14 Teaching As a Natural Cognitive Ability

Implications for Classroom Practice and Teacher Education

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This is a chapter about why we teach. I do not ask what the best way is to teach this subject matter or that. Nor do I ask how we can assess children's learning as a result of teaching. Instead, I ask a deceptively simple question: Why do we teach in the first place? The search for answers to that question takes us to the borders between our biological, psychological, and cultural endowment as humans.

Teaching, or folk pedagogy, the social transformation of knowledge from one person to another or the attempt to engender it in others, is one of the most remarkable of human enterprises. I propose that teaching, which is central to education in the broad sense of that term, can also be seen as an essential domain of inquiry for the cognitive sciences. This is so because, as I attempt to show, teaching may be a natural cognitive ability and is essential to what it means to be a human being. Furthermore, I believe that a search for the cognitive underpinnings of teaching may lead to a description of some of the fundamental building blocks of human cognition and its development.

Learning, teaching's mirror image, has been a major focus of the cognitive sciences, to be sure, but intentional pedagogy aimed to cause learning has, by and large, been flying below the cognitive sciences' radar. Perhaps this is because teaching has been narrowly viewed as residing in the province of formal schooling that takes place in schools where adults teach youngsters. Or maybe cognitive scientists have had enough trouble defining and describing learning and the conditions that bring it about. So if there is difficulty there, the expectation might be that bringing the cognitive sciences to explore teaching, that special case of what sometimes causes learning, would be a daunting task.

These and other possible sources of reticence notwithstanding, I suggest that teaching can be added to the remarkable array of areas the cognitive sciences have studied, but it will not be just one more notch on the cognitive science's belt because teaching has the enormous power to preserve significant

innovations in human society. In short, teaching can enlighten the cognitive sciences and vice versa.

As I see it, teaching can be viewed from perspectives that include phylogeny, cultural evolution, anthropology, primatology, ontogeny (child development from infancy through adulthood), nonnormative cognitive development, and functioning (as in the cases of autistic individuals, brain-damaged people, remarkably gifted teachers, those with teaching disabilities), and more. This however, gets me ahead of my story.

This chapter has seven sections. In the first, I provide different definitions of teaching. In the second section, I motivate reasons why teaching may be a natural cognitive ability. This section concludes with the point that if teaching is a natural cognitive ability, there is a need to determine the nature of the cognitive prerequisites that underlie it. The third section suggests what these cognitive building blocks might be. The fourth section addresses the cognitive conditions necessary for teaching to be learned. In the fifth section, I propose various research agendas to test for these cognitive prerequisites for teaching. In the sixth, I present some implications for teacher education. And I summarize the main points in the seventh, and concluding, section.

Definitions of Teaching

Teaching is a rather elusive concept and is quite difficult to define. Scholars and researchers from various disciplines have used different definitions of teaching and, as a consequence, have developed different calipers to measure it and its effects.

For example, Caro & Hauser (1992) studied teaching from a biological perspective. Their definition of teaching has its origins in evolutionary theory and empirical data; it is as follows:

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

Importantly, Caro & Hauser (1992) argue that this definition of teaching requires neither theory of mind (ToM) nor the intention to teach on the part of the animals whose teaching they described. A few words about ToM are in order here. ToM is an area that has captured the hearts and minds of

developmental psychologists over the past two decades. The main idea here is that people have an understanding that others have minds, that those minds have knowledge, beliefs, etc., and that others' behaviors can be predicted based on their beliefs.

ToM research has focused mostly on young children's social cognition, that is, whether or not young children judge situations in ways that belie their understanding that others have minds. The classic false-belief task requires children to judge if someone would behave in a particular way, a way that indicates that that person has a false belief that is different from reality, where the children being interviewed know what the reality of the situation is.

The classic false-belief task is an interview situation where the experimenter is telling a child a story that is demonstrated with puppets, a chocolate bar, hat, and a dresser. The story has two children playing ball and one of them, Sally, places her hat on the floor and puts her chocolate bar in it. When playing, Sally kicks the ball away and the other child, Mary, goes to retrieve it. While retrieving it, Sally moves her chocolate bar from her hat and places it in her dresser drawer. The child being interviewed is asked where Mary thinks the chocolate is when she returns to play with Sally. A child who says she thinks it is in Sally's hat is thought to have a ToM because he is predicting Mary's behavior based on her false belief that the chocolate is in Sally's hat. A child who says that Mary will look in the dresser does not have a ToM because he does not entertain the idea of someone else's false belief. Considerable research shows that children below age 4 do not have a ToM, as tested by the false-belief task, and children above age 5 do.

