THE COMPUTER IN THE SCHOOL: A TOOL FOR THE BRAIN

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The information world in science education

The impact of the information world in science education begins in elementary school. When a child sends an electronic message to a friend he is using a set of powerful computer tools: word processing, dictionaries, machine translation, digital images, audio, etc. These are "new tools for the brain", that transmit and amplify many feelings, emotions and cognitions in a totally new way. These instruments can work as "intellectual prostheses" for our mind.

I would present a case that illustrates this view. It is related to the emotional impact of the terrorist attack of September 11th in New York and Washington, on Nico, a 11 year-old child living in a remote place from the terrible events. Nico, who is at school in Argentina in his 6th grade, sent the following e-mail in Spanish to his friend, a university professor in the United States:

> "Hola, soy Nico. quería decirte que siento mucho lo que pasó allá en Estados Unidos espero que si tenías parientes ahi en NY que no les halla pasado nada. me dan muchas ganas de volver a verte. te mando un beso grande y mi mamá tambien. NICO".

He did not use the spelling software in Spanish to find some errors in his message, but we can leave the English translation to a machine:

> "Hello, I am Nico. wanted *decirte* that I feel much what happened back in the United States I hope that if you had relatives *ahi* in NY that does not find last anything to them. they give many desire me to return to *verte*. I also send to a great kiss and my mother to you. NICO".

Machine translation, in spite of its current and evident limitations, can be used with great profit in schools – it inspires linguistic criticisms and lively discussions – and will continue to improve. Children enjoy using this powerful tool to check their own proficiency in a foreign language and love to engage the machine in "linguistic loops", i.e. translating an expression from language A to B, and then the translated sentence B into A, and so on. My point is that we are dealing here with a message transmitted by the web that eliminates many practical obstacles such as writing the letter on a paper, addressing the envelop, looking for stamps, going to the post office, etc. Also the e-message has the advantage of reducing the affective distance between both partners, we can even talk of a "distance zero" between them. Moreover we can feel that this information technology is closing the gap between the child and the adult, and the novice and the expert, in a very profound sense.

Even more so because Nico is a hemispherectomized boy and he is using the computer as a "prosthesis", he is hemiplegic and his writing by hand is impaired (Fig. 1). He was given a right hemispherectomy when he was three years old to control intractable epilepsy, and he is successfully performing in life since his surgery using only his left hemisphere. He has compensated his devastating loss and became a regular student at school and a remarkable example of rehabilitation (Battro, 2000).

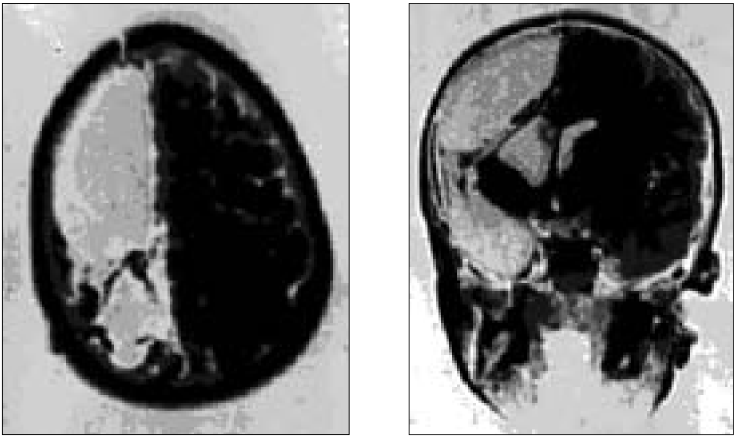

Figure 1. Two images of Nico's brain showing the loss of the right hemisphere at the age of three.

Another related and striking example is Louis Pasteur. As one of his biographers stated: "Le lundi 19 octobre (1868), Pasteur, bien que souffrant d'un étrange malaise, d'un fourmillement dans tout le côté gauche, eu le vif désir d' aller présenter â l'Académie des Sciences, le travail d'un italien, Salimbeni". (Vallery-Radot, 1922). In the following hours "Pasteur suffered a cerebral hemorrhage on his right side... It has been said that after his injury (at the age of 46) 'he had only half a brain'. Nevertheless, after this injury, he did some of his best work" (Wiener, 1948).

These extreme cases of people working normally or being superbly creative in the sciences after the loss of a significant part of their cerebral cortex open, at least, two challenging questions: How much "brain power" do we need in order to learn and create knowledge? We have some 10^{12} neurons in our brain; how many do we actually use in a specific cognitive task? Perhaps this is not a quantitative but a qualitative problem related to the plasticity of our neuronal networks, of what is called "activity-dependent plasticity" (Sharma *et al.*, 2000). We also know that growth of the brain is closely related to growth of action and thought and that both brain activity and optimal cognitive functioning develop in fits and starts (Fischer and Rose, 1997). Modern education should take into account the results of neurocognitive research, and one task would be to understand the biopsychology of computing.

