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DIGITAL INTELLIGENCE: THE EVOLUTION OF A NEW HUMAN CAPACITY

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Many education initiatives around the world show the massive and early unfolding of a new kind of intelligence, a 'digital intelligence' in children of the most diverse cultures and socio-economic conditions at early ages. Those children are becoming the 'digital natives' of this new culture. Children can use computers in creative ways, they learn and teach with remarkable ease in the new digital environment. In this culture *the computer is more than a tool, it creates a new environment*. Our challenge now is to use the new – and universal – digital intelligence in the search of truth, beauty and good.

A new digital generation

Each generation will become more digital than the preceding one

Nicholas Negroponte (1995)

A new environment, a new landscape, a new ecosystem is spreading without frontiers because of the incredible penetration of the computer and the communication technologies in every society, urban or rural, poor or rich. We are living an impressive cultural change that is unfolding from the bottom up, with hundreds of millions of participants, creating a new language, promoting new skills and changing the education parameters. How can we interpret this accelerating wave of changes in the framework of evolution? For Luigi Luca Cavalli-Sforza (2008) 'culture has supplemented biological mutation in producing novelties in the form of inventions'. Jean-Pierre Changeux (2005) explains this impressive leap forward by the 'brain epigenetic capacities to store stable representations of the outside world [that] give human beings the opportunity to create an artificial world of cultural objects at the social level'.

Novelty in a culture is not the result of a random mutation but it is still an unpredictable event whose impact in society has to be evaluated. And this relates to the way the transmission of novelty occurs. In the case of education for centuries the cultural transmission of knowledge was vertical (from adults, parents or teachers to children), now we are witnessing an increasing horizontal transmission (from anybody to anybody) as pointed out by Cavalli-Sforza. This shift has immense consequences on education. In fact humans are the only species capable to teaching (Battro, 2007, Passingham, 2008) and children are very good at that, it is a 'natural ability', in the words of Sidney Strauss (2005). This fact is becoming more and more important as a motor of the digital evolution, because in a society of digital natives there is a growing spiral of teaching and learning at all levels. The acceleration of this process has unique consequences on our culture, in particular in our education. The increasing horizontal transmission of digital skills is adding a most welcomed leverage to the educational system in all places. We have therefore a daunting task in front of us regarding the new ways of teaching and learning in a digital culture. It should be remarked, incidentally, that while we have a wealth of information related to the learning brain that may help to improve the educational practice we still don't know how the teaching brain works. Our understanding of the dialogue between teaching and learning brains will soon increase with the help of new portable and wearable brain imaging technologies to be used in the classroom (Koizumi *et al.*, 2008). In this sense the new trends in *neuroeducation* will also contribute to shape our evolving digital environment (Battro, Fischer & Léna, 2008).

Since the work of Jean Piaget, we know that any particular learning process needs the support of a developmental platform at a specific level of stability (Fischer & Bidell, 1998, van Geert, & Steenbeek, 2008). The core idea of Piagetian 'constructivism' is that we continuously build cognitive structures, and when they reach a certain stability, they become a platform for a new step or stage (Papert, 1986). When a whole population becomes 'digital' the rules of transmission – and construction – of knowledge change significantly. We now have the possibility, perhaps for the first time in history, to follow the evolution of a new human capacity, the digital capacity or intelligence, in a short period of time, in one generation. We can now observe and evaluate the behavioral, cognitive, emotional, and moral changes from early childhood to adolescence in cohorts of hundreds of thousands that are educated in a fully saturated digital environment. The notion of 'digital saturation' can be related to the analogy launched by Jonas Salk concerning the deep relations between epidemiology and education. When we compare passive to active immunization we discover that the first may 'induce a temporary effect of immunity by transferring antibodies from one host to the other, but a long-term immunizing effect 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). I like to use the expression 'digital vaccination' to show the need – and urgency – to give to every child in a country the possibility to develop their own digital intelligence. It is a matter of justice and solidarity. It is also a way to reach the Millennium goals proposed by the United Nations concerning the right of all children of the world to receive elementary education by 2015. This is also the mission of OLPC, the One Laptop Per Child initiative (www.laptop.org, Negroponte, 2007, Battro, 2007).