Premack (1991, 1993; Premack & Premack, 1994, 1996, 2003) argued that teaching among animals other than humans is restricted, generally related to getting food to survive, which makes it very circumscribed. In addition, Premack believes that only humans are sensitive to their young's progress. For example, the mother cheetah does not give extra time to a cub of hers who might be slow in learning how to kill prey, and she is unlikely to keep that same cub back so that she can give him "remedial lessons," at the time that his siblings are on their own.

In contrast to this biologically based definition, psychologists and educators describe teaching in nonevolutionary terms, as can be seen by the following representative quote:

> When faced with the question of determining whether an action is a teaching action, as opposed to some other action 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. The *intention* the activity serves, then, is a part of the meaning of the concept, and not a factual discovery one makes about the activity. (italics added) (Pearson, 1989, p. 66)

Notice that in this definition of teaching, the role of intentionality is crucial, which implicates ToM, as well. This is because the intentionality associated with teaching is to cause learning in others' minds that, in turn, involves an understanding of psychological causality.

A third definition that takes some of its cues from the cognitive sciences, in particular, ToM, involves the intentional passing on of information from one who knows more to one who knows less, i.e., at the base of teaching is a knowledge gap. The definition is that teaching is the acts a teacher performs given that teacher's beliefs about the knowledge state of the other person (the learner), where the teacher has the intention to cause an increase in the knowledge or understanding of another who lacks knowledge, has partial knowledge, possesses a false belief, or has a misunderstanding. This definition is a variant of that proposed by Frye & Ziv (in press). Other forms of teaching, such as engendering knowledge that already exists in the learner's mind, will not be included in this definition, although there is a clear need to expand this definition's generality.

What Caro & Hauser (1992), Pearson (1989), and Frye & Ziv (in press) suggest as definitions of teaching are not mutually exclusive and can be seen on a continuum, with more to be added.

That having been said, we can now turn to a comprehensive view of teaching, one that includes its phylogenetic origins, ontogenesis from its early appearance in children, and developmental course through adulthood.

Teaching As a Natural Cognitive Ability

A broad view of teaching includes at least four levels of explanation for the cognitive machinery in the mind associated with teaching: an evolutionary adaptive problem that machinery solved, the cognitive programs that solve that problem, the neurophysiological infrastructure that serves as a base for the cognitive program, and the cultural underpinnings that are designed by and support the above.

Let us all too briefly examine each and then see how they might work in concert in the case of teaching. Some claim that our neural circuitry was designed by natural selection to solve adaptive problems our ancestors faced during our species' evolutionary history that began approximately 100,000–200,000 years ago, a time when our ancestors were hunter-gatherers. It is probably the case that our brains have not changed much from that time, which is to say that encased in our modern day skull is a brain whose circuitry was selected to solve adaptive problems that existed 100–200 millennia ago.

The solution to these adaptive problems affected individuals' reproduction such that, on the average, the reproductive rate of those with a selected circuitry had more offspring than those without that circuitry.

Space limitations do not allow me to expand on this topic. Nevertheless, these ideas, after their proper exposition and justification, can serve as a partial map of the cognitive landscape of teaching, one that can guide theory and research efforts of those who might find interest in the cognition of teaching in the way I am presenting it.

Significant landmarks on this map are the need to speculate about what conferred reproductive advantage to our ancestors who could teach. A second area of importance is the need to describe the cognitive programs that produce actual teaching, that allow us to know that we are in the presence of teaching and not, say, playing a game, and that allow humans to learn to teach. A third location on the map is the neurophysiological underpinnings of teaching. One point of significance here is whether or not there is dedicated neural circuitry for teaching, as opposed to, say, deception, play, and other forms of social communication, something I doubt very much. The fourth site on our map includes the cultural expression and maintenance of teaching.

This is clearly a general map of where we might want to look, both theoretically and empirically, for the place of teaching in the cognitive sciences. It provides signposts that tell us to pay attention to certain sites. I touch on some of them in this chapter, but in order to motivate the rationale for teaching as a domain that can be studied in the areas just described, I attempt to make the case for teaching as a natural cognitive ability.

There are at least seven reasons to motivate the notion that teaching is a natural cognitive ability. None by itself leads inevitably to this conclusion; however, in concert, they suggest that teaching might just be a natural cognitive ability. In broad terms, a natural cognitive ability is universal and young children effortlessly learn the domain in question without instruction. Let us see how these and other criteria apply to the domain of teaching.

