The Teaching Brain

Antonio M. Battro[1,2]

ABSTRACT—Animals cannot teach as humans do. Therefore, we lack the experimental support of animal studies that are so important to understand the evolution of our basic learning skills but are useless to explore the development of the teaching skills, unique to humans. And most important: children teach! We have at least two new challenges in our Mind, Brain, and Education program regarding the teaching brain. First, to implement new methods to process online the way children teach in the digital environment since the first grade of schooling with the help of computers. Second, we may also explore the teaching brain of children and adults, with the help of wearable brain image technologies in a real classroom setting. Both projects may interact in a dynamic way in neuroeducation.

THE SOCRATIC MODEL

There is much information about the learning brain, but very little about the teaching brain. This situation is strange and needs clarification. We can all agree that education has at least two components, teaching and learning. Very frequently we interpret them as two sides of the same coin, but this can lead to misunderstandings. In fact, education is a very complex system with many components in continuous interaction. Learning and teaching are only two of them, but they are so closely related that sometimes it is difficult to disentangle the two. Moreover, the old Latin expression *docendo discimus*, when we teach we learn, expresses a common experience that we all share. In fact, pedagogy and didactics both stress the feedback obtained by the interaction between teacher and student. In every educational context, teaching and learning form a loop or even a growing spiral of continuous interactions.

Perhaps one of the first descriptions of this process is the famous dialogue between Socrates and the young slave of Meno, as was reported by Plato. "Attend now to the questions which I ask him, and observe whether he learns from me or only remembers," said Socrates to his friend Meno when he started his lesson about the duplication of the area of a square. Socrates asked about forty questions to the boy who mostly answered by yes or no. Only few answers required a simple addition or multiplication. At the end of the lesson the student discovered by himself how to duplicate a square using the diagonal of the given one as the side of the new square. This marvelous demonstration is still a source of joy and admiration for many of us. But Socrates also wanted to prove a cognitive thesis, a most controversial one: "Do you observe, Meno, that I am not teaching the boy anything, but only asking him questions. . . ." And he insists that he is not teaching: "Mark now the farther development. I shall only ask him and not teach him, and he shall share the enquiry with me: and do you watch and see if you find me telling or explaining anything to him, instead of eliciting his opinion." The dialogue ended showing the solution of the geometrical question. And Socrates asked Meno: "What do you say of him, Meno? Were not all these answers given out of his own head?" "Yes," answered Meno, "they were all his own." Today Socrates would be asking us: "Were not all these answers given out of his own brain?" Our challenge will be to explain how.

This introduction may help us to go further into our exploration of the teaching brain. You probably remember the bold statement of Jean Piaget concerning teaching. He said that all that we teach to a child is something that we are not allowing him to discover by himself. In this sense Piaget is a follower of Socrates, but of course his theory of learning is much more elaborate, and certainly it is not based in the idea of reminiscence. We must face the paradox of a master teacher like Socrates trying to demonstrate that he was not teaching at all! However, at a certain point Socrates made a fundamental pedagogical intervention when he saw that the boy was stuck because he was centered on changing the magnitudes of the given sides without success. Using a masterly "change of perspective," Socrates proposed instead to explore the properties of the diagonal ("called *diámetron* by the sophists," explained Socrates), and this "decentration"—in Piagetian terms—led the boy to the right conclusion. This pedagogical trick to change the focus of the learner's attention is often used in our teaching practice and could perhaps be

[1]Argentine Academy of Education
[2]Pontifical Academy of Sciences

Address correspondence to Antonio M. Battro, Chief Education Officer, OLPC, One Laptop Per Child, Billinghurst 2574, piso 1A, C1425DTZ Buenos Aires, Argentina; e-mail: abattro@ross.org

studied in an experimental setting involving brain-imaging equipment with both teacher and student.

In fact, the famous Meno dialogue could become a useful paradigm to test the interaction of teaching and learning at the cortical level at the very precise and crucial moment of the "shift of attention" provoked by the teacher. The attentional neuronal networks have been well described by, among others, Michel Posner and his team (Posner, 2008) and perhaps this robust knowledge may help us monitor the dialogue with noninvasive brain technologies some day.