Recycling our neurons for new digital skills

Stanislas Dehaene has proposed a model of neuronal recycling to explain the introduction of new cultural objects in human history and their embodiment in our brains (Dehaene, 2005, 2007, 2008). In the case of reading, he has shown that there are some neuronal networks involved in the detection and identification of forms in nature that are active also in the perception of written symbols. His neural model works as a hierarchy of collections of neurons. The last level of integration is performed by the activation of the visual word form area WWFA in the left occipito-temporal sulcus, specialized in extracting an invariant representation of the visual words. Dehaene (2007) also uses the immunology metaphor to express the formidable impact of literacy in our brains: 'the *virus of reading* is inoculated via the visual path but its influence extends rapidly to the whole of the language areas, where it multiplies our spontaneous competences. When our children learn to read they return from school transformed; their brain is not the same' (my emphasis and translation). In fact the brain of a literate person is different from the brain of an illiterate, as has been demonstrated by neuroimaging in different tasks. What is incredible is that every child is able to learn to read in any language or script. For more than five thousand years scribes have performed marvelous feats to express the human thought with written symbols, today a child must compact this long cultural evolution in the few years of elementary school. A similar 'cultural preemption' – as is called by Dehaene (2005) – can be hypothesized in the case of the acquisition of the new digital skills: the human brain is prepared to deal with the new digital environment, because it can 'recycle' some neuronal networks with a long evolutionary story to new purposes, as we will see later.

Towards a digital intelligence

When we mention the term 'intelligence' we raise a manifold of questions. I will not summarize the history of this extremely polymorphous and complex concept, but for the sake of our experimental and educational pursuit I will follow now the definition given by Howard Gardner in his classical work *Frames of mind: The theory of multiple intelligences* (1983) and revised in his book *Intelligence reframed: Multiple intelligences for the 21st Century* (1999). To Gardner intelligence is 'a biopsychological potential to process information that can be activated in a cultural setting to solve problems or create products that are of value in a culture' (Gardner, 1999, p. 24). A list of conditions for the identification of a particular intelligence in his theory of Multiple Intelligences, MI, is the following:

1. The potential of isolation by brain damage.
2. An evolutionary history and evolutionary plausibility.
3. An identifiable core operation or set of operations (sub-intelligences).
4. Susceptibility to encoding in a symbol system.
5. A distinct developmental history, along with a definable set of expert 'end-state' performances.
6. The existence of idiot savants, prodigies, and other exceptional people.
7. Support from experimental psychological tasks.
8. Support from psychometric findings.

We have already dedicated a book *Hacia una inteligencia digital* (Towards a digital intelligence) to analyze these criteria in detail (Battro and Denham, 2007) and we have concluded that the digital intelligence DI is a fair candidate to be included in the list of eight intelligences, already accepted by Gardner (intrapersonal, interpersonal, musical, logico-mathematical, linguistic, spatial, bodily-kinesthetic and naturalist). We have detected two core digital operations, first the 'click option', second the 'digital heuristics' (exploration, navigation in the digital virtual space). In fact the interaction between a human subject and the computer is based in a very simple elementary behavior, the 'click option', a decision 'to click or not to click'. This can be represented in propositional form in Boolean lattices (Battro, 2004). On the other side, a series of click options, a chain of decisions, unfolds a complex heuristics of a new kind: the exploration of a new human environment, the globalized digital environment.

