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Teaching, naturally

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ABSTRACT

Teaching is one of mankind's most important achievements. It allows cumulative human culture to exist and enables us to have a history. Despite its significance, it has not been studied much in the cognitive sciences. We review two exceptions to this neglect. Both make claims about teaching as being natural to humans. The first view is that teaching is a natural cognitive ability. This view pays much attention to teaching and little to the learner. A second view is that humans are naturally attuned as learners to teachers' ostensive, pedagogical communications. This view largely neglects the teacher. We propose ways to integrate and expand these two theories that also take into account the dynamic bi-directional nature of the teacher–learner dyad. One is to consider the mutuality or its lack in the ostensive communications between the both the teacher and the learner. A second way is to include the neurosciences to investigate interactions between teachers' and learners' brains during teaching sessions. A third way is to explore a different information flow in such a way that the teacher learns when she teaches, thus suggesting that there are situations where the teacher and learner are one and the same person.

1. Introduction

Teaching is one of the most remarkable of human achievements. Our ability to teach has cemented our culture, constituting an efficient mechanism to transfer information and accumulate knowledge. Surprisingly, little research and theory-building in the cognitive sciences has been done on the topic of teaching. While learning has been studied extensively, human teaching, whose intention is to cause learning in others, has been mostly neglected.

Teaching is bidirectional and consists of a source of knowledge (the teacher), a recipient of that same knowledge (the learner) and the process and mechanisms of transmission of that knowledge when both the teacher and learner actively communicate their understandings to each other. In fact, the mutual dialog between teacher and student is the minimal core of human pedagogy.

Teaching is not a one-way street going from the teacher to the learner. Instead, it involves mutual expectations about and evaluations of the other person in the dyad. Human teachers do not pass on information blindly without taking into account the learner's cognitive, motivation and emotional states. The learner has expectations about the knowledge she will be receiving, and the quality of the teacher's competence to transfer the knowledge. The mutuality of the teaching dyad is such that the learner continuously expresses her understanding and meaning-making which, in turn, gets interpreted by the teacher to adjust further teaching.

The cognitive sciences of teaching, mostly in animal cognition, have cast this bi-directionality largely in the prism of what is termed "social learning". Inherent in that very term is a bias towards the learner. The term is not social teaching. Nor is it what more accurately reflects teaching, which involves a social interaction in the form of a dialog between a teacher and a learner.

We propose taking a small step to redress this bias and suggest a fuller description of the nature of the interactions that occur between teachers and learners. We briefly review two approaches towards a cognitive neuroscience of pedagogy. The first, teaching as a natural cognitive ability (TNCA), is one of the few to address *teaching* from a cognitive sciences perspective [36–39]. Emphasis is placed on what teachers, including toddlers, know and know how to do in order to transmit information to learners when teaching. The learner has been somewhat neglected in this approach.

A second approach, natural pedagogy (NP), gets at infants' *receptivity* to certain kinds of communication [9,13]. These communications are thought to be pedagogical in nature, hence the term NP. It is claimed that infants are born with a bias to learn from pedagogical communications focusing the theory on the perspective of a receiver with the teacher ignored to a certain extent.

We propose a more comprehensive view of teaching and learning that includes the orientations of these two approaches

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and suggest avenues that could lead to a more inclusive framework to investigate information flow in teacher–learner dyads.

Teaching is a form of communication. There are myriad kinds of communication. For instance, Leadbeater and Chittka [22] noted exposure, imitation, inadvertent social information, local stimulus enhancement, matched-dependent learning, observational conditioning, public information, signal, social cues, and social learning. Similarly, Whiten [41] wrote about the following in an attempt to describe the origins of primate culture: contagion, exposure, social support, matched dependent learning, stimulus enhancement, observational conditioning, imitation, and goal emulation. (For a review of kinds of social learning communication, see [19]). Another kind of social communication is teaching. As Strauss et al. [39] noted, human teaching is a special form of social communication, guided by the intention to cause learning in others.

