PRELIMINARY SYNTHESIS

OF THE

FIRST HIGH LEVEL FORUM

ON

LEARNING SCIENCES AND BRAIN RESEARCH:

POTENTIAL IMPLICATIONS FOR
EDUCATION POLICIES AND PRACTICES

BRAIN MECHANISMS AND EARLY LEARNING

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Introduction

The goal of this preliminary report is twofold:

- Providing an overview of the content of the conference
- Synthesizing possible educational policy relevance in relation to the sequence of conferences on the brain and education.

Important issues of brain research as presented in the conference are:

1. Language Acquisition
2. Early Cognition
3. Mechanisms of Reading
4. Mathematical Thinking
5. Emotional Competence

as related to brain plasticity and periodicity.

N.B. This project on "Learning Sciences and Brain Research" was introduced to the OECD's CERI Governing Board on 23 November 1999, outlining proposed work for the future. The purpose of this novel project was to create collaboration between learning sciences and brain research on the one hand, and researchers and policy-makers on the other hand. The CERI Governing Board recognised this as a risk venture, as most innovative programmes are, but with a high potential pay-off. The CERI Secretariat and Governing Board particularly agreed that the project had excellent potential for better understanding learning processes over the lifecycle, but that ethical questions also existed. Together these potentials and concerns highlighted the need for dialogue between the different stakeholders. Once the conceptual basis of the project had been established, initial discussions began with major research and funding institutions: Sackler Institute, NYC (USA), University of Granada (Spain) and RIKEN Brain Science Institute (Japan); National Science Foundation (USA), the Lifelong Learning Foundation (UK), and the City of Granada (Spain); and INSERM (France).

Timetable

- 16-17 June 2000, New York City (Sackler Institute - Cornell University), USA:
  First high-level forum on "Brain Mechanisms and Early Learning";
- 1-3 February 2001, Granada (University and City of Granada), Spain:
  Second high-level forum, on "Brain Mechanisms and Youth Learning";
- 26-27 April 2001, Tokyo (RIKEN Brain Science Institute), Japan:
  Third high-level forum, on "Brain Mechanisms and Learning in Ageing".

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1. Brain-based Design of Educational Programs

Dr. Helen Neville

"The brain is the mechanism that permits learning, that limits and constrains it"

The first questions that were discussed at the outset of this forum were: "What is the role of brain science in terms of education? What specific contribution to learning and education policy does it bring? Perhaps the clearest response to these questions came from Dr. Helen Neville, who answered with a very simple word: "Mechanism." She further explained: "The brain is the mechanism that permits learning, that limits and constrains it. [This] is the reason why some educational curricula are more effective than others and why some are effective only at a specific period. If we understand how these mechanisms work, we will be better able and poised to not only remedy to deficit in learning, but also to design educational programs, which will optimize learning in the developing child."[1] To make this point she presented a research example directly relevant to education by describing what is known about the brain mechanisms regarding first and second language learning.

1.1 First and second language learning

The first thing that Dr. Neville mentioned regarding the subject of language is that comprehending and producing it involves the mastery of different processes. This includes the understanding of context and intent, discourse, prosody, phonology (the process by which the sounds of language are perceived, produced, and combined into the words of language), semantic processing (the process by which words stand for specific objects and events) and syntactical processing (the rules that specify relationships between objects and the rest of language).

She focused her talk on grammar and semantic processing by observing that these two processes rely on different neural systems within the brain. This can be shown, for example by comparing the regions of the brain that are activated when one reads words like "cat", "house" or "car", which provide semantic information, with the regions that are activated when reading words like "up", "of" or "from", which provide grammatical information. She reported that semantic processing activates the posterior lateral regions of the brain[2] of *both the right and the left hemispheres*, whereas grammatical processing usually recruits more frontal regions of the brain *of the left hemisphere only*[3].

[1] Dr. Helen Neville, New York Conference.
[2] That is, the posterior parieto-temporal region.
[3] More precisely, the anterior temporal region of the left hemisphere.

According to Dr. Neville, high level functions such as language are not processed by a single region of the brain, but by different neural systems that differ in their anatomy, physiology, and localization within the brain.

The way the brain processes grammatical information changes with the age at which first exposure to the language is initially acquired

Dr. Neville also explained that these neural systems also differ by the manner in which they develop, grow, and acquire function between birth and adulthood. As she further explained, being able to identify the brain regions that are recruited when processing semantics or grammar, would enable the study of the impact that delaying exposure to either the first or second language has upon these various subsystems.

Results from her lab have shown that whether children start to learn the English language between 4 and 6, 7 and 10, or between 11 and 13 years of age, the brain systems used for the processing of semantic information are the same and located within the posterior regions of the left and right hemispheres of the brain. In marked contrast to this result, the way the brain processes grammatical information changes with the age at which first exposure to the language is initially acquired. People, who learned English as a native language or as a second language between 1 and 3 years of age, recruit, when processing grammar, the left lateral region of the brain. However, those who learn English later (usually as a second language or for instance, deaf people who learn the American Sign Language before learning English) end up recruiting not only the left lateral region of the brain, but also the symmetrical brain areas of the right hemisphere. In fact, the older (13 years +) the first exposure to English language, the more bilateral the brain activity.

This change in brain activation indicates that delaying exposure to the English language leads the brain to use a different strategy when processing grammar. In confirmation of this, she found that when subjects with bilateral activation were processing grammar, they usually displayed more difficulty in using grammar correctly. Dr. Neville was quick to point out that this does not necessarily imply that these people are precluded from improving and becoming more efficient in English but that the bilateral brain activation probably indicates a greater difficulty in learning.

Dr. Neville concurs that one clear educational policy consequence from this research area is that, with impunity, at least until the age of 16 and in fact probably throughout life, whereas grammatical learning is more constrained in time:"The earlier, the easier, and the faster." In fact, her research is even more precise: learning a second language (whose grammar markedly differs from one's own native language – for instance learning French for a native English speaker) after 13 is extremely likely to result in poor mastery of the grammar of this language[4]. This result is at odds with the education practices in numerous countries (including the USA but also numerous European countries), where second language learning starts at approximately 13 years of age.

Semantic learning can occur probably throughout life, whereas grammatical learning is more constrained in time

[4] And also, from a phonological point of view, as Dr. Neville said in her talk: "When you hear someone speaking your language with a non-native accent, you can be sure that he learned it after the age of 12".

Another policy consequence concerns the design of educational programs for the deaf, who are often prevented from using a sign language[5] because some people think it will interfere with their ability to learn a spoken language. Dr. Neville states that if children do not learn a sign language early on, the chance of them being able to master it later is in fact reduced for the very reasons described above. Furthermore, the chances of them acquiring the English language later are also impeded. As Dr. Neville explained: "Deaf kids who learn a sign language from their parents at an age appropriate for language acquisition score much better on tests of English than do those deaf children who do not learn any language until they enter school, where they face an almost impossible task of learning to speak. The acquisition of any formal language can be used to acquire another. It is a very crucial point in curriculum design[6]."

If deaf children do not learn a sign language early on, the chance of them being able to master it later is reduced

1.2 Summary of brain research pertaining to literacy

1. The brain is made up of different neural systems, each localized in different regions. They collaborate to produce higher cognitive abilities, such as: language, mathematical reasoning, attention, memory, etc.

2. The maturation and development of some of those abilities during infancy and childhood may or may not occur concurrently, depending on whether or not a specific nurturing or educational experience occurs at the right time. These periods of time during which the brain regions responsible for this ability are maximally modifiable by experience are called "sensitive periods."

3. If exposure to the relevant nurturing or educational experience occurs after the sensitive period, it does not necessarily mean that learning cannot take place, but that it is likely to occur with more difficulty. If learning occurs, the child will probably use different and potentially less adapted educational methods to learn the corresponding ability.

4. Not all kinds of learning suffer from dependency on sensitive periods. This is the case of semantic learning (learning new vocabulary), which research now indicates occurs throughout the lifespan, an important theme in terms of brain plasticity and lifelong learning.

[5] Such as the American Sign Language, which has a strong grammar of its own.
[6] Dr. Neville, post conference interview.

2. Brain Plasticity & Lifelong Learning

Dr. William Greenough

One can use rats to make inferences about human behavior because not only are they mammals but their overall brain architecture is somewhat similar to that of humans

During the conference, Dr. William Greenough developed a useful classification that related to the contrast just described between vocabulary and grammar learning:

- Learning processes, which depend on a sensitive period, such as grammar learning, correspond to *experience expectant* phenomena in the sense that for learning to occur at all, relevant experience is expected to happen in a given time window (the sensitive period). Experience expectant learning is thought to occur during the early years of life.

- Learning processes, which do not depend on a sensitive period, such as semantical learning, are said to be *experience dependant* phenomena in the sense that ultimately the period during which the experience of learning can occur is not constrained by age or time. This type of learning is likely to occur throughout life.