HOMO SAPIENS DOCENS

All animals learn but only humans teach, in a strict sense. This is the view of most experts in the field and has immense consequences in education (Battro, Fischer, & Léna, 2008; Passingham, 2008; Strauss, 2005).

The explanation of this radical difference is in the human brain, in particular, in the significant development of the neocortex, which is three times as big as predicted from a primate of our size. In the words of Stanislas Dehaene, this amazing increase in the size of our brain allows an expanded neural *working space* that enables us to become "capable of playing with ideas until they became reorganized into unexpected uses" (Dehaene, 2005). Teaching is one essential emergent of this new unexpected capability of our species.

Perhaps we should call our species *Homo Sapiens Docens.* In a sense, *the first human was a teacher*. And most important—and not always recognized—is that children teach! Without the natural teaching capacity shown by children of all conditions and cultures, the survival of our human species would be in trouble. In particular I will underline the enormous importance of teaching in the digital environment of today by hundreds of thousands of children who spontaneously teach other children and their adult relatives. This new fact opens a whole universe to study the teaching brain in the 21st century (Battro, 2002, 2004, 2007, 2007a,b, 2009; Battro & Denham, 1997, 2007).

Teaching is a natural cognitive ability and starts early in life. Sidney Strauss has stressed this fact with precision (Strauss, 2005). The analogies with the acquisition of language are clear. Nobody needs to learn grammar in order to speak; nobody needs to learn pedagogy to teach. Both are natural capacities that develop from the first years of life without formal education. But of course, grammar and pedagogy must be taught, and they are needed to accomplish real progress in speaking, writing, and teaching in formal education. But I will not enter here into a discussion of how to teach to teach.

It is not easy to define teaching or make a classification of the different ways we humans teach. I will adopt Strauss' idea that in order to teach we need to have, first, a Theory of Mind (ToM) and, second, the *intention* to teach. The goal of teaching is to increase the knowledge of some other person; therefore, the teacher recognizes from the start that there is a "knowledge gap" to fill up. There is a developmental trend also in the teaching skills. When children are 3 years old they start to teach by demonstration; around 5 they teach by explanation. Strauss and colleagues observed, for instance, the crucial difference that children make between the *goals of teaching* and the *goals of playing* a competitive game. Teaching aims to close the knowledge gap; playing aims to win the game. What is interesting is that children may cheat in order to win the game but they do not cheat when they teach (Strauss, 2005, p. 10). The conclusion is that "teaching requires an on-line ToM, one that has monitoring and executive function that keeps teaching's complexity in line . . . both the teacher and the learner are reading the other's mind" (Strauss, 2005, p. 12). The example of Socrates and his pupil is very clear on this account. We can follow in that old text every step of the feedback loop between teacher and learner.

THE TEACHING BRAIN IN THE DIGITAL ERA

We lack a theory of teaching based on neurocognitive evidence while we have several theories of learning with robust support in the brain sciences. Our challenge as neuroeducators is to bring a new equilibrium to this distorted image of our disciplines. If teaching in the strict sense is unique to humans, what some authors call teaching with a ToM, we must invent new neurological models to describe and predict the unfolding of the teaching processes. The standard animal models that are so useful for a vast variety of learning skills are insufficient to grasp the human capacity to teach. Of course, we should look for the "evolution of teaching" in other species, and perhaps we can even identify some "proto-teaching skills," as some zoologists are trying to do, but the point is that human language has produced such a radical shift in our cognitive environment that no other animal is able to teach as we do. It is not by chance that I offer the Socratic dialogue as one standard model for teaching.

It is clear that the cognitive gap between primates and men has increased exponentially because of the role of education among generations where cultural traditions are cumulative and are transmitted by language. The essential point is that teaching is—ultimately—based on language, and this is a unique feature of our species. Of course, we can tutor a chimp to understand a concept and some animals even "coach" the young by encouragement or punishment (Caro & Hauser, 1992), but among humans concepts can be introduced "by definition," we do not need to be exposed to instances or concrete examples. Socrates was very well aware of that when he asked Meno if the boy spoke Greek in order to start the geometrical demonstration. Language is the core of teaching. Moreover, I am convinced that a new agenda of research on the teaching brain should explore the way children teach and not be restricted to the teaching brains of adults.

