, Thornton & Clutton-Brock 2011, Thornton & McAuliffe 2006), ants *(*Franks & Richardson 2006, Leadbeater et al. 2006; Richardson, et al. 2007), pied babblers (Raihani & Ridley 2008).
Experimental research on meerkats has shown that a relatively inflexible, hard-wired, pre-adapted mechanism can explain the capacity of these mammals to tune their behavior to the knowledge state of learners. Adult meerkats provide young meerkats preys – scorpions - to help them train their predatory skills. They can provide unarmed or armed preys (venomous scorpions), depending on the age of the learner: younger learners are assigned unarmed preys (scorpions without their sting), easier and less dangerous to deal with; older ones have to deal with the risk of being stung (scorpions with their sting).

Finally, adults cease to provide preys. Experimental manipulations have allowed researchers to identify the mechanisms at play in this form of elementary "mind reading". They've recorded the voice of young meerkats at different developmental stages, and have made adult meerkats listen at them in the presence of pups of different ages. They've observed that, in the presence of an older potential learner adult meerkats do not react to the physical aspect of the latter, but 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, independently of its real age. Since the pitch normally changes with the development, and thus represents a proxi of the developmental stage of the young animal, this solution is quite efficient: meerkats do not put in place complex computations in order to interpret the knowledge state of the learner and choose the most appropriate teaching style. This example shows that a simple cue-reaction mechanism can substitute a complex computation and that some form of teaching (opportunity provisioning, namely by structuring the task for the learner so as to make it easier to learn) can exist in the absence of complex cognitive computations.

Tandem running behavior in ants (*Temnothorax albipennis*) also fits with the functional definition of teaching, and with teaching through local enhancement in particular (Franks & Richardson 2006). In the process of colonizing a new nest, tandem running leaders recruit a nest-mate and guide their companion to the new site by tapping the companions' antennas and adapting to the velocity of the latter. During the process, the teacher evaluates the necessity of pursuing the tandem runnings 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 behavior might have the advantage of permitting transfer, in that the pupil ant learns the route and can successively become a tutor (carried ants do not learn the route). 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. Sensitivity to the learner's state and reaction to that (namely to the learner's errors) has been described also in hens (Nicol & Pope 1996). While this example does not explain the variety of situations in which humans teach by adapting to the learner, it suggests that simple mechanisms suffice for contingent teaching, and that contingent teaching is not necessarily 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 (it can thus be considered as a form of associative teaching). 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 & Ridley 2008). Once more, these examples suggest that it is possible put in place certain forms of teach without mobilizing the symbolic, linguistic, explanatory, conceptual tools that are available to the human mind. Coaching and invitation to

imitation do not share the same quality of empirical evidence as the three aforementioned forms of teaching (opportunity provisioning, local enhancement, exposure to associations) (Hoppitt et al. 2008). Ecological observations of chimpanzees suggest the existence of tolerance to observation, which can be considered as a basic form of invitation to imitation (Boesch 1991, Biro et al. 2003, Moore 2013) and studies on self-medication in chimpanzees offer potential ground to the study of teaching through encouragement and punishment, that is coaching, in non-human animals (Masi et al. 2012).
It is difficult 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's a good reason for looking for less complex calculations; but it is possible that the specific neurocognitive architecture shared by humans implies the recourse to more complex functions even when simpler ones could do the job.