One question raised by Dr. Greenough's seminar was, "How does experience dependant learning occur within the brain?"

Dr. Greenough explored these issues during the 80s and early 90s by observing laboratory rats. Interestingly, one can use rats to make inferences about human behavior because not only are they mammals but their overall brain architecture is somewhat similar to that of humans. As Dr. Greenough stated, "A fundamental characteristic of mammalian brains is that they are organized through a process of intelligent interaction between the organism and its environment."

Dr. Greenough explained that Hebb's law of associative learning describes how learning in the brain occurs through changes in the connection between neurons. In Hebb's research with rats, he found that rats reared in a complex environment exhibit more capability to solve and learn complex maze problems than rats raised in a deprived environment.

Dr. Greenough explained that by comparing the brain of rats raised in an environment as complex as their natural one (that is, with other rats and various objects to explore) with that of rats raised in a deprived environment (little or no opportunity of contact with other rats or objects other than their feeders), Hebb found that rats raised in the complex environment had 20 to 25% more synapses per neuron[7] in their upper visual cortex than rats raised in the deprived environment. Hebb

[7] What was measured was the ratio of the density of synapses to density of neurons. Synapses are areas on the neuron cell where connections with other neurons take place and are the points of communication between neurons. More synapses per neuron are thought to indicate a richer ability of representation and adaptation.

found *that the actual number of neurons does not change, but only the number of connections between them*. In other words, Dr. Greenough says, "Experience embellishes the wiring diagram between neurons of the brain."

Interestingly this change in the wiring diagram occurs between neurons situated in the brain regions[8] most directly involved in the task to learn. Moreover, other studies by Dr. Greenough and his colleagues showed that learning provokes an "orchestrated set of responses involving both neural and non-neural tissue components within the brain". As such, this increase in the number of synapses per neuron is also accompanied by a change in the number of blood vessels (responsible for transferring nutrients from the blood to the neurons) and in the number of other cells called astrocytes (which have a role in the metabolic support of neurons and in the growth of new synapses between them).

The structure of the brain is not pre-determined and may be related to lifelong learning

Relating this to humans, an important consequence of learning in an enriched or complex environment is that when one learns, the regions directly implicated in learning change physically. This is not only due to the formation of new synapses between neurons, but also to the corresponding growth in the brain tissues needed to logistically support these new synapses. This is one aspect of the phenomena of brain plasticity, which describes the capacity of the brain to be physically changed by experience. The key idea is that the structure of the brain is not pre-determined and may be related to lifelong learning. In other words, education and learning have the potential for engaging permanent, physical change in the brain.

3. Early Cognition

Dr. Alison Gopnik

The most important things that children have to learn about , is a kind of everyday psychology about what other people around them think and feel, what they know, and how they understand the world

What kinds of behaviors do infants naturally have and how does this relate to the early skills they demonstrate? Do these early skills have any relation with formal schooling? Answers to these questions is what Dr. Alison Gopnik has found when she states that cognitive observations of infants and young children have shown that they are indeed born with very specific knowledge and skills. However, rather than being strong, unchangeable, innate structures, these skills *evolve a great deal* during early infancy.

Dr. Gopnik illustrated this point by showing how infants understand and learn about how other people around them think, feel, and how it is related to their own thinking and feeling, that is, their "everyday psychology" also referred to as "Children's Theory of Mind." This domain of infant developmental research suggests that one of the most important things that children have to learn

[8] That is, a network of brain regions.

about, if not the most important thing, is a kind of everyday psychology about what other people around them think and feel, what they know, and how they understand the world. This learning about other people constitutes one of the four domains of early learning, that is, before any official schooling takes place. The other three concern language, everyday physics (how objects move and how to interact with them), and everyday biology (how simple living things, plants, and animals work).

Newborn babies can imitate the facial expressions of people looking at them

As she explained, a good example of an innate skill in everyday psychology, is illustrated by the discovery of Dr. Andrew Meltzoff that newborn babies can imitate the facial expressions of people looking at them[9] – for instance sticking out their tongue in response to someone sticking their tongue out to them. As Dr. Gopnik stated: "This means that newborn babies already have a link between what it feels like kinesthetically for them to learn a certain kind of behavior…to produce a certain facial expression. Babies are making these links literally from the time they are born, that is, babies are born recognizing that people are special… that the way they feel inside is linked to the way that other people behave."[10]

In other words, children are born knowing a great deal, far beyond simple perceptual, sensory or motor information. Far from being egocentric or functionally inert from the time they are born, babies already have this deep fundamental link to other human beings. From a cognitive perspective, they already have "highly abstract predictive generative models of an important part of what other people are like. Something that, in fact we argue in the lines of a *theory.*" [11]

Furthermore, as Dr. Gopnik explained, this knowledge is not just static. Over the course of infancy and early childhood, knowledge is being revised, altered, and changed in many different combinations. This revision seems to take place in response to the experience that the child has of the world around him.

To illustrate this latter point, she showed in a study how later through development, children evolve from linking the way they feel to the way other people feel, to understanding how sometimes other people do not feel the same way that they do.

In her experiment, she introduced children to raw broccoli and goldfish crackers (in terms of this experiment, all children disliked the broccoli and liked the crackers). Then, the experimenter would nibble a little bit of the broccoli and nibble a little bit of the goldfish and half the time she would act as if she hated the broccoli and that she liked the crackers and the other half of the time, she would say "Hmmm" when she had the broccoli and "Oh, yuck", when she had the goldfish crackers. She would then put her hand out to the children and say, "Can you give me some?" It turned out that the 18-month-olds consistently gave her the broccoli when she liked the broccoli and gave her the crackers when she liked the crackers. Fourteen month olds on the other hand did not, they would only give the goldfish crackers. Apparently, 18 month olds had already learned this important new thing about other people. . . that is, sometimes people do not feel the same way that they do and they seem to learn it in the period between 14 and 18 months of age.

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[9] *Meltzoff, Andrew N.; Moore, M. Keith. (1977). Imitation of facial and manual gestures by human neonates. Science, Oct, 198 (4312),75-78.*

[10] Dr. Gopnik, New York Conference

[11] Dr. Gopnik, New York Conference

[13] For example, early examples of "everyday science" would include principles of gravity, condensation etc. That is, phenomena readily available in the daily home environment. This does not make reference to the preschooling context in sociological terms. Nor does it make reference to the socio-cultural origins of children and their culturally determined preschooling characteristics on their school training.

What is interesting is that this process of change has a logic, which can be described as a revision of a theory. There is a reason why babies learn this and according to Dr. Gopnik, "When they get to be about a year old and become more mobile, they suddenly start seeing lots and lots of cases in which their desires and those of others are in conflict. They seem to start out with a theory such as, "I feel the same way that you do", as manifested in imitation and lots of other abilities from birth. However, when they meet resistance to their wants and demands, Dr. Gopnik thinks that those situations function as a kind of *counter-evidence.* That they are in fact saying to the babies, "Your initial conception of the world does not make good predictions, it is time to revise them". She hypothesizes that this kind of learning early on in development, particularly learning things like everyday physics, everyday biology, and everyday psychology, uses some of the same cognitive principles that are used in science. She states further that this is a kind of process for theory formation and theory change. "Children are born with these abstract representations of the world, which are already like theories, that enable predictions and interpretations, and that they change, revise, and alter in the light of new information that they get."

Research has begun to show that innate knowledge and skills exist in the infant. In fact, an incredible amount of learning occurs during the early years before formal schooling. In fact, as Dr. Gopnik explained, the challenge in the next 10 years of research in cognitive development is to understand exactly what the learning mechanisms of early learning are like. The research should enable us to understand precisely *how* experience contributes to development.

As Dr. Gopnik added in a post talk interview "early education could and should pay more attention to children's developing areas of natural expertise. In fact, in the past many educators have explicitly thought, based on Piaget, for example, that children could NOT understand psychology or biology at an early age and so these subjects should not be taught. However, recent research suggests that these are areas that are actually at the focus of their interests."

In the interview Dr. Gopnik also suggested how the transition between early learning and school learning could be improved:

- First, "school can be built on the knowledge children have gained in their earliest environments.[13] For instance it might make sense to teach everyday psychology during early school. Or in the case of physics and biology, school could start to teach children from their natural conceptions (and misconceptions) about reality in order to achieve a real understanding of the scientific concepts that describe it."

- Second, "schools could capitalize more on the processes of play, spontaneous exploration, prediction, and feedback (in America this is often called "inquiry"), which seem to be so potent in spontaneous home learning. We should be providing even the youngest children with the chance to *be* scientists and not just tell them about science."

4. Mechanisms of Reading

4.1. The challenge of reading

Dr. Bruce McCandliss

An important number of children (anywhere from 2 to 20%) do not succeed at learning to read

As Dr. Bruce McCandliss explained, children arriving at school, already possess many skills: "These children, who are age 4 to 7, are already experts in visual object recognition and at converting sound inputs into language representations. They have specialized cortical circuitry for this, which is part of the human genetic endowment. They have also (for their age) full command of the syntax of their language, comprehension of sentences and sentence contexts, and the ability to comprehend, from a linguistic input, very complex stories and situations."