First, as mentioned, teaching with a ToM may be *species-typical*. The cognition underlying teaching among some species of animals and human beings has not been thoroughly examined. There is little controversy that chimpanzees, our closest relatives, and other primates do not teach with a theory of mind (Hauser, 2000; Povinelli & Eddy, 1996, 1997; Premack, 1984, 1991; Premack & Premack, 1994, 1996; Tomasello, 1999; Tomasello & Call, 1997). There is some convergence, then, on the idea that human beings are the only species that teaches with a ToM.

As part of this typicality in human beings, we can look at places where social interactions are rich among chimpanzees and other great apes. They

have a rich social organization that includes play, fighting, roles of domination and submission, joint action to achieve a common goal, the formation of coalitions and alliances, and much more (De Waal, 1996, 1998). Yet with all this social richness, there does not seem to be teaching of the kind that takes into account others' intentions among the great apes in their natural habitats. Ethologists report very few accounts of teaching in the wild, and those that have been observed can be explained as something other than teaching.

A second motivation for teaching as a natural cognitive ability is that although other primates do not seem to teach with a ToM, it is incontrovertible that teaching with a ToM is *universal* among human beings. This means that, with few exceptions, every person in every society has taught (toddlers and some autistic individuals may be exceptions here) and has been taught by others (Kruger & Tomasello, 1996; Tomasello, Kruger, & Ratner, 1993). These are universal activities that take place in everyday life in the home, the streets, the workplace, and the fields.

There is considerable cross-cultural variation concerning the amount of teaching that takes place (from very little among the San !Kung of South Africa to very much in Europe and the Americas) and the content of what is taught (hunting techniques among the San !Kung and putting a puzzle together in Boise, Idaho).

The importance of the claim of universality is twofold. It means that everyone is exposed to teaching, which is to say that everyone has the possibility to learn to teach by virtue of that exposure, and that very universality suggests that it may be a characteristic of human's biological and cultural endowments.

Third, teaching is an *extraordinarily complex* enterprise that has much to do with mind, emotions, and motivation-reading. The richness of the kinds of knowledge needed to teach is impressive. As a miniscule sampling, consider this: In order to teach, one needs to know about others' minds, knowledge, beliefs, etc., how one can know when knowledge, beliefs, etc. are missing, incomplete, or distorted, as well as how people learn (Strauss, 1993). One also knows about others' emotions and motivation.

In addition, the number and complexity of inferences that must be made when teaching others are remarkable. As teachers, we have a representation of a problem and its potential solutions. If a student solves that problem in another fashion, we infer that he or she has a different representation of the same problem. Furthermore, we infer what that representation might be, given the nature of the student's solutions, and we infer from the student's responses to our teaching if there have been representational, emotional, and/or motivational changes. This is a miniscule part of what we do when we teach. In short, teaching has considerable complexity.

Fourth is the poverty of the stimulus argument. One of the many remarkable aspects of teaching is that so much of it is *invisible* to the eye. The visible part is the external acts of teaching. It is what we see and hear when we are being taught. It is the teachers' questions, her request for the pupils to reflect on their learning, and much, much more. It is the !Kung hunter's demonstration and explanations to a youngster of how to string a bow and the ways he checks to see if it was learned, and it is the ways master carpet weavers in Mexico teach apprentice youngsters to fashion carpets for local use.

These are but a few examples of what people do when they teach. This is what is visible to the eyes of the learner, the person to whom the teaching is directed, and, as shown, it is very complex.

However, the visible part of teaching is quite impoverished in comparison to the depth of what underlies it, the part that is not revealed to the eye, and what is invisible is the inferences teachers make and the mental processes that lead to these inferences. Furthermore, it is possible that the visible part of teaching does not reveal what gives rise to it. In other words, it might be the case that one cannot infer the invisible (what underlies teaching) from the visible (actual teaching acts). I return to this point in the section Conditions for Teaching to Be Learned.

Fifth, teaching is a *specialized social interaction*, unlike others. Yet it shares some aspects of other kinds of social interaction. For example, people have conversations, they have arguments, people collaborate with each other to achieve common goals, they play, and they engage in deception to achieve private aspirations. The differences between these social interactions and teaching are obvious when we engage in them, but they are similar, too, and what stands at the heart of these social interactions is the intentionality of the individuals involved in the social interactions.

As far as I know, there has been only one study on the development of children's play and teaching (Ziv, Strauss, & Solomon, in preparation). In that research, children ages 3½ and 5½ were taught a board game and were asked if they wanted to play with a friend. All did, of course, and because their friends did not know how to play the game, they had to teach it. This methodology was like that of Strauss, Ziv, & Stein (2002). After they taught their friends how to play, they then played the game together.