***From theory to evidence (2): Minimalist forms of teaching exist among adult humans***

Based on her ethnographic work in the Fiji islands, and on an extensive review of the literature, anthropologist Michelle-Ann Kline has proposed a taxonomy of teaching types across human cultures, ranging from very minimalistic to very demanding forms of teaching - in terms of the teacher's effort (Kline 2015). Her taxonomy focuses on the adaptive learning problems teaching can solve and is thus compatible with the functional-behavioural approach to teaching, while it makes no reference to the neurocognitive architecture that is necessary in order to implement each form of teaching – not even to the minimal requirements made. The taxonomy proposed by Kline includes: I. 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); II. opportunity provisioning, III. 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); IV. teaching by evaluative feedback (when the teacher rewards or punishes certain actions or their outcomes); V. 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) also provides several examples of the variety of forms of teaching, from very simple and not demanding in cognitive terms to complex and demanding exist in the framework of different human societies: in Fiji, 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 a way that enhances the salience of the stimulus to be attended, 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 wave a basket.
In a similar vein, anthropologist Barry Hewlett has shown evidence that hunter-gatherers/foragers of the Congo Basin (Aka and Bofi) do teach to their children, mostly vertically (parent to child) before age 5-years-old 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 pervaded by 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; and: "*Young children often hear stories about how people who do not share properly face sanctions (e.g. illness, death, death of a child).*" (Hewlett et al. 2011)

Reciprocally, children declare that they've learnt how to share food and what to consider edible food from their parents, mainly parents of their same sex. This attitude can thus be considered as a complex form of teaching, which includes 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 kinds of teaching in the forms of tolerance of observation - even when observation is intrusive, e.g. sitting on one's lap while one's 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); and in the form of providing children with 'toys' (axes, spears, digging tools, baskets) that imitate the features of adult tools, but are child sized and are accompanied by a pedagogical attitude, which consists in encouraging, commenting 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 the gestures) of a naive individual consists in adult and young (12-years-old) Aka women teaching B.L. Hewlett how to wean a basket. Finally, there's 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 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, investing also values and norms that are relevant for that particular society.

## DISCUSSION

Depending on how teaching is intended, the range of teaching behaviors is large, ranging from very minimalist to very complex and demanding. Teaching forms are as varied as I. Creating the conditions for another to learn, by: Ia. providing opportunities, eventually simplifying or reducing the task; Ib. tolerating and eventually encouraging their presence and observation, exposing them to relevant associations, stimuli, places, eventually encouraging and facilitating imitation; II. providing coaching in the form of feedback, encouragement, or punishment; III. giving demonstrations and instructions. 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. Nonetheless, on the basis of the analysis of the studies proposed above and of its results, it is possible to show that these behaviors correspond to a finite group of functional prerequisites or building blocks that can be implemented through different neurocognitive architectures and served by more or less complex neurocognitive underpinnings and adaptations.

### (a) Applying the building blocks approach to teaching

No matter the form it takes, teaching is an activity that requires some motive. Premack's Theory of human teaching advances that teaching responds to a motivation to correct deviations from standards that define what makes a behavior or a product acceptable and appropriate. There's evidence that the motivation to enforce social norms about "how things should be done" is present in humans form early age and follows a developmental path. Strauss' Theory of teaching as filling-in a knowledge gap suggests an altruistic motivation to give information to those who miss it, but empirical evidence suggests that this attitude can respond to self-serving motives, related to the social and cognitive advantages of teaching, for the teacher: establishing alliances, acquiring status via prestige, creating common ground, reducing conflicts via conformity (as also shown in the discussion of Tomasello's Theory of instructed learning), obtaining cognitive rewards (in the form of enhanced learning). Finally, the Caro's and Hauser's Functional-behavioral theory evokes altruistic motives related to providing helping information to kins and members of a communal breeding group. What the different forms of teaching have in common is thus some motive for sharing information and influencing others' behavior, for selfish or altruistic reasons. As it has emerged during the analysis of the Functional-behavioral approach, teaching does not entail by necessity having an overt intention to teach. Animal teaching does without intentions, as far as the teacher is sensitive to the learner's states and appropriately responds to them, in virtue of simple cue-response mechanisms that trigger the teaching behavior (ex. opportunity provisioning in meerkats, local enhancement in ants, exposition to association in pied babblers). Teaching can thus take the form of a triggered reaction, which motives are inscribed in the evolved adaptations of the species rather than in the individual's choices.