Human teaching is an intentional behavior on the part of a knowledgeable person, a teacher, who recognizes a knowledge gap between her and another person, a learner. The behaviors in question (teaching strategies) are aimed at expanding the knowledge of that other person who lacks knowledge, has partial knowledge or a false belief [30,43],44. Notice that the focus of this definition is on the teacher and her teaching behaviors and considers the learner mostly in reference to his knowledge state before teaching. One reason for the reference to the learner's prior knowledge state is that one does not yoke teaching to learning outcomes because a teacher can teach without learning being enhanced. This is a strong definition of teaching. Later we will consider relaxing it where only some of these behaviors are observed.

2. Teaching as a natural cognitive ability

Strauss et al. [39] were the first to suggest that teaching is a natural cognitive ability (TNCA) on the part of humans. Of all the criteria which coincide to argue that teaching is a natural cognitive ability, here we elaborate only one: teaching is developmentally reliable among humans. The nub of the argument is that teaching is complex and opaque and although toddlers are exposed to teaching, they are probably rarely taught how to teach. Despite the above, teaching is ubiquitously found at early ages. Developmental research conducted in different industrial countries, in different laboratories and using different tasks indicates convergent paths of teaching strategies [23,38].

To give an inkling as to some of what is involved in children's developing abilities to teach, consider the following situation: a youngster is taught how to play a game she had never seen or played prior to having been taught it. Then, to play the game with a friend who does not know the game, she has to teach him. One might think that, when teaching, she could imitate the experimenter's teaching strategies she had just experienced when she was in the role of learner. But the learner she is teaching would almost surely not respond to her instruction in a way identical to the way she, the teacher, did when she was in the role of the learner. She will then have to teach under conditions that she had not encountered. In order to pull that off, it is likely that she needs a general and flexible representation of how one teaches to cause learning in others' minds, with all its complexity. Children around age 3 already teach displaying this type of versatility [39].

In addition, when teaching, teachers usually correct mistakes as they occur and let things continue when they do not, both of which are at the core of teaching. We shall soon see that infants recognize others' mistakes and not only do they act to correct them, they even anticipate others' mistakes before they are made and act in ways that enable others to avoid them.

We begin with early signs in *infancy* of cognitive abilities that serve as the foundation of teaching. Liszkowski and his colleagues [24,25] and Akagi [2] discovered proto-teaching among preverbal children at age 12 months. Children at this age understand language but do not yet produce it. In a typical study, an experimenter "inadvertently" knocks off an object from a table in full view of the one-year-old. After a while he pretends to look for it and, not finding it, asks the infant where it is, and infants point to its location. In this situation, infants act as if they recognize a knowledge gap between themselves and the experimenter, and act to close it. In situations where the experimenter knows the "lost" object's location, yet asks the infant where it is, relatively few infants point to its location. We refer to this as proto-teaching because it concerns episodic knowledge which may not generalize to subsequent locations or contexts. Teaching involves a form of sharing knowledge that is not dependent on the context of the situation. And teaching results in the learner's emancipation. He is no longer in need of the teacher for what has been learned.

More recent research in this area reveals further indications that infants have some of the basic cognitive prerequisites in place in order for teaching to occur. Knudsen and Liszkowski [20,21] showed that preverbal 12-month olds and verbal 18-month-olds intervene proactively, through actions, by pointing to an experimenter to avoid a mistake the infant anticipates that the experimenter will make. The cognitive ability to intervene when a mistake has been or is anticipated to be made is at the epicenter of teaching.

Several studies tapped children's teaching from *age 3½*, mostly with tasks that involve one child teaching another child how to play a game. Children at this age engage in emergent teaching and do so despite their low performance on ToM tasks, as tested by classic false belief tasks and false belief tasks for teaching [5,11,12,39]. As teachers, 3½-year-olds predominantly demonstrate how to play a game with little explanation accompanying those demonstrations ([3,5,27,28,39]; Wood et al. [42]).

