

PRELIMINARY SYNTHESIS

OF THE

SECOND HIGH LEVEL FORUM

ON

LEARNING SCIENCES AND BRAIN RESEARCH:

POTENTIAL IMPLICATIONS FOR
EDUCATION POLICIES AND PRACTICES

BRAIN MECHANISMS AND YOUTH LEARNING

In co-operation with

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University of Granada*

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Introduction

The goal of this preliminary report from the Granada forum is to:

- Provide an overview of the content of the forum;
- Synthesise possible educational policy relevance in relation to the sequence of conferences on the brain and education.

Important issues of brain research¹ as presented at the forum include:

1. Neurosciences and Genetic Issues
2. Impact of Brain Damages on Learning
3. Adolescents' Learning Modes
4. Mechanisms of Reading
5. Mechanisms of Mathematics

Timetable

- 16-17 June 2000, New York City, USA
With Sackler Institute - Weill Medical College of Cornell University
First high-level forum on "Brain Mechanisms and Early Learning";
- 1-3 February 2001, Granada, Spain
With the University and the City of Granada
Second high-level forum, on "Brain Mechanisms and Youth Learning";
- 26-27 April 2001, Tokyo, Japan
With RIKEN Brain Science Institute and
Japanese Ministry of Education, Culture, Sport, Science and Technology
Third high-level forum, on "Brain Mechanisms and Learning in Ageing".

This report was prepared by Dr. Anthony E. Kelly (Professor of Instructional Technology at George Mason University, USA and a former Program Director at NSF) with assistance from the OECD-CERI Secretariat.

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). Four CERI Governing Board members participated in this Granada forum, acting as chairs and actively contributing in the discussion groups: Ulf Lundgren (Sweden), Alain Michel (France), Jan van Ravens (Netherlands) and Stefan Wolter (Switzerland).

¹ The strategy here, as in NYC, was to ask scientists about their latest thinking on each specific topic. Hence, the points of view presented in the different fora do not necessarily reflect scientific consensus. This strategy has the weakness that particular findings may be reversed with more study, but the organizers balance that against the need to look forward to where this research is going.

1. Setting the Scene

At the beginning of the forum, Dr. John Bruer restated the hope and expectation of the OECD series of fora that new discoveries about the brain

When scientific findings are applied at the policy and educational contexts, they are often misinterpreted or oversimplified

will yield powerful insights into both early childhood and adolescent learning. Nonetheless, Dr. Bruer sounded a note of caution. During his talk, he said, “many policy-makers and educators [have] vastly overestimated what brain science can tell us about learning and education at this point. So our belief is that uniting educational practice and brain science presents a very interesting and challenging research program but we have to be careful not to base our policies on oversimplifications or popular understandings of what we know about the brain.”

Building upon his seminal paper² and his book, *The Myth of the First Three Years*³, Dr. Bruer made a number of important observations. First, he noted that due to lack of familiarity with brain science many of the findings currently being discussed in policy and educational circles are not that new. More importantly, Dr. Bruer pointed out that when scientific findings are applied at the policy and educational contexts, they are often misinterpreted or oversimplified. This problem of misinterpretation cannot be laid solely at the feet of the educational policy communities. For example, Dr. Bruer cited the neuroscientist Dr. Harry Chugani, who claims that there is an important relationship between the absolute number of neural connections in brain tissue and ease of learning over the life span. Such claims lead policy-makers to advocate, and teachers to execute, certain dubious instructional practices.

However, Dr. Bruer focuses on this example to highlight two particular, but perhaps common, weaknesses in this type of research. First, sometimes the neuroscience data cited is based on one problematic study rather than well replicated findings upon which the neuroscience community has reached consensus. Second, this work rarely examines the relationship between specific neural measures and specific measures of learning, but instead engages in reckless speculation based on the naïve assumption that more neuronal connections is equated "better learning ability."

Dr. Bruer elaborated on the neural measures used in Chugani's research: growth and decline of synaptic density (peaking about age 1, and declining to adult levels around age 7), since it has been used as the basis for claims about the optimal time to teach children. The basic neuroscience data come from a study of the visual cortex by Dr. Peter Huttenlocher. These data are difficult to collect and difficult to replicate or reconcile with the work of other scientists studying human or monkey brains. Related to Dr. Huttenlocher's work, Dr. Chugani studied energy use in the brain (as indicated by glucose consumption). Dr. Chugani's findings, looking, again, at the visual cortex, show that there is a rapid increase in brain energy consumption that peaks in this part of the brain about age 2, and slowly declines to adult levels by age 11. It should be noted that Dr. Chugani's data were collected on brains “at rest,” and that in neither Dr. Huttenlocher's nor Dr. Chugani's studies learning tasks were used.

² "Education and the Brain: A Bridge Too Far," *Educational Researcher* 26:8 (November 1997) 4-16.

³ The Free Press, New York, NY, USA, 1999.

Nevertheless, Dr. Chugani, among others, according to Dr. Bruer, claims a relationship between brain synaptic density (as indicated by counts of synapses as correlated with glucose consumption) and optimal times for learning.

Greater learning may be associated with the period in which the number of synapses in the brain is being *pruned*, not multiplied

The popular belief about synapses is underpinned by a simplistic notion: more is better. More synapses must mean more learning potential. Fewer synapses must mean less learning potential. Dr. Bruer demonstrated that when one traces out the development of an objective learning measure, it is often the case that greater learning may be associated with the period in which the number of synapses in the brain is being *pruned*, not multiplied.

By his use of these examples, Dr. Bruer showed that it is important to temper claims from findings in neuroscience with findings from cognitive psychology and cognitive science. When the data from synaptic density studies are placed on a common basis of age with data on a memory task in humans, and when the data from glucose consumption studies are placed on a common basis of age with data on maze learning (in rats and humans) and navigation in humans, the inaccuracy of Chugani-like claims about optimal learning phases is evident.