What is disturbing is that an important number of children (anywhere from 2 to 20%[14]) do not succeed at learning to read (broadly categorized as dyslexia). Dr. McCandliss states that this has detrimental consequences on school performance, as they cannot engage in the most fundamental linguistic exchange and end up, as a result, becoming marginalized from society. As educators have experienced, this inability to read is very difficult to overcome and much time and energy is spent trying to help these children learn to read. However, after they learned through the popular press that there is something that does not occur in the minds of these children, something which actually prevents them from reading, these educators and teachers become interested in understanding why seemingly smart kids can't read.

Being interested in this situation himself, Dr. McCandliss, in collaboration with educational psychologist Dr. Isabel Beck, started working with small groups of impaired children who can read poorly in order to develop new methods to successfully teach these children to read more fluently.

An important result is that these impaired children *were indeed capable of learning to read.* As Dr. McCandliss explained, this was established through a large-scale study undertaken at the end of the 80s. In this study, impaired children able to read were given the mental task to recognize and identify a specific list of words presented visually, which were either unfamiliar or challenging to them. The encouraging result was that, working under the supervision and assistance of a reading specialist for 40 sessions, these children succeeded at doubling the size of their reading vocabulary. "With very focused, extensive practice these children were able to learn the exact words they studied and to recognize them at a later time quite accurately." However, Dr. McCandliss noted that when given novel words that were not on the list, they were no better able to read those words on their own, even after the extensive training.

[14] Dr. McCandliss, post talk interview.

4.2 Alphabetical decoding

This research demonstrated that the core deficit these impaired children had was that *they could not generalize from their experience*. Dr. McCandliss realized that they could not transfer what they had learned about reading words from their existing vocabulary to new words. He posits that at the heart of this capability to learn from experience is a very specific skill called "alphabetical decoding". This requires that when looking at the letters of a written word, one converts the letters into sounds in order to correctly pronounce this word.

Literacy researchers describe it as a kind of "self-teaching" mechanism that enables children to find out, autonomously how new words can be pronounced without requiring the aid of a teacher. As Dr. McCandliss said "If you're going to spend 10, 000 hours attempting to read, this skill of decoding unfamiliar words is critical."

Impaired subjects able to read failed to recruit a region of the brain, called the Left Superior Temporal Gyrus (Left STG), whereas skilled readers heavily recruited this region including the angular gyrus and regions around this area

One may wonder why some children succeed at learning how to read words, whereas for others it is a difficult and imposing task. Part of the response to this question was given a little more than two years ago by a brain imaging study[15] that compared the brain activity of impaired adults able to read, with that of normally reading adults.What was found was that when these individuals focused on the sound structure of words, that is, whether pseudo-words rhymed or not, their brain activity differed. Impaired subjects able to read failed to recruit a region of the brain that is situated a bit above the ear on the left side, called the Left Superior Temporal Gyrus (Left STG), whereas skilled readers heavily recruited this region including the angular gyrus and regions around this area.

According to Dr. McCandliss, there are two ways of interpreting this brain imaging result. The first one is to see it as a confirmation that reading impairment has something to do with phonology and decoding.

A second approach to interpreting these results was to see it as a brain problem that cannot be treated by educational means. "When the study reached the popular press, many teachers and colleagues of mine had a very interesting reaction. They have been struggling with kids that they know are smart but can't read and suddenly they read in the popular press that dyslexia is a brain problem. So they said: If difficulties in learning to read are due to a disordered brain, then, as a teacher, what am I supposed to do about it?"

4.3 Word building

To offer educators a way in which to improve literacy in spite of a potential physical problem, Dr. McCandliss defined a new research program aimed at taking a closer look at the cognitive operation of decoding. He asked, "Are they able to visually encode the letters?", "Are they able to map

[15] Shaywitz et al. (1998). Functional disruption in the organisation of the brain for reading in dyslexia . Proc. Natl Acad Sci USA Mar 3; 95(5) 2636-2641

the letters to their sounds?", "What nascent abilities do they have that we could capitalize on in an intervention?", and "Could we build on whatever encoding skills they have to help them to become better readers?"

Reading impaired children are usually able to decode and pronounce with 90% accuracy the first consonant of a three letter word like "SAT",

One important finding Dr. McCandliss made was that these reading impaired children did indeed possess some decoding skills. For instance, they are usually able to decode and pronounce with 90% accuracy the first consonant of a three letter word like "SAT", but perform less well on the last consonant and are even worse at recognizing the middle vowel. In other words, these children "have got the great ability to pull off a letter and put a sound to it. However, something is breaking down as they get to the last consonant, or the vowel". So the question that Dr. McCandliss asked himself was: "Could we build upon that? Could we break down the decoding process so that these kids' nascent skills of pulling out a single letter and decoding it actually makes it easy for them to engage in a learning task that scaffolds the normal healthy decoding ?"

To answer this question, he conducted a study on impaired children able to read and tried to explicitly teach them how to generalize what they already knew about letter pronunciation. In order to achieve this, he used a reading method called "Word Building", invented by Isabel Beck, whose basic principles are easy to understand: "We'd form a word, using letters on cards. Let's say we form "SAT", and we tell them what SAT is. Then we instruct them to take away the "T" and they know that the "S" and the "A" are still sitting there. And then we're going to drag a "P" to the end." They found that under this condition these children understood that the sound "SA" and "P" should be pronounced successively in order to produce the correct pronunciation of "SAP".

Dr. McCandliss further explained: "In a sense the only thing that is novel here is the final letter. What we think is happening in their mind is that their attention is being drawn to this final letter, and all they have to say is "P" and put it together with what they have done before. The children succeeded and as a result, this process was generalized in a method called "minimal word pairing", where a sequence of words is presented to children that only differ from one another by one letter or "grapheme". This enables reading impaired children to progressively pronounce a larger and larger amount of words: "What they end up learning by this method is that with a small set of letters you can make a lot of words. This is the combinatorial principle, which is so powerful in human language and that some of these kids need to be explicitly taught[16]."

4.4 Toward results

So here we see how an in-depth inventory of the cognitive dysfunction behind reading impairment leads not only to a remediation of this impairment, but probably also to a better understanding and perhaps an improvement of the way reading should be instructed to normally developing children.

The future of this research is rooted in the potential to help fight illiteracy. As Dr. McCandliss explained in a post talk interview, "The ultimate goal of this research is to have a website that is open to the whole world where children with reading problems can log in, participate in a reading

[16] Dr. McCandliss, New York Conference.

assessment, and then engage in reading interventions that are specifically designed to address the particular difficulties that the child is having. The website could monitor their progress, and continually adjust the difficulty so that learning and motivation are maintained at optimal levels.

5. Numeracy

Dr. Stanislas Dehaene

There is a region situated in the back of both human brain hemispheres that is specialized for representing numbers as a quantity
(see figure 1)

If learning to read is one of the challenges that young children face when arriving at school, learning to compute is another one. Dr. Stanislas Dehaene described what is presently known on the brain mechanisms that allows humans to think about and manipulate numbers.

5.1 Elementary numerical skills

There is a region situated in the back of both human brain hemispheres[17] that is specialized for representing numbers as a quantity. Although the evidence is indirect, converging factors show that it is this region of the brain that enables us to answer questions such as, "What's bigger, 34 or 45?" or "Which integer is found between 6 and 8?" or "Is 17 closer to 20 or to 10?" In fact, this region provides us with the ability to represent numbers on a "number line". As Dr. Dehaene explained, "When we speak about 4 + 5 being almost 10, we like to think of 10 as spatially close to the correct answer 9. It is this notion of a spatial number line which, I think, is given by this quantity subsystem in the brain."

Associating a quantity to a number like 3 or 5 is a learned and later becomes an automatic process. However, for children (or adults) that have incurred a brain injury in this precise region, they become unable to understand the quantity meaning of numbers. Dr. Dehaene says that, "These kinds of patients develop a condition called "acalculia", which means inability to calculate. In fact I would like to argue that those patients do not simply suffer from an inability to calculate but also from an inability to understand the quantity meaning of numbers. Typically, these patients will be unable to perform calculations as simple as 3 minus 1. They would answer, for instance 7; or they cannot say what is between 2 and 4. To understand what is between 2 and 4 (notice that it is again a spatial representation), one has to understand that the word "between" applies to numbers, that there is some kind of continuum and that a number can be between two others, and unfortunately, these patients seem to have lost this spatial concept of quantity."