The results are complex and are still being analyzed, but there is a finding that bears on the point of young children being able to differentiate between the goals of teaching and playing in a competitive game. The goal of teaching is to pass on one's knowledge to someone who knows less in an attempt to close the gap in knowledge. The goal of playing the same, competitive game is to win. This difference in goals led to differences in intentions that, in turn led to differences in behaviors: There was no cheating in teaching, but there was in play.

We also found that there were two kinds of cheating (deception) in play: (a) deception about results, found mostly among the younger children, was detected when a child attempted to hide the results of a throw of the dice from the other player, and (b) deception about one's intentions, found mostly among the older children, where the child who was cheating told the other that he intended to make a move that he had not made.

Both kinds of deception involve understanding others' mental states. Deception about results involves an understanding that others can get information from the world via perception, so if one denies the other the possibility of seeing the results of a dice throw, the other cannot know what the results were. Deception about one's intentions concerns the notion that one's desires and intentions are private and cannot be known and checked by others unless one makes them public.

The point here is that at a surprisingly early age, children behave differently in two kinds of social communication situations around the same game. What differentiates them are the goals of the interactions and the intentionality of the children engaged in them.

Sixth, although teaching is *universal* among human beings, it seems to be *learned without formal education*, or even education of the informal kind. A sliver of the 6 billion inhabitants of planet earth has been taught how to teach; yet all know how to teach. All have been exposed to pedagogy; they have been taught, but, with few exceptions, they have had no instruction about how to teach.

There is sometimes a point of confusion here that I would like to clarify. The fact that people have not been taught how to teach does not mean it is not learned. Teaching *is* learned, and the section Conditions for Teaching to Be Learned picks up on this theme.

Seventh, *very young children teach*. There are two kinds of evidence that bear on this matter: Toddlers may request teaching and youngsters teach.

Toddlers May Request Teaching

Toddlers may have a sensitivity to teaching (Strauss & Ziv, 2001). Children, as young as age 2, are involved in an almost obsessive everyday activity of asking what the name of an object is. "What's this called?" is a frequent request they make. Let's look at what may be cognitively involved in this seemingly harmless question. First, they know (in using the word "know," I do not mean that this knowledge is conscious; instead, it is implicit in the

situation) that objects have names. Second, they know that they do not know the name of the object they are asking about. Third, they turn to someone they believe knows the name of the object, indicating they know that there is a knowledge gap. Fourth, they know that if someone tells them the name, then they will know the name. Here is the point: their request here is for someone who they believe should know the name of the object *to teach them*, to pass on knowledge so as to close the knowledge gap. In this interpretation, although 2-year-olds do not seem capable of teaching (Ashley & Tomasello, 1998), they do seem to request it from others.

Youngsters Teach

Research shows that even 3½-year-olds teach (Ashley & Tomasello, 1998; Astington & Pelletier, 1996; Maynard, 2002; Strauss et al., 2002; Wood, Wood, Ainsworth, & O'Malley, 1995). Their teaching shows remarkable understandings about how to bring about learning in others. As an example, Strauss et al. (2002) found that 5½-year-olds and possibly 3½-year-olds, who were taught a board game, could teach it to their same-age friends (pupils). Furthermore, they did not intervene when their pupils played according to the rules of a game the teacher just taught them, but they did intervene at the points when the pupil made a mistake. These two findings, among many others, indicate that very young children teach others.

The combined claims of teaching with a ToM as being typical of and universal among human beings; its phenomenal cognitive complexity; the difficulty, if not impossibility, of inferring this complexity from being exposed to the visible part of teaching; its not having been taught yet 2-year-olds implicitly request teaching; and teaching emerging among 3½-year-olds and 5½-year-olds teaching well, suggest a reasonableness to the idea that teaching is a natural cognitive ability.

If this claim seems acceptable, we can then ask ourselves two fundamental questions: What are the cognitive prerequisites of teaching? and What are the conditions for teaching to be learned?

Cognitive Prerequisites of Teaching

Before reading on, think for a moment about what is involved, cognitively, when we teach others. If you took time out to ponder this, you noticed that teaching is quite complex and requires many cognitive feats. I briefly present teachings' cognitive prerequisites in this section.

I restrict the conversation here to contingent teaching (Wood et al., 1995) that, by definition, has the teacher reacting to the learner's responses to her

teaching. For purposes of exposition, I exclude teaching that does not require altering one's teaching based on the learner's behaviors, as in nonsynchronous teaching by television. That kind of teaching should also be analyzed in terms of its cognitive prerequisites, but that will not be presented here.