Using these examples, Dr. Bruer reaffirmed his stance against the notion of critical periods in learning, that are based on the number of neuronal connections. The notion of critical periods in learning can be criticized not only on the basis of the growth and pruning of synapses, but also in the light of recent findings about brain plasticity⁴. He pointed out that given what we are beginning to learn about brain plasticity and learning across the life span, it may be more productive to focus more on *how* to teach knowledge and skills to a learner population than *when* to teach them.

Repeating a theme from his Educational Researcher article, Dr. Bruer cautioned that wrongheaded claims about the relationship between neuroscience and learning not only mislead policy-makers and educators, but also distract these audiences from firm findings about learning established in over 30 years of cognitive psychological research. Further, these false claims can lead to discrediting established forms of pedagogy in favor of popular “brain-based” pedagogies.

Dr. Bruer illustrated that the rate and ease of learning depend critically on what we already know, not simply on our chronological age. Dr. Bruer cited examples from reading research (Dr. Danielle McNamara) that adults could adopt and

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use reading strategies that were already shown to be powerful for middle schoolers. In the domain of number, Dr. Bruer cited the work of Dr. Robbie Case and Dr. Sharon Griffin with children and Dr. Jeffrey Saxe with adults to show that a deficit in abstract mathematical reasoning (when compared to concrete mathematical reasoning) can be ameliorated by instruction. In both the reading and mathematics examples, instruction improved learning without the need for a mechanistic appeal to a foundation in either neuron count or brain-imaging studies.

Commenting on brain-imaging studies, Dr. Bruer cited the work of Dr. Stanislas Dehaene⁴ as an example of well-designed approach. The value of Dr. Dehaene’s work notwithstanding, Dr. Bruer pointed out that the cognitive task analysis (cognitive models) used by Dr. Dehaene is equally available to teachers to use to guide their instruction. Dr. Bruer advised the emerging field of a science of learning to use these “cognitive models” to bridge simultaneously to improved instruction, on the one hand, and to improved brain-imaging studies, on the other. He ended on the optimistic

⁴ See the report of the 1st forum held in New York: <http://www.oecd.org/els/pdfs/EDSCERIDOCA086.pdf>

note that parallel and (over time) converging work in pedagogical studies, cognitive psychology, and brain science, “will have a great deal to offer educators and policy-makers”.

2. Bridging Neurosciences, Genetic Issues, and Learning

2.1. Towards a Neural Theory of Mind?

Dr. Luis Fuentes and his colleagues explored the problem of linking neural theories of mind to the cognitive functions of brain. This linkage involves the coordination of at least four sources of information: (a) cognitive psychology; (b) functional brain imaging during learning tasks; (c) the results of studies on learning tasks associated with localized brain lesions; and (d) the study of single cell activity in nonhuman primates. This convergence of evidence and methods may be called a science of learning, for the growth of which Dr. Fuentes ended his talk by striking an optimistic note.

Despite the gains in neuroimaging techniques, it should be recognized that none of the techniques provide a complete understanding of the neural substrates underlying cognition.

This approach to the study of learning values task decomposition, and advocates the study of simple cognitive tasks that are believed to involve the orchestration of elementary operations that are localized in the brain. Over the past 40 years, these methods have been used to study how people read, write, visualize, recognize objects, and so forth.

Despite the gains in neuroimaging techniques, it should be recognized that none of the techniques provide a complete understanding of the neural substrates underlying cognition. There remains a trade-off between spatial resolution and temporal resolution for particular measures (for example, fMRI⁵ is very good at seeing where an activation takes place, but not when; the reverse is true for ERP⁶).

The study of patients with brain lesions has lent support to the idea different parts of the brain perform different computations. For example, visual agnosic patients have difficulty recognizing intact faces while other visual ability is unimpaired. Some patients recognize exemplars of a specific semantic category while not recognizing others. Dr. Fuentes believes that this accumulating evidence demands that complex cognitive systems be decoupled into elementary operations. Quoting from the abstract of his talk, "Firstly in primates' studies and then in studies with patients with lesions in the parietal cortex demonstrate that awareness depends on the orchestration of three different operations involved in shifting attention: disengaging, movement, and engaging of attention, performed by the posterior parietal lobe, the superior colliculus and the pulvinar nucleus of the thalamus, respectively. When patients present a lesion of any of these parts of the brain they neglect stimuli appearing in the contralesional side of the lesion. In other words, they lose awareness of information presented to that part of the visual space despite the [fact that they] do not have any other vision problem."

Unlike the development of awareness, the development of self-regulation appears to be tied to the maturation of the frontal lobes. The frontal lobes are implicated in theories of self-regulation by neuroimaging data that several parts of frontal lobes are activated when subjects are asked to perform tasks that are believed to require executive control. For example, in the Stroop task the

⁵ fMRI: functional Magnetic Resonance Imaging.

⁶ ERP: Event Related Potentials, recorded milliseconds by milliseconds.

subject must suppress the meaning of a target word in order to respond to its presented color. During this task, activations occur in the dorsal part of the anterior cingulate cortex. Activation occurs in the ventral part of the anterior cingulate cortex if the task is modified so that emotional words are presented. These data would suggest that the anterior cingulate cortex forms at least part of an executive network for the control of both cognition and emotion.

2.2. Intellectual Performance

In his presentation Dr. Antonio Marin discussed the nature-nurture controversy and its relationship to the heritability of intelligence. He mentioned early work by Dr. Francis Galton that studied the frequency of eminent individuals among relatives of outstanding men. He also touched upon the corrupting effects of the eugenics movement on the question of the heritability of intelligence.

Intellectual performance is a result of many years of training that involves influences of parents, teachers and other people

Dr. Marin pointed out that intellectual performance is a result of many years of training that involves influences of parents, teachers and other people⁷. In other words, Dr. Marin pointed out not only the role of genetic, but also environmental factors. For example, similarities in school grades between parents and children may suggest an appreciable genetic component (that may be reported in the research literature); on the other hand, the influence of environment in this example is also apparent. Further, Dr. Marin points out that, "the genes determining the measurable trait cannot be identified, and it is not possible to make any specific inferences regarding their number, mode of inheritance or mode of action."