Not only is the capacity to associate a quantity meaning to a number automatic but it is also a good example of an innate skill as Dr. Gopnik described. For instance some experiments have shown

[17] The intraparietal sulci situated in the parietal lobes.

that children as young as four and a half months old are able to understand the difference between 1, 2, and 3. "Not only can they discriminate between 2 and 3 objects or 2 and 3 sounds but they can even combine them, so for instance if you show them a visual analogue of the operation 1 + 1, one object then the second object, they can expect that the result will be two objects and will show surprise if you present them with the impossible outcome of a single object".[18]

These elementary numerical expectations can be observed in experiments where 2 objects are shown to an infant of 4 to 5 months and then hidden behind cardboard. Then one of the objects is taken away from behind the cardboard without the infant noticing it. When the cardboard is removed, the infant manifests surprise behaviors such as staring for a longer time at the sole remaining object[19] or other facial display of surprise (raising eye brows or eyes going wide). This experience is a visual analog to the operation "2 minus 1". The expression of surprise shows, at least, that children this young are capable of numerical expectations with respect to simple operations.

In line with what Dr. Gopnik said about children constantly forming and evolving a theory about their surrounding environment, Dr. Dehaene states that these elementary numerical abilities could constitute an "elementary number theory". What is important and noteworthy for infants here are quantity and the differences between "a lot" and "a few". For instance, infants (as adults) will probably succeed at distinguishing between 28 and 56 objects whereas they will surely fail to discriminate between 55 and 56 objects. This is referred to as the *distance effect,* which states that the ability to discriminate between two quantities increases with their numerical difference. Another feature of this theory is that it is easier for infants to distinguish between 2 and 3 objects than between 5 and 6 and it is very probably impossible for them to distinguish between 15 and 16 objects. This is referred to as the *size effect*: The higher the number of objects, the lower is infants' performance at discriminating between the two numbers (keeping equal the numerical distance between the two quantities to compare).

5.1.1 Learning arithmetic

As with any innate skill, elementary numerical abilities evolve with an infants' development and education. Learning mathematics pushes the children to exceed their innate approximation skills. That is, they become able to discriminate between 56 and 57, whether presented as visual symbols (i.e. Arabic numbers) or written words (fifty-six and fifty-seven), they learn to perform arithmetic operations and manipulations.

Dr. Dehaene introduced a simple brain model, one that he referred to as the "triple code model". This describes a system of brain areas active when children are learning or performing arithmetical operations: addition, subtraction, multiplication or division[20]. The basic idea is that when manipulating a number, a child does one of three actions:

- Performs some visual manipulation (like seeing the number as a visual digit i.e. "3");
- Performs some linguistic manipulation (like hearing or reading the number as a word i.e. "three");

[18] Dr. Dehaene, New York Conference.
[19] Longer time than when, in a control experiment, the two objects remain behind the cardboard.
[20] As Dr. Dehaene explained during the conference, the Triple Code model is a simplified model, a work in progress, of what's happening in the brain during mathematical operations.

- Represents it as a quantity (3 is bigger than 1).

Each of these processes involves a different region of the brain (see Figure):

- A visual subsystem localized on both sides of the brain behind the ear and under the brain[21];
- A verbal subsystem situated in distributed regions of the left hemisphere[22];
- The quantity subsystem situated on both sides of the brain diagonal to the ear[23].

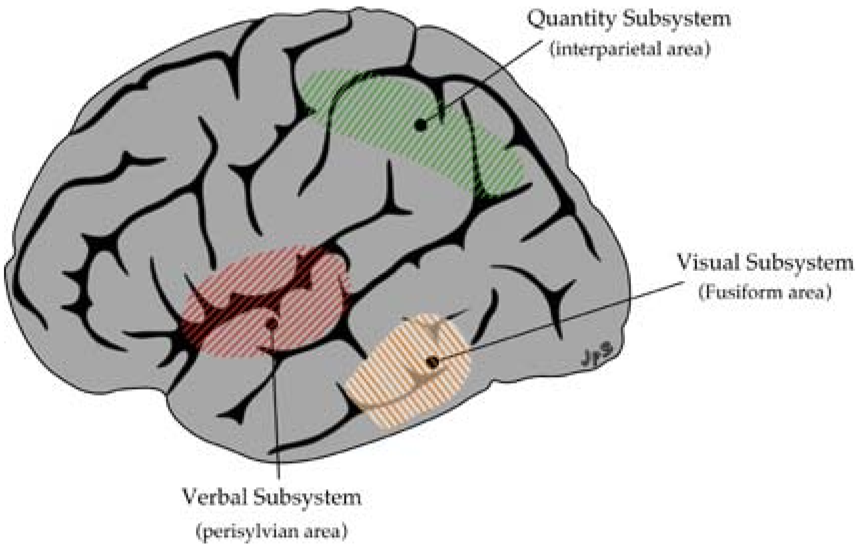

Figure 1: The regions of the triple code model

This model attempts to show that depending on which arithmetic processes are undertaken, information moves back and forth within these subsystems and recruits one, two, or all of them.

Dr. Dehaene cited an example of two seemingly similar calculations that recruit different subsystems of the triple code model, one relying on the verbal system and another relying on the quantity system. He presented subjects with exactly the same addition problem (4 + 5) but in two different contexts. In one case they had to find the exact result, choosing between two results that were both close to the correct result (they were obliged to do the exact calculation). In the other situation they were given two false results, one grossly false and the other approximately correct. The evidence showed that despite the superficial similarity between these two tasks, different brain regions were

[21] Areas corresponding to the fusiform gyrus.
[22] The perisylvian area
[23] Areas corresponding to the interparietal lobes

recruited. The region most active for the approximation task was the quantity subsystem whereas the region most active when performing the exact calculation task was the verbal subsystem.

5.1.2 Why math is difficult for some

One interesting and important educational consequence coming from this model is that it provides a possibility for explaining the difficulty that almost all children have when starting to learn math at school. As Dr. Dehaene explained, "There could be two causes for mathematical difficulties. One possible cause is that some network, like the quantity subsystem, might be impaired or disorganized and as a result, the person might lack access to information about the inclusion of numbers. Another cause, and one which is much more common, is that they have to learn to connect a quantity representation with both verbal and visual symbols.

There could be two causes for mathematical difficulties. One possible cause is that some network, like the quantity subsystem, might be impaired or disorganized and as a result, the person might lack access to information about the inclusion of numbers. Another cause, and one which is much more common, is that they have to learn to connect a quantity representation with both verbal and visual symbols

This connection is long to be established, and it is difficult because it involves symbolic transformations that come with experience, both educational and cultural. The process of quickly and flexibly moving from one representation system to another appears to be a source of difficulty for many children.

This model goes beyond simply indicating the probable origin of mathematical difficulty because it validates two very general properties of mathematical reasoning that support mathematical pedagogy research:

1. The possibility of thought without language.
2. The existence of unconscious processing in mathematics.

5.2 Thought without language

Pedagogical material that emphasises a spatial or concrete objects metaphor for numbers, such as the metaphor of a number line, the Asian abacus or Maria Montessori's number rods, may be particularly well adapted to teach "number sense"

The feature of the triple code model that supports this "thought without language" property is that the quantity representation system is independent from language and provides a purely non-verbal representation of quantity. Dr. Dehaene gave the example of a study at the Massachusetts Institute of Technology (MIT) in which bilingual subjects were trained with facts of arithmetic in one language during one session. They were then tested in the two languages they were familiar with to see whether there was a processing cost of being questioned in a different language to the one they had been trained in initially. What was observed was that tasks that imply exact calculation, partly based on the rote storing of the arithmetical facts, in the verbal subsystem, were dependent on language and were time delayed when languages were switched. However, tasks that relied on approximation showed no time delay when the language was switched.

In terms of educational pedagogy, the possibility of mathematical thought without language emphasises the use of activity that favours the recruitment of the quantity representation system when teaching the number sense to children. One of the participants in a discussion group related to Dr. Dehaene's research, added that, "that kind of concrete quantity subsystem is exploited in Montessori schools and also in Asian countries, where mathematical teaching is based on moving physical objects around, like the Abacus", suggesting that, "this kind of a system works because numbers are presented nonverbally, that is, within the quantity subsystem, using sets of concrete objects and manipulating them."

Dr. Dehaene further explained that the possibility of mathematical thought without language emphasises that rote verbal learning is not sufficient. He also suggests that pedagogical material that emphasises a spatial or concrete objects metaphor for numbers, such as the metaphor of a number line, the Asian abacus or Maria Montessori's number rods, may be particularly well adapted to teach number sense. This is already in use in several schools.

As an illustration of the efficacy of teaching mathematics by accessing the quantity representation system, the Right Start program[24] teaches basic arithmetical skills like counting, correspondence between number and quantities, and the concept of the number line. This program teaches children a spatial analogue of numbers using physical objects like the game of "Snakes and Ladders". This type of training has been successful in remediating children to such an extent that after going through 40 sessions of 20 minutes each, some of these kids started to bypass normally developing children in mathematical class. Interestingly the remediation occurred even if these kids could hardly read, confirming the dissociation between the number sense and language.