The click option and the cortical shift

Pasteur did not need a computer in order to make the remarkable discoveries that have improved our life, but one hundred years after his stroke children all over the world were starting to use the computer to calculate, to write and to draw, to make music and to control elementary robots and sensors (Papert, 1980). Many disabled persons also began to profit from and to enjoy the power of digital machines to learn and to work. Now the computer has conquered, definitely, its place in education. This is the result of many coincidences between the brain and the computer, which seems to bring an incredible expansion to our mental capacities. Everyone, for instance, can agree that the child has an astonishing talent to use a computer, even before he or she can read or write, but few have asked why this is so. This extraordinary matching of the child and the digital machine is both a gift of nature and of culture.

The biological reason is because our brains, and the brains of many animals, are naturally adapted to make "single-option decisions", by yes or no. In fact, ever since the nineteenth century experimental psychologists have intensively used the very simple device of a mechanical or electronic switch to study animal and human behavior. A simple click on a button can produce a cascade of effects in an experimental setting that can reinforce or inhibit a well-defined sequence of tasks. On the other hand, the computer is the cultural artifact that has led to the modern state of globalization of our society. The modern computer, with its flashing screen, its astonishing sound equipment, its keyboard and mouse, its modem, is the right instrument to make interesting things happen, in our own environment or at a distance, with a simple click. What we call the "click option" is only the final step of a *cognitive decision process*, which can be of great complexity. Think about the moment we decide to buy a book through the Internet, it is just a click at the end of a long search on the screen, browsing the digital shelves, reading excerpts and reviews, etc. All this search is part of a *digital heuristic* that belongs to the new *digital skills* developed by a citizen of our global society. Perhaps we are witnessing the unfolding of a kind of *digital intelligence* for the new digital culture of the twenty-first century.

Children of a very young age, even under a year (Bruner, 1883), can learn to make clicks on the computer and produce some significant results. The user's motivation is very high because of the immediate feedback; the answer is automatic and facilitates further exploration. It is a happy coincidence that contemporary technology has produced such a powerful tool that fits so well with children's interests. It would be difficult to imagine the conquest of our world by the computer without children's extraordinary capacity to play with it. A computer industry restricted only to adult experts would be unsustainable. As Nicholas Negroponte rightly says "each generation will become more digital than the preceding one" (Negroponte, 1997, p. 231). This cultural fact is substantial to our understanding of modern education, where, for the first time in history, the pupil may know more than the teacher does. In a sense, the mastering of the new digital field is very similar to the acquisition of a native language. No child needs to read a manual to use a computer or take grammar lessons to speak. Moreover, the computer is a machine that can simulate any particular machine; it is a tool of tools (Minsky, 1967). Equipped with the right interfaces the computer can perform multiple tasks. And this is one of the reasons why we need computers in education, in particular in the teaching of science. As I said before, the most elementary action with a computer is the "click option", wich every child uses with remarkable ease; even those who are severely disabled can learn to produce a click, if properly assisted by an expert (Rose and Meyer, 2000).

In my opinion the computer enables us to expand our brain-power because it might activate some brain areas that were not used to perform some specific tasks in a traditional pre-digital culture. Let us take an example: drawing by hand or drawing by computer. The skillful analogical movements of the arm, the hand and the fingers, which help to make a drawing: this is a very complex sensory-motor process that is controlled by specific areas of the cortex and the cerebellum. But the user can shift to a digital modality that by-passes hand-drawing: the machine will do the drawing and the user only the programming. In this case, the brain makes a "cortical shift" from the analogical task of drawing by hand to the digital task of producing a computer program as in Figure 2. We can also obtain interesting functional magnetic resonance images fMRI to monitor this cortical shift (figure 2, see page I).

Writing a computer program needs linguistic and logical skills, while drawing needs spatial skills, and we can perfectly separate the cortical areas and cognitive modules involved in language and in drawing (Gardner, 1983, 1999). The artist can even *dictate* the drawing procedure to the machine (with a voice recognition device) instead of writing it down on the keyboard (Battro, 1991). It is of great theoretical and educational importance to identify the different cortical areas that are involved in analogical and digital tasks. In the case of Nico, because of his right hemispherectomy both tasks take place in the left hemisphere. I understand this remarkable compensation following brain injury as a proof of *the expansion of the natural neural plasticity with the help of a computer.* The same neurobiological argument favours the use of computers in children in general: new digital tasks will require new digital skills and the exercise of new patterns of brain activation. This opens a new field in education which way be called *neuroeducation*.