Teaching also requires some form of ability, but the abilities that are required for teaching are not necessarily complex and costly in cognitive terms. The human teaching theory and the gap-filling theory postulate that proper, human teaching is based on the capacity of reading and interpreting others' minds, namely on the possession of a theory

of mind. However, the comparison with minimal forms of teaching described by the functional-behavioral approach and the discussion of evidence related to mentalizing capacities in humans and other animals, suggests that it is possible to reduce this prerequisite to minimal forms of mentalizing that enable teachers to track the learner's mental states and to appropriately respond to them. Sometimes a simple cue-response system is sufficient to warrant 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. While cognitive approaches to teaching tend to set a sharp divide between teaching and its precursors, and to identify the divide with the appearance of conceptual forms of mind-reading, this divide is unnecessary in the framework of the building blocks approach: conceptual forms of mind-reading and even meta-cognition can certainly contribute to *some* forms of teaching but are not prerequisites of teaching *at large*. The example of tandem running ants reminds us that even information giving with contingent adaptation of the teacher to the learner can be achieved through simple mechanisms. The form through which the information giving function is implemented (as an adaptation or a specific neurocognitive function) is thus not essential for a building blocks approach to teaching.

Equally necessary for teaching to take place, is the capacity of gathering the attention of the learner and of attracting it on some relevant opportunity, stimulus, place or association, on the teacher's actions, feedback, reward, punishment, demonstration or instruction. Among humans, teachers signal the relevance of the stimulus, its value, possibly its generalizability to contexts and situations that go beyond the here and now of the communicative act. It is debated whether non-human animals possess a pedagogical system of the sort (Csibra 2009). Documented examples of non-human teaching are in fact limited to few situations, in which the task is relatively specific (namely predatory situations) and flexibility is not required (Premack 2004). However, even non-human animal teaching interactions cannot be described as having a purely 'here and now', since they are susceptible of changing the behavior of the learner in all future related situations. Singling relevance can thus be considered as being common to different teaching taxa, if we make abstraction from its specific form of implementation, and become a candidate building block. Dedicated researches are required in order to specify the neurocognitive underpinnings and the adaptations that produce the relevance effect in human and non-human animals. Current research on natural pedagogy resorts to this, but it has been limited to the receptive side of the equation (how babies respond to signals) and to humans. More studies are required in order to precisely identify the nature of the signals emitted by the teacher and to extend the research to animal singling.

Teaching produces effects that affect both the learner and the teacher, and both profit from the interaction, socially and cognitively. This is especially stressed by the Instructed learning theory of teaching. A general effect of teaching, which affects both the learner and the teacher, is the reduction of distance or a shared perspective. After the process of teaching-learning has taken place, in fact, the mental states of the learner and of the teacher are more similar. Processes and mechanisms that operate in the direction of creating a common experience between learners and teachers are also building blocks of teaching.

There are finally several tools that allow teachers to share information and influence

others' behavior. Premack's Theory of human teaching insists on taking into consideration symbolic and non-symbolic tools, namely language for instructing and gestures for demonstrating and for directly modifying the learner's behavior. Symbolic tools nonetheless are not limited to language and can include the variety of mathematical symbols, graphic representations and other cognitive artifacts that are commonly used in human teaching. Moreover, in the case of non verbal subjects, or of non verbal interactions, the role of language can be fulfilled by other forms of information giving tools, such as communicative vocal signals and communicative gestures. Reminding the evidence gathered in relationship with the Instructed learning theory, it is also necessary to add ostensive and iconic gestures to the picture, as they are implied in teaching with demonstration and in imitation in young children. Ostensive gestures are also present in great apes, but their role in animal teaching has not been explored yet (Moore 2016). The Functional-behavioral approach finally broadens the view to performing gestures that enable the teacher to act in the place of the learner, to provide opportunities, to enhance stimuli and places for the learner, to show actions, or to correct and reward the learner's actions. A classification of different forms of gestures in relationship to different forms of teaching, in humans and in non-human animals, is most needed.