Dr. Marin also pointed out that the current ambiguity of these analyses may be due to the inadequacy of the research methods and a lack of statistical power. He believes that we can expect, over time, that the genetic variability of biological factors influencing learning ability and other aspects of human behavior may be as extensive as the influence of genetic variability on human health. Progress on this front can already be seen in experimental analyses of animals. For example it has been shown that a single gene affects differences in patterns of behavior between certain inbred mouse strains. On the other hand, in humans, the Genome Project is finding much genetic variance. Dr. Marin concluded that, "given polygenic phenotypes can be produced by several different genotypes, and it is likely that, taken separately, most of genetic 'susceptibility' factors are not strong enough to be useful in predicting individual phenotypes."

Dr. Marin ended with a caution against falling into a naive biological determinism, in which individuals are viewed as limited by their genes. Adopting this stance he believes would be a terrible mistake.

⁷ Peer-influenced learning, for instance, should be looked at very closely in the future.

2.3. Attention Deficit / Hyperactivity Disorder

In his presentation, Dr. Jim Swanson explored the genetic factors associated with what is popularly referred to as “hyperactivity” among children. Pathological hyperactivity is more technically referred to as attention

Estimates of ADHD (attention deficit/hyperactivity disorder) range from 1% up to 24% in the school-aged population demonstrating differential prevalence data by country

deficit/hyperactivity disorder - ADHD - in the American Psychiatric Association’s *Diagnostic and Statistical Manual (DSM IV)*⁸. A similar syndrome is referred to as hyperactivity kinetic disorder - HKD - in the *International Classification of Diseases, Ninth Revision, Clinical Modification, ICD-9-C*⁹.

Dr. Swanson asked two questions: what is ADHD? And, is ADHD heritable? He presented prevalence data to show that the diagnosis of ADHD is subjective, with estimates of ADHD ranging from 1% up to 24% in the school-aged population demonstrating differential prevalence data by country. Children in the United States are much more likely to be diagnosed as suffering from ADHD compared to children in other countries.

Part of the difficulty arises with the method used to measure ADHD. The DSM and ICD-10 lists of symptoms typically show up in rating scales (such as the SNAP¹⁰) in which an adult (e.g., a parent) is asked to rate—in the case of the SNAP—18 behaviors such as, “*Often fails to give close attention to details or makes careless mistakes in schoolwork or tasks*” on a scale of Not at All/Just a Little/Quite a Bit/Very Much. Statistical analyses of these measures typically classify most individuals as not demonstrating a psychopathology, with a few individuals demonstrating extreme forms of the behavior.

By contrast, when the instrument asks the adult to consider the target individual’s behavior compared to other individuals’ behavior, the resulting data are more or less normally distributed. One such rating system is the SWAN¹¹. The first item on the SWAN is, “*Compared to other children, how does this child do the following: Give close attention to detail and avoid careless mistakes*” with a 7-point rating option, ranging from “far below average” to “far above average.” The former approach asks, “Is the child a problem?” The other approach attempts to locate the child’s behavior on a dimension that is distributed across the entire population. Since a diagnosis of ADHD often brings with it the administration of drugs (e.g., Ritalin), it becomes an important policy question to determine exactly what ADHD might be and be sure that the correct children are getting the necessary psychopharmacological intervention.

Dr. Swanson then showed data using studies of twins to show that heritability is higher for hyperactivity (about .8) than for inattention (about .50). ADHD is highly heritable whether it is viewed as a pathology or an underlying dimension in the general population. He then went on to describe the pursuit of the gene or genes that may explain this heritability. Researchers have focused on genes implicated in the dopamine system since it is associated both with problems of movement and executive control. They have discovered an association of ADHD with a candidate dopamine gene (DRD4). Dr. Swanson described the next steps of this technical research program.

⁸ see <http://www.psych.org>.

⁹ see <http://www.icd-9-cm.org/about.htm> and <http://www.cdc.gov/nchs/about/otheract/icd9/abtcd10.htm>.

¹⁰ The SNAP Rating Scale is a subjective assessment of degree of abnormality.

¹¹ SWAN: Strengths and Weaknesses of ADHD-symptoms and Normal-behaviour.

Their research, to date, leads Dr. Swanson and his colleagues to conclude that up to 50 percent of the children in United States are misdiagnosed with ADHD. In other words, up to 50 percent of the children labeled “ADHD” may be

Their research, to date, leads Dr. Swanson and his colleagues to conclude that up to 50 percent of the children in United States are misdiagnosed with ADHD

inappropriately receiving psychopharmacological intervention. For children who are truly suffering from ADHD, the drugs help the children focus, thereby reducing inappropriate behavior. Studies of the same children in the playground, suggest that there is no overall decline in "hyperactivity" as such. Dr. Swanson also reported that the "hyperactive behavior" of children not suffering from ADHD could be controlled satisfactorily using behavior modification. Moreover, the inappropriate administration of psychopharmacological treatments for ADHD for these children can lead to dysphoria (a form of depression). Dr. Swanson reported being concerned that some parents are requesting ADHD drugs for their children to make them "serious" students. Further, some children are abusing Ritalin as a recreational drug¹². These observations lead Dr. Swanson to want to redefine “true” ADHD not as a form of "hyperactivity", but as a form of minimal brain damage which can be informed by genetic testing¹³.

2.4. Drug Consumption and Learning

Drug addiction is a difficult process to describe and understand because it involves not only neurobiological factors, but also the influences of the social environment, genetic factors, and learning processes Dr. Rafael Maldonado outlined. and compared two theories of drug dependence: the opponent process theory and the spiraling distress of the addiction cycle.