A NATION OF YOUNG TEACHERS

We are fortunate enough to have a large platform to start our research on the teaching brain at early ages because we live in a digital era. I am pointing to the entire new field of the acquisition and the transmission of early computer skills in a completely saturated digital environment, where every kid and teacher has his or her own laptop. The new phenomenon to be studied is the way children interact with each other and with the adults. This focus is now possible with free access to Internet communication and individual laptops as early as the first grade in school, even before children learn reading and writing. This is a new social phenomenon that is making a revolutionary change in the education of millions of children around the world.

I will take the model of OLPC, the One Laptop Per Child program directed by Nicholas Negroponte, where I have the privilege to participate as chief education officer. OLPC is based in the principles of early age, connectivity, ownership, saturation, and free and open source software (see www.laptop.org). This implies a new educational environment that expands the classroom practice in time and space. What we see when we give laptops to children is the new role of teaching among peers and also how children spontaneously teach the adults (parents, relatives, and even professional teachers). This is the first time in history that such a massive explosion of teaching is possible—but educators have been so impressed by the parallel explosion of learning with the computers that they are not always aware of the importance of the new teaching skills developed by the children. It is a new educational phenomenon produced at a very large scale and it will require a profound reformulation of the role of teaching in our society.

The new digital environment in some places is now reaching the point of saturation, where every kid in the country has his or her own connected laptop. This is happening today in Uruguay with the OLPC–CEIBAL program where the whole population of elementary schools, some 400,000 children, is using the same digital platform (www.ceibal.edu.uy). It means that there are now some 400,000 new young teachers in a country with some 40,000 adult professional teachers, a 10-fold multiplication of the national teaching power. It is a kind of digital vaccination for the whole population if we adopt the stimulating metaphor of Jonas Salk, regarding the analogies between immunology and education. When we compare passive to active immunization, the first may "induce a temporary effect of immunity by transferring antibodies from one host to the other, but a long-term immunizing effects can be induced only by the active participation of the host in developing his own antibodies as a consequence of his own interaction with the antigen." Moreover, "'learning' in immunology or in psychology, is something that involves active effort, and that what is learned is significant and effective in proportion to the effort expended . . . the analogy to the educational process needs no longer clarification" (Salk, 1972). In fact this is what a good teacher is doing.

In this extraordinary situation educators should be prepared to see the emergence of new types of teaching that we did not even imagine. Perhaps some of them will be appropriate for brain research in the future. The fact that all the learning and teaching tasks are represented in the same digital environment is a formidable advantage for research and experimentation. In fact, educators can now organize online the follow-up of thousands of learning and teaching activities since the first stages in elementary schools. In particular we can observe online the unfolding of the learning and teaching skills of the children while they are interacting in class or at home. Of course, the methodology to do that at a large scale is not already there but educators are working step by step to attain this objective, in particular, to build a new kind of assessment about cohorts. We could say that, if genetics is about generations, education is about cohorts. Neurocogntive scientists have now the platform, the experimental environment, to explore the new educational skills.

WE NEED MORE BRAIN RESEARCH ON TEACHING

We must recognize that there is an asymmetry between our knowledge of the learning brain and the teaching brain. We have thousands of images of the learning brain in the most diverse situations, but we do not have any image of the teaching brain, as far as I know. My question is, why this difference? I have several explanations. First, without a reliable animal model we face a significant challenge. In fact, the enormous growth of the brain sciences has been based on comparative studies among species, but our problem is that animals do not teach, in the sense that humans teach. It is fairly well established that human teaching is based on a ToM and it is still controversial among experts to attribute a ToM to monkeys or primates (Lorincz et al, 2005). Without this cognitive capability and a language to mediate an interchange, no teaching, in the strict sense, is possible. Therefore, our research on the teaching brain opens a completely new field and can be performed only on humans. This is a key point. But we can still take advantage of basic research performed with animal brains.