Children *age 5* teach by explaining the game's rules. Children at this age also demonstrate the way the game is played, but the dominant teaching strategy is explanation [5,11,12,39,45].

Children *age 7* engage in contingent teaching [42]. This is a kind of scaffolded teaching where a teacher teaches a learner based on her representation of the learner's knowledge state. As that learner's knowledge state does or does not change due to teaching interventions, the teacher adjusts teaching to the new representation of that changing knowledge state. Wood, Wood & Middleton (1978) [45] noted a simple rule for contingent teaching: if the learner succeeds, when next intervening, offers less help. This phenomenon has been referred to as fading. Another rule is that if the learner fails, take over more control when next intervening. Children age 7 were quite proficient at contingent teaching. Ziv et al. [45] found contingent teaching among some children at age 4 and many at age 5. This testifies to an on-line update of ToM. The importance of this for pedagogy will become evident below when we describe how the teacher–student interaction fails in the absence of adequate scaffolding.

In sum, there is evidence for teaching being a natural cognitive ability, at least from data showing that teaching seems to be developmentally reliable among children in modern industrialized countries. Infants appear to have proto-teaching. Children might have a pedagogical stance from age 3, perhaps earlier, about the goals of teaching and perhaps a general and flexible representation of teaching. There also seems to be a spontaneous developmental trajectory from proto-teaching to emergent teaching via demonstration, to explanation and then to contingent teaching. Contingent teaching embodies an on-line ToM and is found among children age 5 and even among some 4-year-olds. These are some of the hallmarks of teaching as a natural cognitive ability. As noted, in the teaching dyad, the TNCA approach emphasizes the teacher quite to the neglect of the learner.

3. Natural pedagogy

In the recent past, there has been growing interest about the possibility of human infants coming into the world prepared to *receive* information from a teacher. The main proponents of this idea are Gergely and Csibra [13], who coined the term "natural pedagogy" (NP) to express that preparation.

Gergely and Csibra [13] and Csibra and Gergely [9] made a series of claims that produced a cottage industry of deep conceptual work that widely covers many domains. Different from the TNCA approach that emphasizes the teaching side of the teacher–learner dyad, the NP thesis deals mostly with the learner. According to this theory infants are thought to be prepared to receive teaching, but not to teach.

What are these pedagogical communications comprised of that are not found in other non-pedagogical communication? Gergely and Csibra claim that pedagogical communication from the teacher to the learner is ostensive communication. Fundamental to ostensive communication is the intent of the communicator. Ostension provides a sort of tag that conveys that information is being intentionally communicated to the recipient.

Signals of teachers' ostensive communication include raising one's eyebrows, talking in *motherese*, eye contact, directing one's speech to the infant and calling the infant by her name. Each and every one of these, alone or in concert, signals pedagogical relevance to the receiver. The ecological argument is that the amount of knowledge acquired by children is remarkably vast and hence there ought to be mechanisms to convey relevance. In NP, relevance is signaled by an implicit set of social markers of intention which conform to an efficient communication protocol to convey information.

From the point of view of the receiver of ostensive cues (i.e., the learner), Gergely and Csibra have been investigating infants' sensitivity to pedagogical communication. But why is this thought to be pedagogical? In answer to that question, we quote Csibra and Gergely [9]: "Clearly the most likely beneficiaries of communication of generic knowledge are children, who are novices with respect to the accumulated knowledge of their culture. That is why we call the specific aspects of human communication that allow and facilitate the transfer of generic knowledge to novices 'natural pedagogy'" (p. 148).

NP theorists argue that toddlers have two fundamental sets of assumptions about the teacher who is transferring knowledge ostensively. First, is that the communicated knowledge is complete, relevant, novel, referential, kind-relevant and generic, or generalizable, and publicly shared cultural knowledge. The second assumption is that communicators are knowledgeable, trustworthy, helpful and convey information accurately.