Contingent teaching situations deal with procedural knowledge, i.e., the knowledge about how to do something. In teaching, there is considerable monitoring of the self and the other. This monitoring involves entering the other's mind, in the sense of attempting to imagine what knowledge he has, what his emotional and motivational states are, and more. Mind-reading has been examined extensively over the past two decades under the rubric of ToM.

Contingent teaching almost surely requires one to have a ToM about others' minds. However, unlike what is tapped in ToM false-belief tasks, teaching requires an online ToM, one that has monitoring and an executive function that keeps teaching's complexity in line. Indeed, there is a multifaceted, mutual, and fine-tuned online monitoring in a teaching situation, where both the teacher and the learner are reading the other's mind.

I now flesh out some of these ideas where I restrict my brief exposition to the teaching feedback loop, monitoring, and executive functions from the teacher's side of the teaching dynamic.

I believe there are likely to be feedback loops between the teacher and the learner when contingent teaching occurs, as well as deep epistemological assumptions about others' minds.

As for the *feedback loops* in mutual monitoring, consider the following: A teacher is explaining or demonstrating something to a pupil. As this is going on, the teacher is looking at the child in an attempt to determine, by the pupil's facial expressions, the ranges of the learner's comfort, concentration, understanding the material, etc. This is a kind of mind- and emotions-reading that all teachers do when teaching.

As the teaching proceeds, she asks the pupil questions and from the pupil's answers, the teacher senses how much of the problem the student is grasping. If the teacher judges that the pupil understands the material quite well, she continues teaching. This seemingly trivial aspect of teaching is quite deep, and we have seen that even a 5-year-old teacher continues teaching a game to a learner when the learner plays correctly according to the rules of the game. This involves mind-reading.

However, if the teacher believes the pupil is having difficulties with the material, she generally does not continue further until the pupil has understood the material at hand. This, too, entails mind-reading. When a teacher (even a 5-year-old teacher) detects a misconception, false belief, partial knowledge,

etc. on the part of the learner, this means the teacher has (a) a representation of the knowledge that is thought to be correct, (b) a representation of the learner's incorrect knowledge, and (c) the ability to detect a mismatch between those knowledge representations.

The loop part is the teacher's attempt to make midcourse teaching corrections so as to enhance understanding, but notice that this requires an online ToM because they are a result of the teacher's reading of the reasons for the learner's misunderstandings as teaching continues. In other words, the teacher changes teaching strategies based on her representation of the learner's mind.

There are different ways to make these midcourse corrections. The teacher might correct the pupil's mistake by telling him what the correct answer is and how one could get to that answer. She might change her teaching technique so as to find another way to help the pupil understand the problem and its solution. She may ask the child what is hindering his correct understanding of the problem. Then, when she has taught the material, say, in a new way she, once again, asks the learner questions so as to determine if it is now better understood, which leads to further choices and more mind-reading on the part of the teacher and so on and so forth.

All of this is very familiar and we have all engaged in it from the perspective of both the teacher and the pupil.

Let us look at some *epistemological assumptions* about the mind and learning that are implicit in teachers' teaching. Teachers have declarative knowledge that

- others have minds;
- the mind contains knowledge, beliefs, etc.;
- what is in the mind gets expressed externally veridically; that is, the pupil's knowledge, beliefs, etc. that are expressed in their words, motor behaviors, etc. accurately reflect what is in the mind;
- there is psychological causality; that is, pupils' knowledge, etc. can be changed by others; for example, by teaching, which is to say that teaching can cause learning to occur in the pupil's mind; and
- teaching that causes learning is an action-at-a-distance change; that is, teaching is conducted outside the pupil's mind but it influences changes in the mind, which are termed "learning" (Strauss, 1993, 2001).

This was a very brief and sketchy outline of some aspects of what I mean by an online ToM. Notice that, due to space limitations, I did not include the learner's ToM about the teacher's mind and her teaching and about the loops

and assumptions involved in the learner's questions about the material he is being taught.

The above suggests that teaching is a remarkably complex enterprise from a cognitive perspective. The fact that very young children can carry off this complexity rather effortlessly is quite surprising. Yet there has been little theory and research development into this area on the part of cognitive scientists and educational researchers. My conceptual framework for explaining how youngsters can teach is guided by the notion of teaching as a natural cognitive ability.

Conditions for Teaching to Be Learned

I mentioned that although teaching may be a natural cognitive ability, it does not somehow magically and spontaneously come into existence. It must be learned. All children are exposed to teaching, yet it is rare that they are instructed about how to teach.

The question before us is what conditions should be met for teaching to be learned? I present a list that takes its lead from work done by Pinker (1979), where he attempted to describe the conditions that are prerequisites for language to be learned. Here I simply apply them to teaching.