The mirror neurons discovered in the monkey by Giacomo Rizzolatti and his team may give a good example because a mirror neuron system has also been found in humans. However, "unlike the monkey one, [the human] is able to describe both the goal of an action and the movements necessary to achieve it" (Rizzolatti & Buccino, 2005, p.242). Both are necessary for teaching. Also the role of mirror neurons in the evolution of language has been explored. We can, therefore, hypothesize that mirror neurons play a role in teaching too and we certainly need to create an experimental protocol with noninvasive brain technologies in order to know more.

Second, brain research has been mostly a laboratory task upon isolated individuals, while teaching is a social activity that creates a new human environment for education. Our schools and our classrooms are the result of a long history of the construction and transmission of knowledge. Until recently it was impossible to use noninvasive brain technologies outside the laboratory, but now we have access to portable and wearable equipment that can be used in numerous settings and in very different circumstances (Koizumi, 2007). I predict that the classroom will soon become a chosen environment to study the teaching brain in interaction with the learning brain.

Third, there is a problem of scale in education. It is true that the basic unit of education is the *duo* of a teacher and a student; the Socratic dialogue with the boy is a perfect example of this duality, with the addition of Meno, as an observer and critic. Without doubt we should start the exploration of the teaching brain with such a duo. I suggest that Socratic dialogue could be reproduced in a laboratory using brain-imaging equipment to monitor the event. The fact that most answers in the interchange between Socrates and the boy were restricted to yes or no might greatly facilitate the design of a protocol for a "Meno experiment." Perhaps a reader of this article will explore this idea.

However, we should go beyond the basic duo of one teacher and one learner. Normally teaching is a one-to-many task. Moreover, the essence of education is to expand knowledge and values beyond all kinds of borders—religious, political, social, geographical, etc. It is not enough to have an isolated class as an experimental environment for studying the teaching brain as a case study. We need larger populations. The ideal would be to have a whole region, even a whole nation, as the teaching platform to be investigated. This may sound utopian to many, but we are not that far from such a possibility.

As already mentioned, a new invention, the computer, has radically modified the teaching and learning environment in impressive ways. Children not only teach each other how to use a computer but they also teach their elders. Therefore, a horizontal dimension is added, and the traditional vertical dimension from adult to child is sometimes reversed in the transmission of knowledge, with considerable consequences in education. As educators we must recognize that we are only at the beginning of the global digital era, but some day it will be possible to explore the dialogue among teaching and learning brains in the most diverse settings and with very large populations. The challenge will be to follow a cohort of students and their teachers during several years in their educational environment with the help of wearable brain-imaging equipment.

BRAIN RESEARCH CAN INVALIDATE SPECIFIC METHODS OF TEACHING

The epistemology of Karl Popper has underlined the key function of falsification of a proposed scientific model. He went further in asserting that no scientific theory can be directly proved but can only be invalidated. This pragmatic restriction is of course of great help when we consider modern theories of teaching too. In fact the cognitive neurosciences have an important role in providing a litmus test to reject a given theory of teaching. It must be clear, however, that the neuroeducator is not prescribing a particular method or theory but only modestly advising the colleagues to be cautious in the practice of teaching because some methods may risk contradicting neuroscientific evidence and fail.

Let us take an example in the theory of teaching to read, known as the "whole word method." Essentially this pedagogy proposes that the child directly associates the written words or even sentences to their meaning, sense, or reference without explicitly teaching the grapheme-phoneme correspondence. An enormous amount of resources and time was spent in deploying this pedagogy, especially in Europe and some Latin American countries. The results were unsatisfying in most cases, even if it could benefit some individuals. One of the reasons for this failure is that the method does not follow the real functioning of the reading networks of the developing brain, Stanislas Dehaene, in his recent book on the "neurons of reading," has dedicated a whole chapter to this issue (Battro et al., 2008; Dehaene, 2009). Essentially, contemporary findings in neuroscience show that the reading skills should be taught; in most children they do not evolve by a kind of natural development. Learning to read needs long practice and is supported by additional years spent in practicing converting graphemes into phonemes. And most important "each day in school modifies an impressive number of synapses" Dehaene, 2009 when children learn to read. With the help of computers, this extended practice grows exponentially, as we are seeing in the digital environments promoted by OLPC, among other experiences around the world.