We have some evidence from the neurocognitive sciences to establish the biological foundations of the click option. Among others the extensive research done by Michael Posner and his team on the attentional neuronal networks offers a good platform for further research on this basic 'digital option' (Posner, 2008a, 2008b). It seems that the executive attention process depends mostly of the activation of the Anterior Cingulate and Lateral Prefrontal cortices, as well on the Basal Ganglia. The prominent neuro-modulator here is Dopamine. Some simple digital skills are observed in very young children, even before they can read or write. We are astonished by the natural and easy way children interact with computers, but if we consider the simplicity of the click option, there is some good and profound reason for that. The answer is in the brain, in the way the click option is prepared and executed. Exactly the contrary occurs when children learn to write by hand. Analog skills need considerable more time. The difference is striking in all accounts, but many schools are still reluctant to provide a digital environment to young children. We must overcome this prejudice. The human brain is already prepared to perform simple decisions from the very beginning of our mental life. The fact that even some animals (birds and mammals) can make a 'click option' and use a computer in elementary tasks is a sign of the deep evolutionary importance of the digital skills (Battro, 2004).

What we lack, however, is a sound neuronal basis for the other core digital intelligence: the 'digital heuristics' expressed by search, exploration and navigation on the network. If we follow Dehaene's model we need to know how the brain recycles the old neuronal networks to explore ('read') a new digital environment with a computer. I would propose, tentatively, to test the neuro-circuitry involved in the spatial abilities. In particular, we find universal spatial invariants in the representation of the urban environment. I will take the model of the 'image of the city' so well studied by the MIT team directed by the great urbanist Kevin Lynch (1960, 1977). In his work it was proved that any landscape or townscape is represented by a set of five invariants: *paths, borders (frontiers), zones, nodes (attractors) and landmarks (singularities*). Normally, children follow a developmental sequence starting with the representation of the paths and borders and ending as the last step with the landmarks (Battro and

Ellis, 1999). What is interesting for our purposes is that this spatial representation has fractal properties. In other words, the five basic representations are scale-invariant. We find the same five invariants in the representation of a large sector of the town and also of a part of it (a big neighborhood with a park and a small rose garden in a corner of that park show the five invariants already mentioned). I find this fractal invariance as a key to understand the way we explore the digital landscape, the virtual space of the new global environment. In fact, some results show that even in the cultures of hunter-gatherers, these spatial invariances are already detected, and support the tracking skills of the hunters (Leibenberg, 1990). In the same vein Dehaene has investigated the invariance of letters and words involved in reading (size, orientation, position, format, etc). In the virtual space of the digital world we could interpret the sequence of links on a computer as a path, the frames as borders, the folders and menus as zones, the click options as nodes, the icons as landmarks. We can hypothesize that perhaps the same old neuronal circuits used to navigate in the real environment are recycled in the virtual digital space. The famous study of the London taxi drivers has shown how much the brain can change by the exercise of a spatial skill in the everyday practice of navigation in the streets of a large city (Maguire *et al.*, 2000). In this case the posterior part of the hippocampus is enlarged and the anterior part shows a decrease. We don't yet have a comparative evidence for digital navigators, but the study could be done. We need of course more research in this case but everything shows that our globalized culture is producing a new generation of experts, of 'digital natives' with a new kind of literacy that cannot be reduced to the traditional one. Their brains should also be different.

An important aspect of the increasing relevance of our digital intelligence is found in the world of disabled persons. We know how to build many kinds of devices to interface with the computer. Most of them are based on the elementary click option, which is the core of a digital intelligence. Motor and sensory disabled persons can operate a computer with simple switches, using their voice, or a voluntary movement of any part of their body, head, eye, finger or foot (Battro, 2002). In some cases a 'mental click' without any motion can trigger a series of voluntary decisions via the computer using implanted electrodes in the brain of severely disabled patients (Kennedy *et al.*, 2000) or even without invasive technology, just by detecting the local changes in neuronal activation from the skull (Koizumi, 2007). The click option gives the opportunity to reach a new world of knowledge, of communication, of work. The advances in the field of computer prostheses are incredible, and we are only at the beginning. We know, for instance, that hemispherectomized children can use a computer perfectly well; we don't need both hemispheres to acquire computing skills (Battro, 2000, Immordino-Yang, 2007, 2008). These, of course, are extreme cases but they show the road. As Steven Rose said, the future of education is in the margins (Rose & Meyer, 2000). When we allow free and early access to computing and communication no child is left behind and the disabled can enjoy the same privileges. Moreover, many times those devices, equipment and software, provided for the most disabled persons are in fact used by many others, for instance a software tool that helps those children with reading disorders is also useful in the standard classroom.