**(b) Identifying the building blocks of teaching**

In synthesis, building blocks of teaching can be sorted in three main groups: motives for sharing information and altering others' behaviors, making an information relevant in a shared experience, tools for sharing, giving, altering.

***1. Motives for sharing information and altering others' behaviors***

Three types of motives can be attributed to teaching behaviors: (1a) the promotion of conformity to standards that define what makes a behavior or a product acceptable or appropriate, and the relative motivation to correct deviations from them; (1b) the willingness to share and give information, that can be itself motivated by altruistic or by self-serving motivations; (1c) a motivation to create common ground, that can lead to cooperation as much as to conformity. The attitude to conform to social norms has been studied in other primate species, such as vervet monkeys: when male migrate into a new group they tend to adopt local behaviors in relationship to food preferences (van de Waal, Borgeaud, Whiten 2013). It would be useful to enlarge the view so as to understand whether non-human teaching behaviors respond to motivations other than altruistic (connected to kin selection and inclusive fitness), and whether a sharp divide separates human and animal teaching on the basis of their motivational building blocks.

***2. Making an information relevant in a shared experience***

The second group of building blocks deals with capacities that are required to perform teaching. It is the group where we find the greater gap between educational-cognitive and functional-behavioral characterizations, because the former tend to evoke high-order skills such as possessing a theory of others' mind or the ability of mind-reading, meta-cognition, intentionality and to exclude non-human animals from the picture; while the latter tend to react by excluding cognitive processes in favor of pre-wired adaptations. The building blocks approach precisely helps reduce this gap: it is sufficient to extract

the functions served by each of these skilled abilities and adaptations, and to make these functions independent from their specific implementation. We thus obtain the following capacities as functional prerequisites for teaching: (2a) responding to or tracking others' mental states, so as to be able to react to them in a sufficiently specific way, according to the circumstances; (2b) attracting attention upon an opportunity, stimulus, place or association, the teacher's actions, feedback, reward, punishment, demonstration or instruction that the learner should attend to. The first of the two building blocks (2a) is responsible for the identification of whom to teach to, and for adapting (more or less) flexibly to the learner. The second building block of this group (2b) has to do with the capacity of the teacher to make the information relevant for the learner. The two building blocks have the effect of producing a shared experience between the teacher and the learner. However, this shared experience can also emerge from other conditions: it can be the product of the time-lockedness of the interaction between the teacher and the learner, or be the results of special signals, of various forms of communication, of the presence of a shared objective, or of a shared object – e.g. book, video and other artifacts that make it possible to create synchronicity at distance. The capacity, by various means, of (2c) creating a shared experience is thus a third building block of teaching. 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. Tools for sharing, giving, altering***

The third group of building blocks for teaching is represented by the tools that make it possible for the teacher to modify the learner's behavior, to share or give information and to create common ground (thus serving 1a, 1b and 1c). Following the analysis of the theories and evidence presented above, we obtain the following building blocks for the third category: (3a) communicative signals, (3b) communicative gestures that allow information giving, (3c) performing gestures that enable the teacher to act in the place of the learner, provide opportunities, enhance stimuli and places for the learner, show actions, correct and reward the learner's actions.

**(c) Distilling the common core of teaching**

The building blocks belonging to each category can be differently combined to give rise to different forms of teaching. Moreover, the variety of possible implementations of the three groups of building blocks is huge. This diversity can easily justify the impression that teaching is an ambiguous term not referring to 'one thing' but many. For instance opportunity providing as in the case of meerkats teaching can be motivated by the willingness to give information for altruistic motives related to kin selection, implies the capacity of responding selectively to the learner's mental states and probably that of making the stimulus relevant to the learner, and uses performing gestures to provide opportunities in the form of simplification of the task. Teaching by exposing learners to associations in pied babblers might be grounded on the same building blocks motivations, but uses communicative signals rather than performing gestures; it is not evident, from the studies on pied babblers' teaching how parents track the learning states of their pupils. Teaching by local enhancement in ants can depend on the same motivations, puts

in place a system of evaluative feedback, which implies a recurrent system for tracking behaviors, and uses gestures that act directly on the learner rather than on an object, but are not signals. The three forms of teaching certainly imply different adaptations and neurocognitive underpinnings specific to each species. Teaching has however a common core, represented by the fact that combinations of building blocks are limited in number and in types.