TEACHING DISABLED AND TEACHING GIFTED CHILDREN

Sidney Strauss introduced the notion of "teaching disability" but it still needs exploration (Strauss, 2005). I am sure that further research with children will show several specific teaching disabilities. In my experience with disabled children and computers I became aware that many autistic children were not only unable to learn to use a computer but also were unable to teach. A plausible hypothesis is that the common cause in these two failures is the limited unfolding of their ToM.

On the other side, neuroplasticity also plays a major role in the acquisition of teaching skills, even of gifted teaching skills, similar to what we have observed for learning skills, in particular, in those children that have some brain impairment. The extreme case is perhaps the astonishing capacity of some hemispherectomized children in both learning and in teaching. I will mention only in passing the case of Nico, a right hemispherectomized child, with an intact cerebellum, (Battro, 2000, Immordino-Yang, 2007, 2008), who is now a dynamic young man, studying in high school, writing and reading without any problem, using the computer every day and having obtained a diploma in informatics for physically disabled employees in secretarial jobs. He is also thriving in fencing skills and participating in international competitions. It seems that he is also a good teacher of fencing among his colleagues. He does not need his right hemisphere to learn and teach. His intact left hemisphere is enough.

THE NEW CHALLENGES

There are, however, some pitfalls that we should be aware of. In the first place we should avoid reducing neuroeducation to a branch of medicine, neurology, or genetics. Any review of the scientific literature shows a consistent and perhaps increasing bias toward the study of the troubles of the educated brain instead of a larger view of the whole spectrum, including learning without difficulty. This trend may impoverish our Mind, Brain, and Education disciplines. While we must help with all our dedication those who are in need of special care and education neurocognitive scientists should be careful not to privilege the research of the disabled brain and learning disabilities over other common situations in education that also need urgent consideration.

Second, learning and teaching should be considered in interaction, and educators should avoid focusing only on learning processes. Currently the problem is that we lack the right tools to explore the teaching brain while we have developed a wealth of instruments and methods to explore the learning brain. We should strive to reach a more equilibrated state with a better balance in the near future. The essential fact that children teach could become an immense source of knowledge about development of the teaching brain from the first years of schooling to the university. The study of groups of children learning and teaching together will also play a key role in such research. In particular, the extensive use of computers will provide a platform to facilitate online studies and assessments that were unimaginable only a few years ago.

Third, teaching is a privilege and also a responsibility. The fundamental role of the teacher in our societies is unfortunately not always understood, and educators must work to promote the universal values of teaching in all possible situations. Neuroeducation will bring new hopes to teachers because it is already enlarging the field in theory and in practice, by bringing a wealth of resources from other disciplines into schools.

CONCLUSION

We must recognize that many great discoveries in the neurocognitive sciences were made with very young subjects, when the brain was growing at a fast rate. Children are experiencing the formidable explosion of their intelligences in the early years of schooling, but a huge proportion of the young population on Earth has no access to a sound elementary education. This is not only a blatant injustice but also a dramatic evolutionary failure.

The challenge is recognized in the Statement of The Millennium Goals signed by the United Nations in September 2000: “We recognize that, in addition to our separate responsibilities to our individual societies, we have a collective responsibility to uphold the principles of human dignity, equality and equity at the global level. As leaders we have a duty therefore to all the world’s people, especially the most vulnerable and, in particular, the children of the world, to whom the future belongs.” And two of the articles in the Statement are explicit about our responsibilities as educators:

19. “To ensure by the year 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling and that girls and boys will have equal access to all levels of education.”

20. “To ensure that the benefits of new technologies especially information and communication technologies, in conformity with recommendations contained in the ECOSAC Ministerial Declaration, are available to all.”

We can collaborate in this ambitious and urgent project from the new perspective of the neurocognitive educational sciences. We know that every human brain is radically changed by education and this neural transformation is the only way biological evolution may continue in our species as Cultural Evolution. We do not expect larger brains to evolve, we only need to make better use of the brains we already have. And the way to do that is educating our brains.

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