We may have a glimpse of some future applications of neuroeducation in the paper published by Stanislas Dehaene and his colleagues (1998) concerned with arithmetic (number comparison). In this experiment, the (adult) subject pressed a key with the left or right thumb to decide whether digits presented visually were larger or smaller than 5. We know that the precentral right and left brain areas control, respectively, the left and right hands. This fact enables the experimenter to make very accurate inferences about the cognitive tasks performed by the subject by a kind of "reverse neurology" which predicts the behavior (the number comparison) from the (right or left) brain activation. As the authors say: "Once we understand the function of a given brain area or network of areas, it should be possible to use on-line activation measurements to infer what kind of task the subject was performing". This very interesting experiment opens many intriguing questions about the validity of what might be some day a “reverse education assessment”, i.e. the evaluation of a given cognitive performance from the corresponding brain pattern produced during the task. To sum up, neuroeducation can be understood as a bridge – under construction – between the neurosciences and the sciences of education.

The dual world (real/virtual) of science education

We are living in a dual world, where many things have a double representation: the newspapers are printed on paper, and, at the same time, are published in the Internet; a molecule is produced in the laboratory and is simulated in the virtual space; a museum has real visitors but also as many, or more, virtual visitors on the web; a surgeon performs a hemispherectomy but also can simulate it by virtual surgery, etc. As a result, many human activities can be projected in two dimensions, real and virtual; the result is a path on a 2D cognitive space defined by these two orthogonal coordinates. Many people believe that the virtual is taking the place of the real, but this is a misunderstanding. It is just another, independent, dimension of our world. What happens is that the virtual dimension of journalism, chemistry, the visual arts, medicine, etc, is acquiring increasing relevance in our cognitive world. This is why the use of digital devices, of computer hardware and software, is also of increasing importance in education in general and in science education in particular.

The interaction with a computer enhances the child’s cognitive field: learning to read hypertexts enriches the mental process with new perceptual modalities and new links, programming a robot develops new skills, simulations and animations open new windows to imagination and action (Resnick *et al.*, 2000). The enlarged (digital) educational field is, certainly, changing science education. In a celebrated paper entitled ‘Unlearning Aristotelian Physics’, Andrea diSessa (diSessa, 1981) used a computer to provide new insights about the notion of force. He programmed a dynamic object that could be directed to a target using very simple commands on the computer, such as Kick, Right and Left. The game was to hit the target with a minimum speed, like a landing on the Moon (Abelson and diSessa, 1981; Battro, 1986). Many children and young adults were tested and most of them failed in an “Aristotelian manner”, because they used the intuitive strategy: aim and shoot. They rotate the moving missile towards the target and then a Kick was given following the common intuition that “objects move in the direction you push them”, i.e. that force correlates with changes in position. This is what diSessa calls now a *phenomenological primitive* or *p-prim* (diSessa and Sherin, 1998). The result is that the missile makes an "Aristotelian corner" and continues its movement without hitting the target. Only a few students applied the Newtonian idea that force correlates with changes of velocity (F=ma) and one of the preferred strategies (a "Newtonian corner") was to produce a turn and a Kick to stop the missile, then turn again and Kick to finish.

The important point is that the new brain imaging techniques can be used to test some cognitive changes produced by current education. For instance we can study the changes from Aristotelian to Newtonian performances in the subject's brain in the same way we can analyze the different cortical processes in reading strategies in English and Italian (Paulesu, *et al.*, 2000). We are moving from the general notion of "embodiments of mind" (McCulloch, 1968) to the study of specific "embrainments of science", a new task for the twenty-first century.

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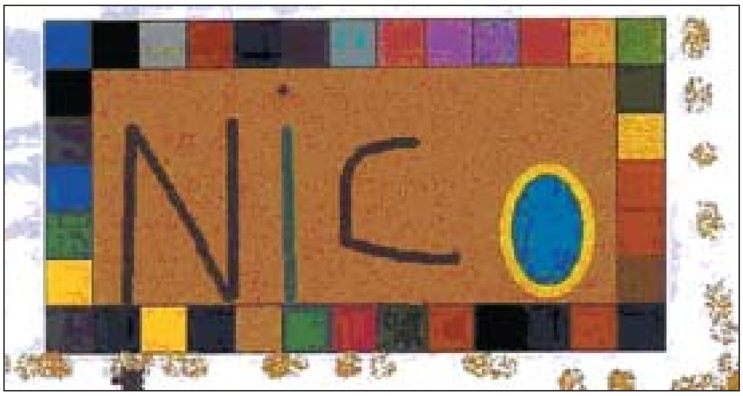

Figure 2. Two different ways of drawing. Analog task: The name Nico was hand-written with the mouse as a pencil. Digital task: The colored framework was generated by a computer procedure (Logo). Different cortical areas are involved in these tasks. In this case, because of the right hemispherectomy both tasks take place in the left hemisphere.