5.3 Unconscious processing

Brain scans of subjects showed that they were processing quantity without being consciously aware of this type of processing

The feature of the triple code model that supports the property of unconscious mathematical reasoning is the fact "that the access to quantity meaning of a number is a completely automatic procedure in the human brain, that it is extremely fast, and that it can occur even if you have absolutely no awareness of it occurring[25]." In proof of this property, Dr. Dehaene described an experiment where the brain scans of subjects showed that they were processing quantity without being consciously aware of this type of processing.

He knew that the system was accessed unconsciously because in some experiments they used subliminal masking. On a computer screen he presented a sequence of visual stimuli placed at the same location, which terminated with a clearly displayed digit, like the digit 9, visible for about 200 ms. The subjects were told that they have to decide whether this digit is larger or smaller than 5 by

[24] Information on the Right Start Program can be found in Dr. Dehaene's book, *The Number Sense*, Oxford University Press, Getty Center for Education in the Arts
[25] Dr. Dehaene, New York Conference

pressing the right or the left hand key. Prior to this, they only see rapid flashing of some letters. Unknown to the subject, another number is hidden within the sequence of letters. This number is presented during a short period (43 ms) and because the letters mask it both forward and backwards they cannot see it. Even though subjects do not report seeing this number, it is registered by the brain. He repeats the masked number twice. Using a brain scanning technique called "functional Magnetic Resonance Imaging (fMRI)", Dr. Dehaene noted that in the left and right parietal regions -- exactly the areas which are active when processing the quantity meaning of a number -- there is more activation when the hidden number represents a different quantity than the visible one than when it represents the same quantity. Dr. Dehaene states that when the item is repeated twice, there is a reduction in activation (due to habituation), in both the left and right areas of the brain.

6. Goals for Education?

An important question that one might focus on is what neuroscience research can offer educators in terms of setting realistic goals for education. Several seminars have introduced the concept of the emotional brain and its relationship to education.

6.1 The emotional brain

Dr. David Servan-Schreiber

One important function from the point of view of education is that "emotional valence" enables the child to evaluate a given situation

One response in regards to the goals of education included not only achieving cognitive literacy that is, ensuring that children assimilate and master more knowledge and skills on traditional subjects like arithmetic or grammar, but also acquire emotional competency.

Why this analysis is important is due to the existence of what Dr. David Servan–Schreiber refers to as the "emotional brain"[26], which is a set of brain structures deeply buried within the brain in charge of processing emotions. As Dr. Masao Ito explained, we share these emotional structures with other mammals. However, what distinguishes us from other mammals is that our cortex, which is responsible for higher-order information processing like planning, action, attention, etc. is much more developed. That development, however, should not overshadow the functional importance of the emotional brain in our life and during child development and education.

One important function from the point of view of education is that "emotional valence" enables the child to evaluate a given situation. Our emotional brain makes us more than "mere computers processing information" because it allows us to deal with and to take into account the *value* of this information enabling us to have, according to Dr. Ito, "Feelings or a sense for the beautiful."

[26] Located in the limbic system of the brain.

In its interplay with the cortex, the emotional brain also contributes to a "social judgment", and what Dr. Servan-Schreiber called "success". In the large sense, success can be defined by a set of loose but meaningful criteria such as the ability to define and engage in a proactive and rewarding professional career, life satisfaction, establishment of meaningful friendly and intimate relationships and lack of self-provoked life trauma. That is, the maturation process of becoming a responsible citizen.

A striking example of the critical contribution of the interaction between the emotional and the cognitive parts of the brain to social judgment is given by the story of a previously very successful and intelligent (IQ 130) accountant in Iowa, studied by Dr. Antonio Damasio. After removal of a part of his brain due to a lesion, the communication between the cognitive and the emotional parts of his brain were severed. [27] Following the surgery he continued to have an IQ well above average for several years during which he was under medical observation. However, his social judgment became so impaired that he lost his job, failed to keep another job, got involved in a number of shadowy business ventures and eventually divorced his wife of 17 years only to remarry a wealthy woman considerably older than him whom he described as "an aging socialite."

This example describes an extreme case of the total loss of social judgment. More importantly to the process of education is the fact that this individual still had an IQ well above average *after* the operation. Dr. Servan-Schreiber used this story to highlight his concern with the use of IQ measures, and "Their limited capacity to predict ‘social success’. The skills measured by IQ are not a sufficient condition of social judgement". He cited a study[28] of Harvard students whose intelligence scores while they were undergraduates were <u>not</u> predictive of what they would become 30 years later in terms of salary, productivity, status, life satisfaction, friendship, and intimate relationships. A similar study[29] conducted in a suburb of Boston where all children were from families on welfare showed that their emotional childhood abilities were much better predictors of adult success than their IQ scores.

6.2 Mental imagery and emotional regulation

Mental images have been found to have the same effect on the body, as do actual images

The emotional brain not only has connections to the cognitive parts of the brain as seen in the above example but also to the perceptive areas of the brain as well[30].

This part of the brain according to Dr. Kosslyn not only is engaged in perception but also with mental imagery or visualization. Dr. Kosslyn reports that research has shown that it has much of the phenomenology of perception in that many brain areas are activated during visual perception as in imagery. Because of this, mental images have been found to have the same effect on the body, as do

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[27] What was removed was the orbito-frontal cortex, a part of the cortex situated between the two eye orbits and which has extensive connections with the emotional brain, especially with the amygdala. For more information on this case see *Antonio Damasio (1994) Descartes’ Errors: Emotion, Reason and the human Brain. New York: G.P. Putnam. And Eslinger, P. J. and A. R. Damasi (1985) Severe Disturbance of Higher Cognition After Bilateral Frontal Lobe Ablation. Patient EVR Neurology 35, 1731-1741.*

[28] *Felsman J.K., Vaillant G.E. (1987) Resilient children as adults: A 40-year study*. In *Anderson, E.J., Cohler, B.J. (eds) The Invulnerable Child. New York: Guilford Press*

[29] *Block, J. (1995) On the relation between IQ, impulsivity and delinquency. Journal of Abnormal Psychology 104:395-398.*

[30] Including the areas in the occipital lobe that first register visual input from the eyes.

actual images. In Dr. Kosslyn's research, subjects were asked to mentally visualize aversive stimuli, such as a battered face or a burned body. This caused skin conductance and heart-rate changes, especially in those individuals that reported ease in visualizing. This ability, he states, will differ dramatically among individuals depending upon how easily they naturally imagine and retain visually produced mental images.

In fact, Dr. Kosslyn showed that visualizing aversive stimuli activated certain brain areas more than did visualizing neutral stimuli (such as a lamp or chair). Interestingly enough, one of the brain areas activated was the anterior insula (within the limbic system), known to be involved in registering autonomic or hormonal activity in the body. As Dr. Kosslyn points out, research is just beginning to demonstrate that visualizing aversive events not only affect the body, but also appears to be registered by the brain.

What these findings suggest is that people can alter their emotional state by forming specific images that affect bodily functions including the endocrine and immune systems. Given these findings, Dr. Kosslyn posits that there are three possible applications of imagery to education:

- Imagery as a memory aid. It is well known that objects are remembered better than words, so visualizing objects named by words makes the words more memorable;

- Imagery as a hormone regulator. This, in turn can then affect cognitive abilities. For example, it is known that the level of the hormone testosterone affects spatial ability. It is known that winning a competition raises this level and losing a competition lowers it, thus, it is possible that visualizing such situations can also affect this hormone, which in turn would affect spatial abilities;

- Imagery as used in psychotherapy. The techniques employed in this field can be used to overcome anxieties, such as math and reading phobias.

In concluding, Dr. Kosslyn emphasized that the efficacy of imagery in modulating or changing an emotional state depends on the person's ability to form and then use imagery. He was careful to add that it was not yet clear whether practice or training in imagery could make changes in self-regulation and that further research was needed in this area.

6.3 Emotional competency

What is emotional competency? Characteristics according to Dr. Servan-Schreiber include self–awareness, restraint, compassion, conflict resolution, and cooperation.

Stress and fear in the classroom can impair the capacity to learn by reducing the ability to pay attention to the learning task because of the bodily and emotional demands implicated in the fear system

As this type of mastery is important, especially in social environments like school and work, how can educators (whether they are teachers or parents) assist young children in becoming emotionally competent? And should it be a goal of education? The conference participants did not provide definite answers to these questions, however research is beginning to demonstrate that it could be related to cognitive competency.

One difficulty in answering these questions lies in understanding how much emotional processing is unconscious (in the sense of out of our awareness) and uncontrollable (in the sense of not easily subject to will). Dr. Joseph LeDoux illustrates these differences by focusing on a subcomponent of the emotional brain, the amygdala. This structure has a critical role in processing the emotion of fear[31].