The substrate of the different components of drug dependence involves a large number of neurobiological systems, each one implicated in a specific element of the addictive processes

The opponent process theory is primarily a descriptive theory. It proposes that many hedonic processes are opposed by negative affective processes. Thus, the opiate drug's "high" would be opposed by the "low" of the withdrawal syndrome. Over time, the user builds up a tolerance to the positive affective properties of the drug, when at the same time becoming sensitized to its negative effects. Thus, the goal of drug use becomes the avoidance of the negative aspects of withdrawal and not the attainment of the drug's "high".

By contrast, the spiraling distress and addiction cycle model explains addiction by grounding it in the dysregulation of brain reward systems. Thus, this theory calls for the integration of social and experimental psychology with neuroscience. In this model, the drug addict's spiral into personal and social disintegration can be described by using the language of the opponent process theory, but expressing it in terms of underlying neural mechanisms.

According to Dr. Maldonado:

“[the] neurobiological mechanisms involved in the different components of these dependence processes are different. For instance in the case of opioid dependence, chronic opioid

¹² see <http://www.usdoj.gov/dea/concern/ritalin.htm>

¹³ Conclusions of this importance should be replicated before having influence on policy decisions.

administration produces processes of homologous regulation affecting the endogenous opioid system and its intracellular signaling system. Together with the homologous changes, numerous non-opioid systems that include classical neurotransmitters and neuropeptides have been reported to be also modified during opioid dependence producing a heterologous regulation of these processes. Each neurobiological modification plays a specific role in opioid dependence. Thus, the adaptations occurring at the level of the intracellular system coupled to the opioid receptors seem to be crucial for the manifestations of the physical component of opioid dependence, whereas these changes do not participate in the rewarding effects of opioids. In contrast, the heterologous regulation occurring at the level of the dopaminergic system seems to be essential for the rewarding properties of the opioids but they do not participate in the somatic consequences of opioid withdrawal. Therefore, the substrate of the different components of drug dependence involves a large number of neurobiological systems, each one implicated in a specific element of the addictive processes”.

While the problems of drug addiction typically arise in adolescence, Dr. Maldonado’s talk was not directed at the problems facing adolescents, per se. Nonetheless, in the longer term, we can expect progress in the treatment of drug addiction by understanding the relationship between its underlying neural processes and the learning and adaptive functions of the brain.

2.5. Brain Damages and Acquisition of Mathematics

Dr. Stanislas Dehaene’s presentation made the general point that arithmetic competence in some cases may depend upon the integrity of neuronal circuits that are partially under genetic control.

Deficits in multiplication, approximate subtraction, subtraction, and cognitive estimation can be related to fetal alcohol syndrome

He described dyscalculia, a dysfunction in which there may be normal, even top-level functioning, except for deficits in even simple arithmetic calculation. Dyscalculia shares some similarities with dyslexia, particularly in reference to the prevalence (somewhere between 3-6% of the population of children may suffer from developmental dyscalculia).

Dr. Dehaene described several conditions in which mathematical ability was impacted because of a biological abnormality. Deficits in multiplication, approximate subtraction, subtraction, and cognitive estimation can be related to fetal alcohol syndrome. For example, in the Cognitive Estimation Task patients performed poorly on estimates of common sizes (e.g., what is the height of the highest tree?). There is some evidence that these patients may know the correct answer linguistically (knowing that the answer is a ten-foot Sequoia), yet still make numerical approximation errors.

Dr. Dehaene described young women suffering from Turner’s syndrome (monosomy of the X chromosome). Turner’s Syndrome is a genetic disease in which there is a partial or total deletion of one X chromosome and this affects 1 in 2500 girls approximately. These subjects can work with the symbols relatively well – they can read and write number dictation, but they are always a little bit slow in all these tasks. But major impairments were seen in subitizing (i.e., the ability to perceive a set of dots and decide optically their number), multiplication, and estimation (particularly items in which strategy use, not rote learning is required).

Similar findings occur for children with fragile X syndrome. He presented evidence to suggest that abnormalities in the parietal lobe may be related to difficulties in numerical representation and intuition. In normal subjects there is a clear pattern of bilateral parietal activity accompanied by frontal and cingulate activity. In fragile X patients, there is an abnormal absence of

activation in those parietal areas, especially in the right hemisphere. This study showed that there is a specific dysfunction (no activation) in this particular area of the brain when subjects cannot do the task. Very careful anatomical studies of that area are required to show whether there is an underlying deficit in this particular region.

Dr. Dehaene concluded that our ability to acquire mathematics rests on basic intuitions of space, time and number, which are provided by specialized cerebral circuits. Yet, he cautioned against simple reductionistic conclusions that ignore contributions from the innate architecture, environmental influences, and instruction that recruited domain-general mechanisms (e.g., attention, working memory). Moreover, he argued against a stance of biological fixism, stressing that handicaps can be overcome with prosthetic devices, and that a better understanding of our neuro-developmental trajectory should lead to improved rehabilitation strategies.

3. The Adolescent Brain as a "Work-in-Progress" and Youth Learning

3.1. Implicit and Explicit Learning

There is much debate about the existence and character of implicit vs. explicit learning and its relationship to instruction. In his talk, Dr. Pio Tudela illustrated how cognitive neuroscience

Experiments using imaging techniques indicate different neural circuitry supporting implicit as opposed to explicit learning

Research could be used to help clarify and explicate debate among cognitive psychologists about the existence and characteristics of dissociable human learning systems. When a person learns about the environment without intending to do so and learns about it in such a way that the resulting knowledge is difficult to express, this process is often referred to as "implicit learning". By contrast, learning in which intentional attention is paid to the encoding of knowledge and in which retrieval is more conscious is called "explicit learning". Dr. Tudela linked implicit/explicit learning to characteristics of adolescence and early youth cognition.