Recent research shows that toddlers act as if they hold these assumptions. In a representative experiment, a toddler is shown a toy with several functions. The toy's functions were demonstrated under two conditions. In the first, a teacher showed a learner how to work only one of the functions. In the second condition, a teacher showed a learner that toy's same function but suddenly told the toddler that she just remembered that she had something else to do and left the room. In both conditions, preschoolers were shown the same function. In the first condition, the teacher showed that function, and the toddler could have inferred that that was the only thing the toy could do, whereas in the second condition, the teacher's demonstration of the toy was curtailed by the teacher leaving mid-stream. The preschooler could have inferred that there might be other functions but, because of her haste, the teacher could not demonstrate them.

If learners assume that teachers provide complete and reliable information, those in the first condition would not explore the toy's other functions, whereas in the second condition, they would. And that is what findings showed [6], suggesting that learners make inferences about the teacher's intentions to communicate complete and relevant information.

In a similar vein, but now with older children, Gweon et al. [16] showed that youngsters between the ages 6 and 7 were able to evaluate the quality of information (complete or incomplete) they received from a teacher and the reliability of the teacher based on the completeness of the information the teacher conveyed. Youngsters also explored further a toy's functions based on their evaluation of the teacher's reliability. All of this suggests that youngsters are capable of evaluating both the quality of the information they receive and the quality of the teacher who is transferring that information. Based on the latter, their further learning seems to be a function of their evaluation of their teacher's reliability.

A further claim regards the origins of the NP predisposition. Basic to this view is the idea that the receiver of the communication must have a predispositional sensitivity to detect ostensive signals from the teacher. Where could it come from? An abbreviated answer to this question is that they have an innate adaptation for receiving pedagogical communication. More specifically, Gergely and Csibra [10,13] argued that a new teleological conceptualization of tools was introduced in early hominids more than 2 million years ago. Tools now had permanent functions. Evidence for this comes from, for example, their storing tools rather than discarding them. Tools were also used to manufacture other tools, thus evidencing recursive teleology. But tools in and of themselves do not indicate the relevant properties of the goal that guided the manufacturing of tools. Hence the paradox: the most relevant aspect is cognitively opaque and made learning from imitation difficult, if not impossible. NP theory argues that this difficulty in learning may have provided selection pressure that led to the unique human communication system that allows the transmission of culturally-relevant knowledge.

In sum, NP constitutes a theory which accounts for what, how, when and why children learn when being taught. Infants appear to naturally expect a teacher to manifest relevant, complete, and novel information via behavioral demonstrations about the referent. Pedagogy, then, allows fast and efficient transfer of opaque cultural knowledge.

We have presented two views of teaching, both of which claim that it is natural to human beings. Strauss and his colleagues argue that actual teaching, being the source of the transmission of information, is a natural cognitive ability that is enormously complex cognitively, yet achieved even by toddlers with precursors in infancy. But in the TNCA view, little emphasis is placed on the side of the recipient of teaching, the learner. In contrast, Gergely and Csibra, in positing the theory of NP, deal mostly with the learner and the receptivity she comes into the world with concerning pedagogy. In so doing, they neglected the teacher. Both theories overlook the bi-directional nature of teaching.

We now turn to ways to more comprehensively combine these two views by examining how natural teaching and natural receptivity to teaching are related and developmentally intertwined. We examine the bidirectional flow of information between both participants in a teacher–learner dyad.

4. Integrating and opening up TNCA and NP

Here we present three ideas that we believe can organize new paths to investigate pedagogy as a dialog between a teacher and a learner.