Imagine, "You are standing on a street corner and a bus is coming at you. You first jump and then you notice the bus. Your brain has the ability to detect and respond to danger in a highly structured way that keeps you alive without too much thinking[32]." This capacity to detect and respond to danger is due to your amygdala (only parts of it though, as the amygdala also has other emotional contributions) *interrupting* whatever you were doing or attending to in order to trigger a rapid bodily reaction critical for survival. However remote this example may seem from an educational situation, the neuroscience of fear has established several facts that are critical for understanding the role of emotion in education.

First, as Dr. Servan-Schreiber pointed out, this function of interruption is directly relevant to the school context, as it is responsible for distractibility. Dr. LeDoux concurred and stated that stress and fear in the classroom can impair the capacity to learn by reducing the ability to pay attention to the learning task because of the bodily and emotional demands implicated in the fear system.

Also important is the fact that the amygdala itself is capable of learning things about the external world. For instance, if rats are presented with a sound signal at the same time that they receive a foot shock, they will very rapidly, in typical Pavlovian learning fashion, behave by freezing whenever they hear the stimulus. What is surprising is that if the auditory cortex of these rats is removed (which at least prevents sound analysis of the stimulus), they will still continue to freeze whenever the sound is presented. Dr. LeDoux's research has shown that the learning of the association between the sound stimuli and the fear response (freezing) occurs in the amygdala. In other words, he reports that there is a part of the brain (the amygdala) that can learn about emotional associations independently from the part of the brain, that is, the cortex, that is in charge of cognitive processing.

So what is the role of the cortex? How does it contribute to the processing of emotions like fear? To respond to these questions, Dr. LeDoux described another experiment in which rabbits were initially trained to distinguish between two sounds of the same loudness but of different frequencies. Only one of these sounds was systematically associated to a foot shock. As in the previous experiment, the rabbits rapidly learned to freeze whenever they heard the sound associated with the shock. However, after removal of their auditory cortex (leaving their amygdala intact), they displayed a fear reaction (freezing) to *both* of these sounds presumably because the amygdala only processes signals in broad terms and both sounds were treated as equal signals for the following foot shock.

The cortex enables the processing of more complex emotional stimuli (in the above example, discriminating the frequency of the second sound from the first one) and eventually the ability to damper automatic emotional responses when analysis of these signals enables one to establish that, in fact, there is no danger (as it was the case when unimpaired rats heard the second sound).

What research has shown thus far is that emotion and cognition occur within the brain *at the same time but separately.* These two functions, of course, collaborate to determine the individual's ultimate behavior but there can also be autonomous aspects to emotional processing and learning that place demands on the body independently of attention.

[31] Dr. LeDoux views the concept of the emotional brain, as a whole, as rather imprecise. In fact, his research identified specific brain networks of which the emotion of fear is the product. Other emotions may be the products of different brain networks, possibly unrelated to the fear system.

[32] Dr. LeDoux, New York conference

Additionally, emotional processing is broad, rapid, automatic, unfiltered by attention and corresponding to what can be described as *impulsive*. In fact it shows that we also have a *temperament or personality*, whose nature and evolution escape normal cognitive instruction. Indeed, as educators have reported, when placed in front of a new educational context, not all children respond in the same way. Some are fearful, others display frustration while still others show positive, sometimes uncontrollably positive, excitation. Research on the amygdala and the impulsive aspects of emotional processing enables one to understand that the complexity of achieving emotional competence relates establishing communication between the emotional and the cognitive parts of our brain and that some aspects of the temperament do not easily fall under the control of our cognition.

6.4 Emotional processing

Extroverted children are supposedly more motivated by positive rewards, whereas introverted ones will be more sensitive to fear and punishment

In terms of temperament, there has been previous behavioral research on how children react to reward or punishment within an educational context. Extroverted children are supposedly more motivated by positive rewards, whereas introverted ones will be more sensitive to fear and punishment[33].As Dr. Michael Posner explained, "We should not make us forget that children also have a certain capacity to dampen their impulsive behavior and delay gratification. This later term can be described as inhibiting one's impulses."

Dr. Servan-Schreiber cited one longitudinal study from Walter Mischel and colleagues[34] that illustrates the importance of delayed gratification for education. In this study children 4 years of age were faced with the task of resisting eating one marshmallow displayed before them as they were alone in a (otherwise empty) room in order to get two marshmallows later upon return of the experimenter. The delay of time during which the child succeeded in resisting the impulse to eat the first marshmallow turned out to be significantly correlated with the achievement of later academic success as measured by the ability to deal with frustration and stress, task perseverance, and concentration. In addition, the group of students who exhibited a longer delay of gratification as pre-schoolers turned out to get much higher SAT (Scholastic Aptitude Test – a test incorporating various components of math and reading skills given to adolescents in order to access their potential success and entrance into schools of higher education) scores than those exhibiting a short delay. In fact, there was a significant correlation between delay time and SAT scores.

6.5 The brain mechanisms of self control

Brain research (drawing upon cognitive science and child development research) has been able to identify a critical brain region whose activity and development directly relates to the performance and development of self-control

As Dr. Posner reported, this capacity to control one's own impulses in order to delay gratification constitutes one aspect of a more general behavioral and emotional skill called "effortful control", which relates to children's capacities to

[33] *Rothbart, M.K., Jones, l. B. (1998). Temperament, Self-Regulation and Education. School Psychology Review, 27,(4),479-491.*

[34] *Shoda,Y. Mischel, W., Peake, P.K, (1990) Predicting adolescent cognitive development and self-regulatory competencies from pre-school delay of gratification: identifying diagnostic conditions*. Developmental Psychology 26: 978-986.

self-regulate their behavior both in school and at home. Effortful control can be assessed by synthesizing answers from parents to questions about their child's tendency to concentrate on activity (focused attention), to exercise restraint (inhibitory control), to enjoy low intensity stimulation (low intensity pleasure) and to exhibit awareness of subtle change in their environment (perceptual sensitivity).

Dr. Posner also reported that brain research (drawing upon cognitive science and child development research) has been able to identify a critical brain region whose activity and development directly relates to the performance and development of self-control. Typically, a classical experience conducted to measure cognitive control is the "Stroop effect". For example, having to name the color of ink in which a conflicting color word is printed. The challenge is to pay attention in order to resist the first impulse to read the word in order to focus on naming the ink color.

As Dr. Posner explained that performance in Stroop-like tasks tend to activate a very specific region of the brain situated on the frontal midline, just behind the orbito-frontal cortex and called the *anterior cingulate.* The anterior cingulate seems to be a critical component in the brain networks, which are responsible for paying attention and regulating not only our thoughts (as in the Stroop task described above) but also our emotions in order to achieve what can be described as the intentional or voluntary control of behavior[35].

6.6 Effortful control: An educational variable

As Dr. Posner states, "There is good reason to think that we have methods to gain understanding of the development of important aspects of self-control in children".

There is good reason to think that we have methods to gain understanding of the development of important aspects of self-control in children

A potential benefit from this research is the opportunity to better understand, assess, and identify the underlying brain mechanisms of self-regulation.

In concluding, Dr. Posner added the following: "Since individuals differ in effortful control, one might ask: Why are they different?". One way of approaching that problem is to see how heritable effortful control is, as a variable. Dr. Posner reports that twin study research lead by Dr. H. Goldsmith and colleagues has shown that it was 60 to 70% heritable.[36] In a post talk interview, Dr. Posner was asked whether this result meant that there was nothing that could be done about effortful control in terms of education (or remediation). He responded, "No, it is well known that the expression of genes can depend upon experience. In addition, even 60-70% heritability leaves a lot of room for experience. We are very interested in training children in attentional skills, but little is yet known on how best to do this."

[35] For a review of the various theories attempting to understand the anterior cingulate's role in the regulation of mental and emotional activity see *Bush., G., Luu., P., Posner. M.I. (2000) Cognitive and emotional influences in anterior cingulated cortex. Trends in Cognitive Neuroscience Vol.4 N.6 [39] 209-249*

[36] *Goldsmith, H. H. , Bihun, J. T. (1997) Conceptualizing Genetic Influences on Early Behavioral Development. Acta Paediatr. Suppl July (422), 54-59..*

7. Concluding Remarks

The purpose of this first "Brain Forum" was to highlight the brain mechanisms as related to early learning. OECD's CERI's goal was to create collaborations between the learning sciences and brain research involving researchers and policy-makers. As a neuroscience approach to learning has not yet been much developed, OECD was interested in researching whether relevant data coming from the neurosciences exists that could better guide education policy-makers in improving educational practice.

One of the hallmarks of CERI since its foundation has been to bring together specialists from different cultural and institutional backgrounds on horizontal projects and link them directly to policy makers within OECD member countries. As Sir Christopher Ball said, "The value of this forum, which brought together brain scientists, educators, and policy makers, demonstrated cooperation between people who perhaps didn't work together in the past and have never expected to, and it has begun to outline for itself a program for the future".