Dr. Tudela showed that the results of neuropsychological studies (research with amnesic patients, Parkinson disease and Huntington's disease patients) and experiments using imaging techniques indicate different neural circuitry supporting implicit as opposed to explicit learning. During his presentation, he noted:

"PET¹⁴ scans of subjects taken while they are performing random versus fixed sequence blocks of trials show that different brain areas are involved in single and dual task (competing stimuli) conditions. For the dual task condition, they include the left supplementary motor area, motor cortex and a more posterior focus (spanning the borders of Brodmann¹⁵ areas 40 and 7). This parietal focus is supposed to be part of the "where" processing stream implicated in processing spatial information. For the single task condition, more inferior cortical regions were found, going from bilateral changes at the junction of parietal/occipital cortex and then becoming lateralized to the right hemisphere (in area 21) of temporal lobe that has been related to the "what" pathway related to object identification. The main frontal regions include premotor cortex (area 6) and dorsolateral prefrontal cortex (area 46) related to spatial working memory."

¹⁴ PET: Positron Emission Tomography

¹⁵ Dr. Brodmann introduced a number scheme for dividing the human cortex into many small regions, each of which has slightly different neural properties.

Two brain-based learning systems have been proposed based on these PET data and on recent behavioral experiments indicating that in dual task situations, if the stimuli of the second task are not presented randomly but follow a particular fixed sequence, interdependent effects may appear. The first proposed system is an implicit dorsal system that learns within one dimension only, and the second is a ventral system that can learn cross-dimensional sequences (composed of a combination of two simple sequences). Interestingly, this second system learns in either an implicit or an explicit manner. Awareness as such is not required to learn cross-dimensional sequences rather it may emerge from implicit knowledge. Once explicit knowledge is acquired it may enhance activity in the brain regions that sustain implicit cross-dimensional learning and activate additional brain regions.

Dr. Tudela listed characteristics of implicit learning (i.e., inductive, unconscious, and abstract) to link it to instructional strategies, recommending that instructors remain aware that:

Expertise often depends on exposure over many hours to particular cases, rather than the learning of sets of rules

- 1.- Regular exposure of efficiently planned tasks in a rich learning environment can support inductive learning.
- 2.- Explicit theoretical instruction can support and guide, but not replace, the role of practice, particularly with regard to procedural knowledge learning.
- 3.- In some cases, explicit knowledge may interfere with implicitly acquired knowledge.
- 4.- Implicit learning may be an important factor to explain expertise. Expertise often depends on exposure over many hours to particular cases, rather than the learning of sets of rules. Supporting this notion is the finding that experts are often unable explicitly to describe their decision making.
- 5.- New research on hunch and intuition by Dr. Lieberman links social intuition and implicit learning. Dr. Liebermann related social intuition to the development of nonverbal decoding skills acquired by means of implicit learning. Thus, in learning, social aspects of the process should not be neglected.

3.2. Maturity of the Prefrontal Cortex?

Dr. José-Manuel Rodríguez-Ferrer in his presentation raised an hypothesis. He suggested an alternative way to understand some of the difficulties facing adolescents and young adults

Brain imaging data that shows that the prefrontal cortex is slow to mature even among those in the 20 to 30 year age bracket

by relating psychological maturity with measures of the maturity of the prefrontal cortex, and not to attribute the characteristic social, behavioral, and psychological characteristics of adolescents to some possible hormonal substrates. Dr. Rodríguez-Ferrer's claim is based on brain imaging data that shows that the prefrontal cortex is slow to mature even among those in the 20 to 30 year age bracket.

The prefrontal cortex can be, functionally, divided into three main regions: the dorsolateral prefrontal cortex, the lateral- and the orbital cortices. The dorsolateral prefrontal cortex is mainly related to the cognitive functions of the prefrontal cortex, in particular with processes involving attention and mnemonic functions (working memory) and in the planning of behaviours. Lesions of

this area produce severe cognitive inabilities in humans. One of the most striking is the inability of making correct planning of behaviours and to inhibit sensory interferences. On the other hand, the other two regions of the prefrontal cortex (the lateral and the orbital cortices) are related to social behaviours, regulation of emotions and motivation. Lesions of these regions produce dramatic changes of personality (impulsivity and irritability), deficits of emotional control and impairment of moral judgement.

The activity of the frontal cortex involves the participation of other structures to which it is connected. Thus, the dorsolateral prefrontal cortex is mainly connected with parietal and temporal association cortical areas. Meanwhile the lateral and orbital areas are mainly connected with limbic structures such as the hypothalamus, the amygdala, the entorhinal cortex and the ventro tegmental area of the mesencephalon (VTA).

Recent studies using magnetic resonance techniques have obtained brain images from adolescents (11-22 years) and young adults (22-30 years). The most striking results derived from these studies show: (i) that during adolescence brain volume and myelination (the process by which neural connections are matured, and measured as amount of white matter volume) increased linearly during adolescence; and (ii) that the prefrontal cortex is the only cortical area that continues with the process of myelination after adolescence. This prefrontal maturation seems to occur throughout all the young adult period (22-30 years of life).

Linkages between these measures and adolescent development remain speculative and await scientific study.

3.3. *Mental Simulation*

In his presentation, Dr. Stephen Kosslyn discussed the role of mental simulation in thinking. In particular, he described the Reality Simulation Principle, which holds that mental Images have the same effects on the mind and

The Reality Simulation Principle holds that mental images have the same effects on the mind and body as the corresponding actual situation

body as the corresponding actual situation. He showed a Shepard mental rotation task and a gear/pulley task, each of which requires one to mentally simulate the task in order to solve it. Dr. Kosslyn made three main points in his talk: (a) there are distinct types of imagery; (b) there are individual differences, people are not equally good at the different types of imagery; (c) there are task-by-abilities compatibilities. The Reality Simulation Principle has two main applications in the context of education: (1) for teaching reasoning (e.g., as in the above examples of spatial mechanical reasoning, but it can also be used for symbolic reasoning); and (2) as a memory aid.