First is the learnability condition. This condition is twofold. It posits that teaching can be learned in the first place. It also states that the cognitive system can adapt to any teaching it is exposed to. We need to show that the learning mechanisms are adaptive in that they allow learning of any kind of teaching. As mentioned in a previous section, although teaching is universal, it has many forms that are culture-bound. These culturally varied forms of teaching should be able to be learned by any child in his or her normative development. In other words, if we were to take an infant of French parents and, upon birth, put him in the !Kung culture and were we to take an infant born to !Kung parents and have him raised by a French family from birth, the !Kung-born child will learn to teach like the French and the French-born child will learn to teach like the !Kungs.

Second is the equipotential condition. This suggests that all kinds of teaching are possible. We touched on this in the section dealing with the many ways that people have come to teach.

Third is the cognitive constraints condition for learning to teach. The explanations we offer for how the learning of teaching occurs should be consistent with what we know about young children's basic cognitive abilities. For example, we should not suggest learning mechanisms for teaching that are beyond what we know about young children's attention, short-term memory, etc.

Fourth is the time condition. The point here is that learning to teach takes time. It is not a spontaneous, instantaneous acquisition. See Feldman (1994) for an exposition on the relations between universal and nonuniversal achievements and the place of spontaneous versus instructed conceptual acquisitions.

Fifth is the developmental condition. The learning mechanism should allow a description of the development of teaching that is consistent with data about the sequential trajectory of children's understanding of teaching and their actual teaching. For instance, were research findings to continue to find that $3\frac{1}{2}$-year-olds teach mostly through demonstration and $5\frac{1}{2}$-year-olds teach mostly through explanation with demonstrations, we would need a mechanism that could explain this developmental sequence.

The sixth condition involves constraints on input. The idea here is that the learning mechanisms must not require input that is unavailable to children. Were we to surmise that the input needed to learn to teach was not available to children, we would have a serious problem.

Teaching can now be seen as remarkably complex. Accounting for this is at the heart of our research agenda.

Research Agenda

The answers I propose for what a research agenda on teaching would look like are linked, of course, to my conceptual analysis of teaching as a natural cognitive ability. I address six areas where one can go empirically to study cognitive prerequisites.

One is research on primates and lower animals. This allows us a view of the phylogenetic emergence of teaching and what is necessary for its occurrence. We can also speculate about the reproductive advantages afforded by teaching when humans emerged as a separate species.

Second, we can shed light on the cognition of teaching via more research on young children, where we can (1) expose the ontogenesis of teaching's cognitive prerequisites that lead to the emergence of teaching and (2) describe the developmental trajectory of teaching from its emergence to its maturity. Research in this area is currently being conducted with Margalit Ziv and our students at Tel Aviv University: Noah Mor, Ayelet Solomon, and Liat Ornan.

In a third area, one can attempt to describe the nature of teaching among extremely gifted adult teachers. This would be a description of the adult end point of the full development of teachers' cognition.

Fourth, it is possible to consider teaching that has been compromised by developmental or neuropsychological problems. Were we to have hypotheses about the nature of teaching's cognitive prerequisites and were we to know what specific cognitive difficulties arise from developmental or physiological problems, we could predict nonnormative teaching.

This is analogous to knockout experiments in genetics, where a gene is knocked out and its phenotypic expression is studied. In the case of teaching, we can observe teaching in individuals who have had problems in the course of their development. We would choose developmental problems based on what we believe the cognitive prerequisites of teaching are.

I mention four groups of problems that could be studied:

- High functioning people with autism. They might not have a ToM (Happe et al., 1996).
- Brain damaged individuals; for example, those with prefrontal brain damage in the area that may be dedicated to ToM (Sabbagh & Taylor, 2000; Stone, Baron-Cohen, & Knight, 1998). Work in this area with Naama Friedmann and Noga Balaban at Tel Aviv University will begin soon on this topic, which gets at the neurological underpinnings of the cognitive machinery that leads to teaching.
- Individuals with specific language impairment, such as pragmatic deficit. Anna Gavrilov, an MA student at Tel Aviv University, is studying this, under the guidance of Naama Friedmann, Margalit Ziv, and myself.
- Teachers who have what I have coined "teaching disabilities," a term and concept that does not appear in the literature. Some teachers have enormous difficulties teaching, and it would be of interest to attempt to determine the nature of their teaching problems. This research would identify levels and kinds of teaching disabilities, something that would allow us to gain an understanding of the cognitive machinery that underpins teaching.