Many would agree that policy making has not yet found an application for brain research in education and that, conversely, brain researchers have not found practical applications for their research in the learning sciences. Notwithstanding the remarkable progress in fundamental research in the past decade, notably in mathematics and language, the number of findings that can be exploited or that have been exploited by the learning sciences remains sparse (probably because there has been little contact between neuroscientists and learning specialists).

Dr. Eric Hamilton highlighted that perhaps contact has remained limited because important results are becoming either lost or bypassed as there is no common language for the policy maker or the teacher to really understand the important nuances. "The complaint we often hear in education research circles is that simplifying constitutes reductionism – that is, you go down to the level of the brain were you reduce problems past the point of utility."

However, after this conference, one result was clear. A common vocabulary was starting to bridge the gap between brain scientists on the one hand and policy-makers on the other. Policy-makers were learning things and starting to consider possible neuroscientific answers to questions they have had regarding difficult educational decisions. Additionally, neuroscientists were expressing their interest in providing the type of information policy-makers might need, as well as focusing their research in directions that could potentially have more relevant educational policy consequences.

The New York conference, of which this summary paper concerns, highlights four main areas discussed:

- Brain plasticity;
- Brain periodicity – sensitive periods for certain achievements;
- Emotional intelligence/flexibility – role in academic success;
- Literacy, regarding mathematics and language.

7.1. Myth of three

One important theme that was presented in this conference was that the first three years of a child's life are not as important from a "window of opportunity" perspective as previously thought. Though many important achievements occur during early childhood, it would be a myth to say that everything is determined during this preschool period. As Dr. Posner said in his concluding talk, " I think we did bury the myth of birth to three and replaced it with ideas of the importance of both plasticity and periodicity. In other words, the brain is plastic and yet certain things happen at certain periods in our life that are important both for the early years and, of course, for lifelong learning."

The brain is plastic and yet certain things happen at certain periods in our life that are important both for the early years and, of course, for lifelong learning

This is a very good example of one of the major discoveries of brain science: the plasticity of the brain, i.e. its capacity to be changed physiologically by experience. Here the experience that leads to these changes is a very structured, educationally oriented one, focusing on teaching the mastery of a very specific cognitive task: alphabetical decoding. In other words, reading impairment is not simply a brain problem but a pedagogic one. Additionally, and in reference to periodicity, Dr. Neville showed how grammar learning is constrained by time. The later it is learned, the poorer the result.

Clearly, one strong educational policy consequence of this is that if it is possible to identify which subsystem(s) of the brain is (are) subject to sensitive period constraints and which is (are) not, the development and implementation of sensible educational and rehabilitation programs could become a goal for education policy-makers. It is one thing to know that learning a language later is usually more difficult but another to establish this in such a way that public education policy decisions can be based on it. Any public policy decisions concerning second language learning and any remediation (for instance to improve language learning for late language learners) will have to take into account how the brain processes language in order to insure effectiveness.

Dr. Rodney Cocking reiterates that the objective of educators is to try and get learners to be more efficient and effective at monitoring their own learning activities. He reflects that it is becoming clearer that education needs to be focused on mastering the complexities of problem solving, that is, planning and creative problem solving and that learning models need to be developed that focus on higher order and more complex cognitive processing.

Dr. Kosslyn adds that in terms of cognitive processing, the environment is actually turning on or regulating one's genes, "your interactions with the environment are crucial for how your genes are working, which is crucial for how your brain is developing". So, the idea about engineering a learning environment appropriately is crucial because as he maintains, the environment and the organism are part of a single system.

7.2 Widening the goal of education

From children's theory of the mind to effortful control and emotional mastery, there are several important aspects of a child's personality that can have an enormous impact on life-span

The emotional brain is what enables children to understand the concept of the value different information contains

development. To such an extent that self-regulation, understanding of the self and of others, should become as important in learning as other traditional topics such as mathematics and reading.

As seen in the reports offered by numerous conference neuroscientists, the education and nurturing of children interact deeply with the development of their brain and of their natural expertise. This is particularly important regarding those aspects of education where emotional competency or flexibility is important. As Dr. Ito explained, the emotional brain is what enables children to understand the concept of the value different information contains. It is also what Dr. Servan-Scheiber mentions is important in the maturation of a successful citizen. Some researchers questioned whether the educational system could accommodate the nurturing of emotional competency. Currently, these personality aspects are not addressed in school systems or by educational policies as explicit educational variables on which to concentrate. By discovering the neural basis of these personality variables, neuroscience can contribute to making them more explicit and understandable potentially, enabling an evolution of school toward the teaching of emotional and self-regulation competency. One important benefit for educational public policy is a greater precision and insight about how this type of self-regulation develops in children and how its development relates to the maturation of underlying neural systems.

7.3. Developing tools to ameliorate the literacy problem, worldwide

Dr. Posner proposed a tool to begin to address literacy worldwide, " I have a specific idea that comes from listening to Dr. McCandliss' discussion of literacy and reading. Reading is a common need of people in almost every society, irrespective of the culture. International globalisation makes the ability to read and write critical to be connected to one's overall environment". He states that the first aspect is literacy in one's own language. What he proposes is an international literacy project, based on the new web-based technology and providing instruction in a wide variety of languages, particularly in Third World countries.

International globalisation makes the ability to read and write critical to be connected to one's overall environment

Sir Christopher Ball stated in his conclusion that what he has been looking for as an educator, is "a proper theoretical basis for my subject. Why do we do the things we do? Where is the theoretical basis through which we can derive teaching practice and learning success when it happens?" He states that most of education in the past has been routed in behavioral psychology and now, via the brain fora, "we have an option of shifting to brain science or better using both those excellent sciences as the theoretical basis for our subject". Some people have argued that educational policy can only be surmised by looking at research results coming from cognitive psychology[37] and that localization studies, like those in neuroscience research, are only rediscovering what is already known. For instance, in his conference presentation, Dr. Andries Sanders openly wondered whether brain localization studies merely offer that "the brain correlates of mental processes or leads to basic new insights".[38]

Indeed one of the important revolutions coming from brain research in the nineties, confirmed by numerous presentations during this conference, is that studying the brain from "the outside", the

[39] That is, the study of the mental operators behind thinking, language, attention and memory. The goal of cognitive psychology is to produce hypotheses about these mental operations by finely observing the behaviour of people when undertaking these mental activities.

[38] Dr. Sanders in his conference talk and also in his review distributed at the outset of the forum: "A Bird's Eye View on Brain and Learning in Infancy and Early Childhood."

goal of cognitive psychology, and observing the brain from "the inside", the goal of neuroscience, is in fact complementary. Cognitive psychology studies and discovers thinking and learning behaviors and helps generate hypotheses about the mechanisms that account for them, neuroscience directly studies and establishes (or confirms) what these mechanisms are.

7.4. Providing recommendations to policymakers

Policy is of course about values and values differ deeply in different cultures and different environments, and so one is hard pressed to make clear recommendations for policy

As seen throughout the report, one major benefit of brain science is to provide a safe and objective framework on which educational policy decisions can be based. For instance, it can be reassuring as well as beneficial in understanding that a major public policy theme such as "lifelong learning" is grounded and supported by a growing set of brain and cognitive science observations.

Perhaps a last and yet important message is that research programs like the ones presented in this conference can be further applied to other aspects of education and development such as social development, emotional mastery learning or mathematical learning. Developing these extended programs will certainly enable us to better understand the extent and nature of the educational policies in these domains.

As Dr. Posner wisely concluded, " Policy is of course about values and values differ deeply in different cultures and different environments, and so one is hard pressed to make clear recommendations for policy".