Based on his brain-scanning studies, Dr. Kosslyn reported that approximately 2/3 of the same areas used in vision are also used in visual mental imagery. He noted (using a monkey brain as an example) that every area that projects downstream (i.e., an "afferent" connection) to another area receives from it a feedback connection (i.e., an "efferent" connection). Building upon this feature, Dr. Kosslyn claimed that in mental imagery people actually "play the visual system backwards," using information stored in memory to activate parts of the brain that receive input from the eyes.

Dr. Kosslyn described the visual system, by using the oversimplification of it's having a "what" system (which runs along the bottom part of the temporal lobe) and a "where" system (which runs up to the back top part of the parietal lobe). If an animal is trained to make a shape

discrimination and then the bottom parts of the temporal lobes are removed, the animal has a deficit in shape discrimination, but not in location discrimination. Equally, a lesion in the back top parietal lobes devastates the ability to discriminate between locations, but leaves relatively intact the ability to discriminate between shapes.

Dr. Kosslyn distinguished four different forms of mental imagery, obtained by intersecting two distinctions. First, between depictive and spatial imagery, which is the distinction between the "what" and "where" system. Spatial imagery is for locations, independent of what is actually there; it is concerned with locations, not shapes. Second, categorical vs. specific ("co-ordinate") processing - with the left hemisphere of the brain's being better at categorical kinds of processing, whereas the right is better at processing specific examples or instances (not categories). Intersecting these axes results in four cells by combining depictive and spatial versus categorical and specific.

More specifically, a categorical representation defines a class, for example, hinged things, or the equivalence class, "left of" some object, which allows for broad generalizations. Categorical representations, however, lack a precise metric. A second representation, one that is co-ordinate, is required in order to specifically locate an object. Categorical representations discard precise metric information, while co-ordinate representations retain it.

Dr. Kosslyn then described a number of experiments to show that in normal subjects there is hemispheric specialization associated with categorical vs. co-ordinate representations: the right cerebral hemisphere is better with the metric, the left with the categorical. In one experiment, he showed that when a subject is given a decision that requires a precise metric calculation (i.e. which of two dots are closer to a line) the decision is more rapid when stimuli were presented initially to the right hemisphere. The converse held true for categorical representations. Categorical location judgments (e.g. deciding whether something was "on" or "off" something else) were more rapid when the stimuli were initially presented to the left hemisphere.

Corroborative evidence was found in patients with brain damage: left parietal damage impaired the ability to do categorical spatial relation tasks (as measured by both time and errors); right parietal damage impaired co-ordinate spatial relations. Further confirmation came with a PET neuroimaging study. When subjects were asked whether an X was within half an inch of a bar, the only activation was in the right hemisphere for this co-ordinate task. For the categorical task ("Is X above or below the bar?"), all the activation was in the left hemisphere.

Dr. Kosslyn provided evidence that there is a similar hemisphere specialisation for imagery. He described a task in which in the co-ordinate version, subjects were required to build up a figure using segments in which they had to remember precise positions. In the categorical condition, the subjects were required to build up a figure on the basis of its verbal description. When subjects were cued to visualize, those forming images on the basis of memorized descriptions only showed left hemisphere activation, whereas those forming images on the basis of memorized co-ordinate representations showed only right hemisphere activation.

Dr. Kosslyn concluded that there are different forms of imagery. He noted that on-going research in his laboratory indicates that any given person typically can use one form more effectively than the others, and thus it is most useful to take advantage of such differences when using the Reality Simulation Principle in education. Specifically, information should be presented in the way information that takes advantage of a given person's "cognitive style." One size does not fit all.

3.4. Mathematical Skills

Dr. Diego Alonso's presentation dealt with the evidence suggesting brain mechanisms in the acquisition of mathematical skills.

The brain recruits different regions to accomplish different tasks in mathematics

Dr. Alonso pointed out that much of the brain research findings that arrive at the classroom level do so in a very simplistic fashion. For example, teachers and parents hear about “left brain vs. right brain” processing. This level of analysis is very coarse and provides little guidance for instruction.

By contrast, recent research in mathematics learning and its relationship to neuroscience (particularly the work of Dr. Dehaene) has shown that the brain recruits different regions to accomplish different tasks in mathematics. Both behavioral and brain-imaging studies suggest that the processing of exact arithmetic uses the left frontal lobe (a region usually active during verbal memory tasks). On the other hand, arithmetical estimations involve the left and right inferior parietal lobes (areas associated with visual and spatial tasks). The prefrontal cortex and the anterior cingulate cortex play an important role during complex calculations by controlling nonautomated strategies. It should be noted, however, in mathematical processing that other parts of the brain are involved in addition to the ones noted.

Dr. Alonso then asked the audience to consider several promising directions for neuroscience research in mathematics learning and problem solving. He pointed to work by Dr. Margarete Hittmair-Delazer showing that a patient with acalculia, who failed to solve very simple arithmetical tasks (for instance, 5×4 , $7 - 3$), nevertheless, was able to calculate the value of some simple algebraic expressions. By this example, Dr. Alonso showed the vast amount of work that yet must be traversed for neuroscience to be able to understand deeply teenagers' learning of advanced mathematical problems, such as those of algebra, analytic geometry, trigonometry, complex numbers, probability, and so forth.

Dr. Alonso speculated that the circuits devoted to coordinate these “complex” mathematical tasks are possibly located in the *prefrontal cortex* and the *anterior cingulate cortex*, which are related with the supervision of nonautomated behaviors (planning, sequential ordering, decision making, error correction, maintenance of intermediate results, and so on). Solving a nonelementary mathematical task requires the *prefrontal cortex* to coordinate the actions of several networks implicated in it.

Yet, as Dr. Alonso pointed out: the brains of teenagers are a work in progress, raising questions about the appropriate time, and (perhaps more important) the appropriate way, to teach advanced mathematics in the context of these observations about brain maturation. Dr. Alonso also suggested that number sense is a spatial intuition, which may involve the inferior parietal lobes, and wondered whether the traditional mathematical formalism-only version allowed students to use their intuition most effectively.