## CONCLUSIONS AND FUTURE DIRECTIONS

Drawing on the concept of minimal functional prerequisites or building blocks, evinced in the course of the paper from current theories of teaching and related evidence, it is now possible to provide a characterization of teaching behaviors that goes past disciplinary approaches.

### (a) A characterization of teaching based on building blocks

Teaching refers to a variegated set of behaviors that can take different forms and be implemented by different types of neurocognitive architectures. Despite their diversity, teaching behaviors all share some functional prerequisites at the cognitive level: they have a common core of motivations, capacities and tools. Teaching behaviors draw on motivations to influence other's mental states or behaviors, share and pass information to others for self-serving and altruistic motives. They require capacities for tracking others' mental states or reacting to them appropriately, and moreover of capacities for attracting the learner's attention, focusing it on a task or object and more generally for signaling the relevance of some particular stimulus. And they put in place a variety of tools: communication tools, gestures and courses of action that have the effect of achieving the motivations described above. In the absence of these prerequisites or building blocks, teaching should not develop and evolve, since they constitute a cognitive bottleneck for teaching behaviors.

### (b) Comparative advantage of the building blocks approach as a framework for empirical research on teaching

The characterization of teaching presented in this paper is susceptible of creating a common ground for pursuing the research of the necessary conditions for teaching. Even the conflict between the cognitive and the non-cognitive theories disappears at the building blocks level of description, leaving us with a unified framework of research. Teaching has in fact been defined as a set of behaviors that share common functional prerequisites at the cognitive level, but the specific mechanisms that implement these prerequisites are not part of the definition. This leaves the door open for a greater latitude in the search for the mechanisms that put teaching into play in different species, in different circumstances, in relationship with different neurocognitive architectures. The building blocks approach provides a suitable framework for neuroscience and animal studies to orient the search for specific neurocognitive underpinnings and adaptations, case by case.

In addition to creating common ground, the building block's framework can serve as a compass for orienting future research about *who can teach* and *how,* in that it makes predictions that can be tested experimentally. Building blocks are in fact prerequisites, hence bottlenecks, for the development and the evolution of teaching. At this date, models that simulate the conditions for the evolution of teaching only include ecological and 'economical' factors - the costs of social learning vs individual learning, the costs of teaching, the difficulty/opacity of the content to be learnt (Fogarty et al. 2011). Should building blocks requirements be included, these models would become more realistic and

susceptible of making testable predictions about who can teach among biological organisms. The same consideration applies to predicting the presence (or the absence) of teaching at different developmental stages and in relationship with specific neurocognitive deficits, thus contributing to answer the question of *who can teach.* It is to be hoped that other disciplines, namely artificial intelligence and robotics, will join their efforts so as to provide simulations of the appearance and forms of teaching behaviors in relationship with the different combinations of building blocks. The fact that building blocks are functional and do not depend on one type of implementation makes the building blocks approach especially suitable for creating common ground with the sciences of the artificial.

It is also possible to use the building blocks approach as a tool for completing current studies on animal and human teaching; e.g., in the case of identified teachers it is possible to check for building blocks in the missing categories not yet explored. Finding such missing parts on the basis of predictions would also give support to the approach. *Vice versa*, different combinations of building blocks can be used as predictors of the emergence of different forms of teaching, in biological and in artificial systems.

In synthesis, the building blocks approach paves the way to pluri-disciplinary studies of teaching and is a valuable framework for empirical research. Some promising strands of research have been identified in the course of the paper, that deal in particular with the understanding of self-serving motives at the origin of teaching, the nature and ontogentic development of pedagogical gestures, on the side of the emitter, the classification of different types of teaching gestures and actions.

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