Annex I

19 June 2000

LEARNING SCIENCES AND BRAIN RESEARCH:

POTENTIAL IMPLICATIONS FOR EDUCATION POLICIES AND PRACTICES

First High Level Forum 16-17 June 2000

Brain Mechanisms and Early Learning

Agenda

Friday, 16 June 2000

Session 1: 9:00 - 12:00 / Synthesis of Brain Research and Learning Sciences

8:30 - 9:00	*Registration*
9:00 - 9:10	Pr. Mike Posner, Director of Sackler Institute Dr. Jarl Bengtsson, Head of CERI (OECD) *Opening - welcome*
9:10 - 9:30	Pr. Andries Sanders Cognitive Psychology Unit Department of Psychology Vrije Universiteit Amsterdam, The Netherlands on *"Some reflections on the potential relevance of brain research to learning processes and educational curricula for pre-school children"*
9:30 - 9:50	Pr. William Greenough Director, Center for Advanced Study Chair, Neuroscience Program Beckham Institute University of Illinois, USA on *"Brain's mechanisms of learning and memory"*
9:50 - 10:10	Dr. Jarl Bengtsson, OECD - CERI
10:15 - 11:15	Small group discussions (three groups 12-15 people each)
11:15 - 11:35	*Break*
11:35 - 12:00	Presentation of the results of the 3 discussion groups by rapporteurs

Friday, 16 June 2000

Session 2: 14:00 - 17:20 / Cognition and Emotion

14:00 - 14:20	Pr. Joseph LeDoux Center for Neural Science New York University, USA on *"Personality and the Brain: Closing the Gap"*
14:20 - 14:40	Pr. Masao Ito Director RIKEN Brain Science Institute, Japan on *"Brain mechanisms of cognition and emotion"*
14:40 - 15:00	Dr. David Servan-Schreiber Medical Director Center for Complementary Medicine University of Pittsburgh, USA on *"Emotional Context of Learning"*
15:00 - 15:20	Pr. Stephen Kosslyn Department of Psychology Harvard University, USA on *"Using Mental Imagery to Regulate Emotion"*
15:20 - 16:20	Small group discussions (three groups 12-15 people each)
16:20 - 16:50	*Break*
16:50 - 17:20	Presentation of the results of the 3 discussion groups by rapporteurs

Open Session: 20:00 onwards

20:00 -	Pr. Mike Posner Director of Sackler Institute on *"Linking Brain Development to Education"*

Saturday, 17 June 2000

Session 3: 9:00 - 12:00 / Numeracy, Literacy and Language Acquisition

9:00 - 9:20	Dr. Stan Dehaene Research Director INSERM, France on *"Brain Mechanisms of Numeracy"*
9:20 - 9:40	Pr. Helen Neville Assistant Director Institute of Neuroscience University of Oregon, USA on *"Brain mechanisms of first and second language acquisition*"
9:40 - 10:00	Dr. Bruce McCandliss Assistant Professor Sackler Institute, USA on *"Cortical circuitry of word reading"*
10:00 - 11:00	Small group discussions (three groups 12-15 people each)
11:00 - 11:30	*Break*
11:30 - 12:00	Presentation of the results of the 3 discussion groups by rapporteurs

Session 4: 13:00 - 15:20 / Learning and The Brain: Relevance of Interdisciplinary Approaches

13:00 - 13:20	Dr. Rodney Cocking Program Director National Science Foundation, USA on *"New Developments in the Science of Learning: Using Research to Help Students Learn "*
13:20 - 13:40	Pr. Alison Gopnik Department of Psychology University of California, Berkeley, USA on *"Cognitive development and learning sciences: State of the art"*
13:40 - 14:50	Small group discussions (two groups 18-22 people each)
14:50 - 15:00	*Break*
15:00 - 15:20	Presentation of the results of the 2 discussion groups by rapporteurs

Concluding Session: 15:20 - 16:00

15:20 - 15:35	Pr. Mike Posner Director Sackler Institute, USA on *"Scientific reflections on the results of the forum"*
15:35 - 15:55	Dr. Eric Hamilton Acting Division Director National Science Foundation, USA on *"Policy reflections on the results of the forum"*
15:55 - 16:10	Sir Christopher Ball Chancellor of the University of Derby, UK on *"General conclusions of the forum"*
16:10 - 16:20	OECD Secretariat and Sackler Institute: on *"Next steps"*

Annex II

22.01.2001

LEARNING SCIENCES AND BRAIN RESEARCH:

POTENTIAL IMPLICATIONS FOR EDUCATION POLICIES AND PRACTICES

Second High Level Forum 1-2-3 February 2001

Brain Mechanisms and Youth Learning

Draft Agenda

Thursday, 1 February 2001

17:00 – 17:30	Registration

Session 1: 17:30 - 20:30 / Synthesis of previous forum and outlines

17:30 - 18:15	Manuel Chaves, President of the Region Andalusia José Moratalla Molina, Mayor of Granada José Rodriguez Tabasco, President of the Diputacion de Granada David Aguilar Peña, Rector of the University of Granada Julio Rodriguez Lopez, Caja General de Ahorros de Granada Jarl Bengtsson, Head of CERI/OECD Opening - welcome
18:15 - 18:30	Bruno della Chiesa Administrator CERI / OECD on *"Synthesis of the main results of the first forum"*
18:30 - 19:00	John Bruer President McDonnell Foundation, St Louis, USA on *"Brain Science, Mind Science, and Learning Across the Lifespan "*
19:00 – 19:15	Candida Martinez Consejera de Education (Regional Minister for Education) Junta de Andalucia (regional government), Seville, Spain on *"Main policy questions at high school level"*
19:15 - 19:45	Mark Fletcher Academic Director, English Experience, UK on *"A classroom challenge to neuroscience (and to education): The Brain-friendly revolution - Reality or Neuro-babble?"*
19:45 – 20:30	Plenary discussion
20:30 onwards:	*Dinner offered by the City of Granada (Carmen de los Martires)*

Friday, 2 February 2001

Session 2: 10:00 - 13:30 / Bridging neurosciences and genetic issues

10:00 - 10:45	Luis Fuentes, Rafael Maldonado and Antonio Marín Professors Universities of Almeria, Pompeu Fabra (Barcelone) and Seville, Spain on *"Bridging neurosciences and the genome research / Genetics and intellectual performance"*
10:45 - 11:00	Jim Swanson Professor University of California, Irvine, USA on *"Genetic Factors Associated with ADHD"*
11:00 – 11:15	Stanislas Dehaene Professor and Research Director INSERM, France on *"Impact of early brain damage on childhood acquisition of mathematics" (fetal alcoholism syndrome, Turner syndrome and other genetic diseases)*
11:15 – 12:15	Small group discussions (five groups of about 12 people each)
12:15 – 12:30	*Break*
12:30 - 13:15	Presentation of the results of the discussion groups by rapporteurs
13:15 - 13:30	Respondent: Alain Michel General Inspector Ministry of Education, France on *"Ethical issues related to genetics and neuroscience: educational perspectives"*
14:00 - 16:00	*Lunch offered by the Caja General de Ahorros de Granada (Savings Bank)*

Session 3: 16:00 - 19:00 / Adolescents' context of learning and learning modes

16:00 - 16:15	Pio Tudela Professor University of Granada on *"Implicit and Explicit Learning: A cognitive neuroscience point of view"*
16:15 - 16:30	Jose Manuel Rodriguez Ferrer Professor University of Granada on *"Specificities of post-puberty period: harnessing hormons?."*
16:30 - 16:45	Stephen Kosslyn Professor Harvard University, USA on "*The role of mental simulation in thinking*"
16:45 – 17:45	Small group discussions (five groups of about 12 people each)
17:45 – 18:00	*Break*
18:00 – 18:45	Presentation of the results of the discussion groups by rapporteurs
18:45 - 19:00	Respondent: Heinz Schirp Director Institute for School and Continuing Education , Land Nordrhein-Westfalen, Soest, Germany on "*Adolescents' learning, from an educational policy point of view*"
20:30 onwards	*Dinner offered by the University of Granada (Hospital Real)*

Saturday, 3 February 2001

Session 4: 9:00 - 12:00 / Numeracy, Literacy and Creativity

9:00 - 9:15	Diego Alonso Professor University of Almería on *"Brain Mechanisms of Youth acquiring mathematic skills*"
9:15 - 9:30	Bruce McCandliss Assistant Professor Sackler Institute, USA on *"Brain Mechanisms of Reading Skills: from novice to expert*"
9:30 - 9:45	Guy Claxton Professor University of Bristol, UK on *"How brains make creativity, and how schools strengthen or weaken young people's creative birthright"*
9:45 - 10:45	Small group discussions (five groups of about 12 people each)
10:45 - 11:00	*Break*
11:00 - 11:45	Presentation of the results of the discussion groups by rapporteurs
11:45 - 12:00	Respondent : Rodney Cocking Program Director, Human Cognition and Perception National Science Foundation, Arlington, USA

Saturday, 3 February 2001

Concluding Session: 12:00 - 13:30

12:00 - 12:15	Pilar Ballarin General Director of Educational evaluation and teacher training Junta de Andalucia (regional government), Seville, Spain on *"Policy reflections on the results of the forum*"
12:15 - 12:30	Masao Ito Profesor, Director RIKEN- Brain Science Institute, Japan on "*Scientific reflections on the results of the forum and opening to Tokyo"*
12:30 - 12:40	Jean-Claude Ruano-Borbalan Director "Sciences Humaines" magazine on "*Reflections on the forum, from a scientific journalist's point of view"*
12:40 - 12:55	Sir Christopher Ball Chancellor of the University of Derby, UK on "*General conclusions of the forum*"
12:55 - 13:00	OECD Secretariat and University of Granada: on "Next steps"
13:00 - 13:30	José Moratalla Molina, Mayor of Granada Julio Iglesias de Ussell, Secretary of State for Universities Ministry of Education *"Concluding words"*
13:30 - 16:00:	*Lunch offered by the Diputacion de Granada (Palacio de Bibataubin)*
16:00- 18:00	*Visit of the Alhambra*
18:00 onwards	*Open programme*