On a more speculative note, Dr. Alonso pointed to the work of Dr. George Lakoff and Dr. Rafael Nuñez suggesting further possible work for neuroscience: to what extent do people use, *image-schemas* (that is to say, spatial relations such as containment, contact, center-periphery, etc.) and *conceptual metaphors* (cross-domain mappings preserving inferential structures) to create and understand mathematics?

Any or all of these areas may prove fruitful for future research involving neuroscience.

3.5. Reading Skills

In his presentation, Dr. Bruce McCandliss built upon the talk he had given at the first forum. He elaborated on how humans master the cultural skill known as reading, pointing out the

At least one brain region appears to be critical in distinguishing the difference between a normal reader and a dyslexic reader

importance of developmental impairments in the acquisition of this particular skill. With the shift from struggling to sound out words to automatically recognizing words, it appears that different brain mechanisms come into play. This insight may hold important implications for interventions aimed at young readers as well as for understanding the development of adult level word recognition expertise.

At least one brain region appears to be critical in distinguishing the difference between a normal reader and a dyslexic reader. This region (involving the superior temporal gyrus on the left side of the brain somewhat near the primary auditory cortex) has been suggested by Dr. Hickock and Dr. Poeppel as being involved in attending to the sound structure of words at the level of phonemes. Dr. Elise Temple at Stanford University found that, like many of the adult fMRI studies of dyslexia, 10-year-old children with symptoms of dyslexia fail to normally activate this brain region during tasks related to reading and phonological skills: Instead, the dyslexic readers show a greater than normal recruitment of a frontal region, perhaps as a way of compensating for their core difficulties with phonological processing.

Then Dr. McCandliss described a new line of specialized intervention work (which he conducted with Dr. Isabel Beck) that was specifically crafted to help a group of reading impaired children attend to the phonemes within the words they were reading. He tested his intervention in a 12 week study by randomly inviting half of these children to work through 24 sessions of the intervention and inviting half to join a waiting list to receive the same intervention later (the control group). Over the course of the 12 weeks the control group maintained a stable pattern of reading deficits marked by an inability to read novel words and low reading comprehension, even though many in this group had schooling and tutoring opportunities during this time. In contrast, the intervention group improved in accuracy for each phoneme position within a reading test of novel words. Standardized tests were used to compare the gains that the intervention group made over the 12 weeks (25% of a year) to the progress that most children make in an entire year. The intervention group's decoding skill improved by 120% of the gains children typically make in a year and their general reading comprehension levels improved by 60% of the gains children typically make in a school year.

Dr. McCandliss explained that we can now trace how specific learning experiences might impact particular brain mechanisms. Expanding on some of the early fMRI work with these children that he presented at the New York forum, he demonstrated how fMRI can be used to not only compare brain activity differences between reading impaired and non-impaired children, but how repeated scans in the same children can be used to investigate the impact that the intervention described above leads to changes in the brain areas children recruit while reading. This exciting work builds upon the observation that good readers showed robust activation in the left superior temporal gyrus region for both familiar words and novel word forms, whereas reading impaired children showed no such activation in this region during the same task. These same reading impaired children returned for a second scan after the 24 sessions (three months) of the cognitive intervention involving Dr. Beck, and there was evidence that these children increased their recruitment of this area both for the familiar words and for the novel word forms.

Dr. McCandliss then shifted the focus of the talk to the development of expert-level perceptual skills. He discussed accumulating evidence that as adults spend hundreds of hours

developing expert level recognition skills. There are changes that take place in the functional organization of parts of the visual cortex. Many studies in primates and other work have demonstrated that the expertise of these species in face recognition is in part supported by specific areas in the visual system that appears to be specifically specialized to respond to faces (the fusiform face area of the extra-striate cortex). Furthermore, recent studies by Dr. Gauthier suggests that similar sorts of expert specialization in the perceptual systems of the brain can be learned in adulthood as a result of extended hours of practice: she used fMRI to study the visual brain systems of expert ornithologists and experts on cars to discover specialized activity in this extra-striate region (adjacent to and somewhat overlapping with the fusiform face area) for these experts, but only when viewing pictures related to their own area of expertise.

Following from this example, Dr. McCandliss asked us to consider a larger question: do visual areas of the human brain become specialized for processing visual words? He cited converging evidence that when a subject was presented with visual words, versus some other control condition, there was increased activity in an area of the extra-striate cortex often referred to as the “visual word form area”. This same area is not activated by spoken words, suggesting that it is specifically related to processing the visual forms of words (rather than the sounds or meanings of words). However, there are currently many questions about how this area develops this specialization over learning experiences, and what sort of information about words it represents, what computation it carries out, and what role it plays in the split second during which our brain turns information about letters in the eye into information about word meanings in the mind. All of these questions are the subjects of active investigations in several labs.

One big question is what form of information about visual words does the visual word form represent? Does it represent abstract information about visual words such that it can respond to two very different visual forms (i.e. “*read*” vs. “**READ**”) as if they were the same? Does it just code information about letters, such that it would respond the same to “READ” and the anagram “DARE”? Dr. McCandliss presented preliminary evidence from his recent fMRI work investigating these questions in skilled adult readers. Using a habituation paradigm, he presented the same visual stimuli (i.e. “read”) over and over until the visual word form stopped producing a response. He then demonstrated that when he presented a probe stimulus with the same letters reorganized into a new word (i.e. “DARE”) there was a robust response from the visual word form system, but when he presented the same word in new visual features (i.e. “**READ**”) the system did not respond: Apparently the visual word form system codes some form of abstract information beyond letters; and might be involved in organizing letters into particular words.

Dr. McCandliss also showed evidence for an “eye-mind lag” that is less than 250 ms using ERP methodology (in which the head is surrounded with electric sensors, and samples

During the first 100 ms, the brain has no idea whether it’s looking at an English word or a consonant string

of the electrical activity are taken 250 samples per second). Dr. McCandliss and colleagues found that during the first 100 ms, the brain has no idea whether it’s looking at an English word or a consonant string, after this, around 150 ms, the visual word form system starts to differentiate between strings of consonants and letter strings that might form real words.