Biological and educational evolution

I would like to conclude with a reflection on some profound changes that the new digital skills are producing in our culture and the analogies we can establish with the biological evolution. Cavalli-Sforza (2008) says that the development of human language 'has given enormous power to another type of evolution, parallel and interactive with the genetic one: the evolution of culture, intended very generally as shared knowledge'. I think that this idea can shed some new light on the meaning of the invention of the computer as a new tool that is spreading around the planet and creating a new (digital) environment. I propose the following analogies between evolution and education:

EVOLUTION	EDUCATION
Mutation	Invention: computers
Natural selection	Adaptation: digital intelligence
Genetic drift	Digital drift: cohort stabilization (digital natives)
Migration	Globalization: networking

Evolution is about generations, education is about cohorts. A cohort is a group of subjects defined by experiencing an event in a particular time span. The new event to be studied is the education of the digital intelligence. I understand by 'digital native', in the strict sense, the child who has started to use a computer *before* the age of reading and writing. For instance all children starting with a laptop in the first grade (6 years old) belong to cohort 1, the cohort of digital natives. All children starting with a laptop in the second grade (7 years old) belong to cohort 2, and so on. This collection of different cohorts is heterogeneous but will become homogeneous with time, in other words every child will be a digital native if we continue to give a laptop to every child entering school every year. We can say that the school system at this end stage has been 'stabilized' because all schooled children belong to a homogeneous and stable population of digital natives. This is the objective of the OLPC initiative. When the entire educational system of a given city, region or country is stabilized, then, and only then, we can make fair comparisons among ages because all of them are digital natives of different ages. We are witnessing how diverse and multiple individual digital skills naturally improve with practice since early ages and shape with other partners of the same digital culture a new cognitive and practical environment. I consider this phenomenon of homogenization of a population 'saturated' with computers, the analog of the 'genetic drift' that can lead to the final homogenization produced by statistical chance in the evolution of biological populations. The essential difference is that the 'digital drift' is not produced by chance but by the strict execution of a deployment plan and in a short period of time, in the case of the OLPC program the period of homogenization is six years (the elementary school years in most countries). In short, cohort studies are key for educational research and this 'very large cultural experiment' is starting now and will reach millions of children around the world.

A good example in process is Uruguay where some 400,000 children and teachers (www.ceibal.edu.uy) are now receiving a laptop in ownership in the context of an educational national program to saturate the whole public and private elementary school system by 2009. Other thirty countries are following the same trend (www.laptop.org). A case study on 'digital evolution' is now taking place in Niue, a small island nation associated to New Zealand, a 250 Square Km coral island in the Pacific with a population of 1700 and some 400 children, attending two schools, elementary and primary. The island is well connected already by wifi and OLPC has given this year 500 laptops to every student and teacher on the island. Therefore Niue could be considered the first fully saturated 'digital nation'. It is expected that the 'stabilization' of the new digital environment in different regions of the world will provide valuable information about the multiple ways of unfolding a digital culture. This fact reminds the story of Charles Darwin in the Galapagos Islands. Darwin discovered in those islands a variety of finches that were later described as thirteen different species, and this discovery became a landmark in the genesis of the theory of evolution. Are we going to find different varieties of digital natives depending on the culture of the different human societies? We hope so.

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