The first idea is to apply the notion of ostensive communication to teaching and to add information content and channels to the equation. We ask in addition to their being fine-tuned to receive ostensive communication, are children also fine-tuned to produce ostensive cues when passing on information in natural channels of the teacher–learner dyad? This question can be answered by investigating ostensive cues used by children when they convey information of pedagogical relevance while teaching. Studying this question allows a way to probe teaching efficiency. In short, the core of the idea is to examine the developmental trajectory of the dynamics, synchrony and mutuality in ostensive communication between the learner and the teacher.

The teacher, as a source of information, emits ostensive communications when teaching and the learner receives them and signals back that she is ready to receive the information and has received it and, to simplify matters, it has been understood or misunderstood. The idea to study children's developing use of ostensive communication when teaching has the potential to open up studies on the dynamics of the teacher–learner dyad that is bidirectional. It takes into account the source of information (the teacher), the recipient of that information (the learner), the back and forth flow of information between the two (the content of the teaching and learning), as well as the channels that are used for the information flow (e.g., demonstrations and explanations). By investigating these aspects of teaching and learning, we can also examine the synchrony and mutuality of this dynamic information flow.

The second idea for an expanded model of the teacher–learner dyad is to include the neurosciences into investigations of teacher-learner dialogs [4,18].

From a cognitive neuroscience perspective, the difficulty of investigating an educational dialog reflects the intrinsic tension between well-controlled versus more ecologically-valid experiments [1,31]. A way to somewhat mitigate this conundrum may rest on what is probably the most famous educational dialog in the history of pedagogy: the teacher–student interaction between Socrates and Meno's illiterate slave. In the dialog, Socrates teaches the slave boy to double the area of a square. Above and beyond its symbolic and historical importance in our Western civilization, this dialog was recorded in extenso by Plato in such a way that it could be standardized and tested today in different cultures [14].

Our suggestion to include neuroscience in the search for a deeper understanding of the teacher–learner dyad comes at a propitious moment. Neuroscience has recently begun to shift from a single-brain to a multi-brain frame of reference. Hassonn et al. [17] state that "neural processes in one brain are coupled to the neural processes in another brain via the transmission of a signal through the environment. Brain-to-brain coupling constrains and shapes the actions of each individual in a social network, leading to complex joint behaviors that could not have emerged in isolation." This shift in frame seems to be particularly pertinent to the investigation of an education dialog.

The march along this path, capitalizing on the Socratic dialog, was begun by [14] and Holper et al. [18]. They discovered a remarkable similarity of errors in the reasoning of modern students with those committed some 2400 years ago by Meno's young slave, demonstrating universals in human reasoning across cultures and eons. More pertinent to pedagogy, nearly half the students – those who were taught how to solve the problem in ways that closely resembled Socrates' teaching – failed to generalize this knowledge, even to almost identical tasks after having been taught.

These results, derived from a replicable model of the teacher–student interaction, questioned the efficacy of the Socratic dialog, and suggested that the pedagogical experience with this organization of information flow is helpful only for students who can scaffold the new knowledge via representations that had been formed prior to the teaching session. This, in turn, led to a provocative hypothesis: students with no prior knowledge would be more engaged during the dialog, and would show signs of increased mental effort, yet they will generalize less. We present this as a fruitful bridge between education (success of the dialog), cognitive psychology (effects of prior knowledge on learning), and neuroscience (mental effort measures revealed by activity in the frontal cortex) [35,15].

In a second study, this counter-intuitive hypothesis was confirmed [18]. Students who showed smaller prefrontal hemodynamic responses during the Socratic dialog a fortiori showed successful knowledge transfer. In addition, the correlation in brain activity between teachers and students was indicative of the pedagogical success of the dialog, revealing a measure of mutuality which is pertinent for pedagogical success.

Results demonstrated a strong positive correlation in activity between students and teachers in efficient educational dialogs (in which the student transferred the knowledge) and, conversely, a significant negative correlation in dialogs in which the student could not generalize knowledge. Hence, brain measures signaling relevant pedagogical variables (the transfer) can be obtained in a realistic educational dialog.