Fifth, one can analyze teaching using formal systems of analysis, such as artificial intelligence (AI). One could attempt to build an intelligent system that can detect teaching. One could also introduce teaching to models in an attempt to determine the roles of teaching in the evolution of artificial life systems (Parisi & Schlesinger, 2002), and one can model how an intelligent system can communicate with another intelligent system in the form of teaching (Goldman & Kearns, 1991). The use of AI and computational models can bring about rigorous definitions and descriptions of teaching that are currently virtually nonexistent.

Tzur Sayag, a student at Tel Aviv University, is doing work in these areas. In a computer environment, he is growing virtual teachers that teach virtual

learners and is studying how teachers learn to teach, the importance of teachers having complete knowledge of a learner's mind (neural network) in learning how to teach that learner, and more (see Sayag & Strauss, 2004).

A sixth area that has captured the hearts (and minds) of a branch of cognitive psychology – ToM theory and research – is an excellent candidate for research on cognitive prerequisites of teaching. But, as mentioned, the classic research and theory-building will probably have to be extended because ToM research has looked at young children's social cognition about others' belief systems, whereas teaching is dynamic and interactive and requires a procedural online ToM about others' minds and how learning occurs in those minds.

Teacher Education

Making statements about teacher education when there is so little research concerning teaching as a natural cognitive ability requires more than the usual caveats and admonitions. However, I will not take that route. Instead, I throw prudence to the winds and speculate considerably beyond what discretion calls for.

Let me begin with a statement about what I do *not* want to say about teacher education. I do not believe that because children at age 2 show a sensitivity to teaching by requesting it, those at age 3½ have the rudiments of teaching, and 5½-year-olds are quite good teachers, there is no need to teach adult teachers to teach. On the other hand, there is no point in teaching adults to do something they were already quite good at in early childhood.

That having been said, let's see what the implications for teacher education might be, given the conceptual framework I attempted to elucidate in these pages. I discuss two: (1) a possible explanation for adult teachers' resistance to constructivist teaching methods and (2) the role of subject matter knowledge in teaching.

Adult Teachers' Resistance to Constructivist Teaching Methods

Research in science and mathematics education has discovered that most children and adults hold misconceptions about, say, the physics of objects' trajectories. These misconceptions appear early in life and seem to be quite resistant to change through teaching, although some adults overcome this resistance and become experts.

A weak analogy can be drawn to the case of teacher education. We cannot say that there is such a thing as a misconception about teaching because consensus does not exist as to what correct teaching is in the way that there is consensus about the trajectory of objects. On the other hand, teachers often seem to teach with a direct-transmission model in mind, whereas teacher education courses are often geared to teachers engaging in constructivist teaching. There might be some resistance to understanding the constructivist approach, and if that is the case, we might want to determine the nature of the model teachers hold that offers resistance to teaching via constructivism.

Constructivist teaching methods have gained contemporary currency (and many interpretations), and are based on the idea that children are active constructors and not passive recipients of knowledge they are taught. Teaching, in this view, involves the sharing and joint co-construction of knowledge. Reddy (1979) labeled this the tool-builder's metaphor, and Sfard (1998) called this the participatory metaphor. Many teacher education courses, both preservice and inservice, present instructional methods that foster this approach. My personal experience is that these courses have not had a huge success when we examine teachers' teaching when these courses end. Teachers often return to their former, direct transmission ways of teaching.

I often hear reasons for this lack of overwhelming success. One is that the school classroom is a culture that makes constructivist teaching difficult. This culture includes expectations on the parts of the principal, pupils, and parents concerning what teaching should be like.

Teachers' reticent use of constructivist teaching methods can also be explained by teachers' cognition of the teaching/learning process. In other words, one can appeal to the notion of teaching as a natural cognitive ability as a possible impediment to constructivist teaching. Research I have conducted over the past decade (Strauss, 1993; Strauss & Shilony, 1994) indicates that teachers and adults who are not teachers have a model of teaching that knowledge is directly transmitted from the source of knowledge (the teachers) to its recipient (the learner). This model resembles Reddy's (1979) conduit metaphor and Sfard's (1998) acquisition metaphor.

It is possible that adults' teaching is influenced by their natural cognition, which is to say, that at the heart of the direct transmission model of teaching is the natural cognitive ability I am elaborating in these pages. If that is the case, we might have a way of describing what stands at the core of the resistance to instruction about constructivist teaching.

The Roles of Pedagogical Content and Subject Matter Knowledge in Teaching: An Appeal to Separate Them

Shulman and his co-workers (Shulman, 1986; Wilson, Shulman, & Richert, 1987) proposed a taxonomy of the kinds of knowledge teachers employ.