This constitutes only a first step of a program to investigate brain-to-brain coupling activity in real educational setups where knowledge is acquired in bidirectional orchestrated interactions between teachers and students. Because of the intrinsic variability of human teaching and the fact that it involves the conjunction of several cognitive functions (language, theory of mind, motivation, introspection, executive function and more) teaching may be a domain where neuroscience may help dissect and factor out its constitutive components above and beyond what has been done so far by behavioral inspection. Moreover, neuroscience may help ground and distinguish teaching from other forms of (non-pedagogic) communication in a way that it is not only subject to semantic discussion but is also anchored to a specific set of cognitive processes identified by behavioral (speech, gestures) and brain processes. The question of whether one can classify pedagogical from non-pedagogical communication from brain activity remains open and may shed light on the mechanisms which orchestrate teaching abilities.

Our third idea suggests that we could rethink the information flow in teacher–student interactions. Heretofore, when presenting the TNCA and NP approaches, we focused on the view that information flows from the teacher to the pupil in a unidirectional educational dialog. We have been suggesting that a bidirectional dialog is more adequate to describe the teaching dialog.

But there is a twist here. We may also learn when we teach others, which reverses the direction of information flow. This is not a recent insight. Around 2000 years ago, Seneca the Younger wrote in his letters to Lucilius Junior that we learn if we teach (*docend o discimu*). Fast-forwarding to 1842, this notion was revisited by the French essayist, Joseph Joubert, who wrote in *Pensees*: *"To teach is to learn twice"*. What do we know about this 172 years after Joubert? Unfortunately, not much.

The majority of investigations that studied the restructuring of knowledge from the teacher's perspective come from educational science, mainly in research on peer tutoring [34]. More generally, collaborative learning methods such as reciprocal teaching and peer-tutoring have been shown to be an effective way for the teacher to consolidate her own knowledge [23,29,32,33,40]. These studies constitute scattered efforts conducted under very different conditions. As Roscoe and Chi [34] argued, we currently lack a theory which may unify these findings in a conceptual framework. This can be seen as a challenge to create such a framework. The expanded view of pedagogy may be an avenue for such a creation.

An even more interesting scenario of atypical information flow in pedagogy is when the pupil and the teacher are one and the same. In the introduction we argued that the teacher–pupil dialog is the core of pedagogy. However, a single mind may enact both roles in an educational experience. This has been often described as 'learning by explaining' [26] where it is argued that explanations are not necessarily directed to another individual. Instead, explaining novel information to oneself can facilitate learning and foster generalization [7,8]. Self-explanation has been shown to scaffold the acquisition of both procedural and declarative knowledge. As with peer-tutoring, while the effectiveness of explanation on learning is well documented, the cognitive mechanisms underlying this effect are only beginning to be understood.

5. Summary

We presented developments around a new area of scholarship and scientific work regarding how actual teaching (teaching as a natural cognitive ability) and receptivity to others' teaching (natural pedagogy) are natural in human cognition. After making the case for each, we suggested three ways to expand theory-building and empirical studies around these two views of pedagogy. The first idea was that we could borrow the claim that infants are seen to be receptive to learning in situations of ostensive communications and apply it to children's ostensive communication when teaching. This opening could include the content of what is being taught and the channels of information flow. A second idea was that the neurosciences could be harnessed to help us understand the dynamic information flow in the teacher–learner dyad, and if the synchrony and mutuality (or their absence) influence learning outcomes. A third idea was that we can open up our consideration of the direction of information flow by considering non-standard flow directions, as in cases where a teacher learns from her teaching. In this case the teacher and the learner are one and the same person.

As we stated at the outset, teaching is one of mankind's most exceptional achievements. We believe that advances in the cognitive and neurosciences provide us with an opportunity to enhance our understanding of the complexities of the dynamic and mutual information flow between teachers and learners that ultimately plays a leading role in human cumulative culture and history.

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