Among the kinds of teacher knowledge Shulman proposes are pedagogical content knowledge (PCK) and subject matter knowledge (SMK).

In broad strokes, PCK refers to teachers' professional knowledge about how to make subject matter understandable to children. It includes teachers' knowledge of students' preconceptions about subject matter, which concepts and skills are particularly difficult for children to learn, what makes them difficult, ways to make these difficult concepts and skills easier, and how these are different at different ages. In shorthand form, it is the knowledge teachers have about children's minds, how their minds work when learning takes place, and the roles of instruction in fostering learning.

The area of teachers' SMK has many aspects, only two of which are briefly discussed here: definitions of what subject matter (SM) of disciplines is and how that subject matter is organized mentally by teachers (i.e., what their SMK is).

Definitions of Subject Matter of Disciplines

The psychological description of the SM of disciplines, and its related pedagogy, has a century-long history. Among the most influential contemporary scholars to study these issues is Schwab (1962). The core of his ideas includes two main aspects of the structure of SM in disciplines: its syntactic and substantive structure.

The syntactic structure of disciplines concerns the ways researchers obtain data, interpret it, and draw conclusions. In short, it deals with ways people in a field come to know and understand it. The ways one knows and understands a discipline are discipline-dependent: Knowing and understanding music are not the same as knowing and understanding physics or literature or psychology. Those special ways of knowing that characterize each discipline are part of teachers' SMK and their understandings of it should influence how they teach.

The substantive structure of SM in a discipline pertains to the main concepts of a discipline and their relations. As an example, the main concepts in cognitive developmental psychology, from the structuralist viewpoint, are logico-mathematical structures as the psychological entities that interpret the world and guide behaviors; assimilation and accommodation as invariant psychological functioning; disequilibrium as a mechanism of structural change, etc. For information processing adherents, among the main concepts are knowledge organizations as the principal psychological entities that influence the interpretation of environmental data and that guides behaviors; attention mechanisms that influence which environmental information gets

acted on; encoding, maturation, and automatization as mechanisms that foster learning, etc.

Substantive structures influence researchers' views of their discipline and lead them to ways they choose to obtain the data they interested in, interpret that data, and draw conclusions. In other words, substantive structures influence syntactic structures, and vice versa.

What constitutes a discipline or field has been a subject of intense investigation in the history and philosophy of science and the social sciences. What teachers understand to be the syntactic and substantive knowledge of disciplines comprise most of teachers' SMK.

Research and theory development led me to appeal to keep SMK and PCK separate, rather than see them as inextricably intertwined, as Shulman (1986) suggested. The main idea is that *how* we teach is related to our understandings of the mind and how learning takes place in others' minds. *What* we teach is related to our SMK.

Let me give an example of what I mean. Many teachers believe that complex material is difficult to learn, and one way to make that complex material easier is to break it up into its component parts. This teaching strategy is guided by a view of the mind and learning. In contrast, the places where teachers break up the material into its parts are connected to their SMK.

My theoretical work suggests and my research shows that teachers with considerable and deeply organized SMK and those whose SMK is impoverished and organized in a shallow manner *teach the same way*, a way guided by their conception of others' minds and learning (Strauss, Ravid, Magen, & Berliner, 1998; Strauss, Ravid, Zelcer, & Berliner, 1999; Haim, Strauss, & Ravid, in press).

In contrast, these same studies found that *what* these teachers taught was very different. Teachers who broke up complex material did so at the places where they thought that the subject matter could be broken. And because they had different SMK, due to their different knowledge organizations, the subject matter they taught was different.

In contrast to Shulman's (1986) suggestion that PCK and SMK are inextricably intertwined, my work indicates that teachers' SMK should be kept conceptually separated from their understandings of how it is learned (PCK).

An implication from my view is that we should not have illusions that teacher education courses about how to teach difficult concepts in, say, history (i.e., teaching PCK) should influence their SMK about history. Similarly, there is no reason to believe that teaching teachers about history (SMK) will influence the ways they will teach history.

Summary

I sketched a brief position about how teaching has the possibility of shedding light on the cognitive sciences and vice versa. As far as I know, some of the areas mentioned above have not been studied at all, and the others that have been studied have had little research conducted in them. And when that research was conducted, it was not motivated by the conceptual account I have been giving here about teaching as a natural cognitive ability.

I believe the positions outlined here* have the possibility of opening up research on teaching so that it could include the nexus where humans' biological, psychological, and cultural endowments are examined. And in so doing, we may be exploring an area that is fundamental to what it means to be human.

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