These effects vary with maturation. Even for average reading 10-year-olds, when presented with words that they know really well versus consonant strings that they have never seen before, show a very muted response, which appears to be specific to memorized words. However, adults show a visual word form response that is robust for both words they know well, and for novel letter strings that could be legal words, since they follow the regular patterns of the English language for combining vowels and consonants into pronounceable words (the grapho-syntactics rules). Apparently

sometime between age 10 and adulthood the visual word form system develops this form of expertise.

Dr. McCandliss ended his presentation by noting that he and his colleagues intend to further explore these areas and their relationship to the development of expertise in reading across the lifespan. Between 5 percent and 10 percent of school children have difficulty in reading. The social and personal costs of reading difficulties are, of course, enormous, and thus so are the potential impact of scientific insights.

4. Conclusions by Sir Christopher Ball¹⁶

Sir Christopher Ball, who was the "rapporteur général" of this forum, as well as in New York, grouped his remarks "around three headings: first, the value of the forum; second, the emergence of the new learning science; third, some possible implications for the future.

We can offer the "spectacles of learning" perhaps as a result of these discussions

"We have enjoyed a most fruitful conversation and we proved that we can converse from our different points of view and our different areas of expertise and knowledge. We have had a valuable exchange of information, and most of us carry away some new findings, which will be critically important in the months and years ahead. You have seen, I have seen, the thirst of both education and policy makers for scientific insights in this area. That thirst for insights on behalf of education and policy has to be balanced with the caution that our scientists, led by John Bruer, have repeatedly given us. The warnings about the dangers of oversimplification, of drawing premature conclusions and making premature applications of findings (that still are in the realm of being tested and fully understood) were very clear. The challenge here is to distinguish between facts and fiction.

I was very taken by a discussion, which I think of as the "spectacles and cheating debate": it raises quite an issue for the work we are doing together. Brain scientists might in their work be able to give us insights, procedures, which will enable young people to do what I am now doing, place a pair of spectacles so that I can again see you all. We can offer the spectacles of learning perhaps as a result of these discussions. Some educators, and I was one of them, ruefully commented: "but isn't that possibly like cheating?" The functions of education are not just to develop skills and to socialise people so that they can play a part in our complex societies, but also traditionally to sort them (by ability and aptitude). As we help people become more skilful, sometimes or often the sorting function gets in the way: we should have to come back to the "spectacles and cheating debate".

Do we in our schooling sufficiently take account of the fact that has been put in front of us, that the teenage brain is merely a work in progress? The implications for educational policy and practise are absolutely enormous. And then Guy Claxton's remark, "learning is learnable", is a huge challenge to the way we practise and think about education and the systems we create to help people to learn.

The richness of this conference is such that it would be quite easy to hold another conference over the next 2 or 3 days on the missing agenda¹⁷. What might have been discussed at this conference but was not, or was only discussed in passing? We have not done justice to gender, though we have touched on it once or twice. We have not done justice to cultural diversity and its

¹⁶ Chancellor of the University of Derby, UK

¹⁷ Some of the topics listed in this "missing agenda" started to be addressed in the subsequent Tokyo forum.

implications both from the research we have heard about and for the different educational practices that have been referred to. We have not done justice to self-esteem referred to on several occasions, but not properly explored. The last item on my list of what was missing was a discussion about peer group influence. I know, as a teacher, that while teachers are important in young peoples progress, they are not as important as parents are, and while parents are important, they are not as important as the peer group is. And unless we tackle why and how peer groups are so important in the development of the growing brain, we shall be missing part of the subject from the point of view of education.

"I would like to add a word about learning science (and here I follow Rod Cocking and agree with everything he said). We have, in New York, again here and looking forward to the Tokyo forum, been privileged to be present at the emergence of a new science: the science of learning. New sciences come by harnessing two or more disciplines and gaining such fruitful insights that they become sciences in their own right. We are still discussing what the disciplines are that make up learning science, and we have one or two attempts to encapsulate them today. I think we need 5 circles: the neuroscientists and the cognitive scientists; the social psychologists; the educators; the policy-makers; and the circle of health care. As these circles interact, it is not a one-way street, it is not even a two-way street between education and brain science. I think it is more like a roundabout. The task of the new learning science in the 21st century will be the task of any science to explain, to predict, to create applications and to create in the end human benefit. I would challenge our new learning science to move from communication, which we are beginning to get quite good at, at least in these fora, to co-operation. The second challenge is to create for the general public, as well as for ourselves, a much better model of the complexity of "brain and learning", and to present it in an accessible form.

"I would like now to speculate a little on the implications of the work that we are doing together. These implications could be, and I believe will be, of considerable importance.

First, I think there is an implication that derives from the discussions of this forum: we must move away from a learning system, which is curriculum-led towards a learning system which is pedagogy-led. I liked Rod Cocking's suggestion that we needed a "science of pedagogy". Let me put that in simple language: as a learner, I know that the "how" of my learning governs the "what" of my learning. If I can learn in a way that satisfies me, I will learn anything you want me to; but if I cannot learn in a way that is comfortable for me, then I will not learn anything, even if I want to learn it, let alone if you want me to learn it. The "how" governs the "what". The pedagogy is more important than the curriculum. And yet across the world (but not everywhere), we have educational services which are curriculum-led: that is not the way to create a "brain-friendly" educational service. Here, I quote Mark Fletcher: "the key to teaching and learning is how we feel"¹⁸.

A second implication is that perhaps it is high time to think in terms of two separate professions, the sorting profession and the "skilling" profession. There is a curious oddity to the history of education in the developed world, that enables us to believe that teachers can do two activities at the same time, when it is quite obvious that the two activities get in the way of each other: sorting young people by ability and aptitude, and skilling them and socialising them so that

¹⁸ Dr. Heinz Schirp, as a "respondent" in Granada: "Emotions are a key factor for processes of awareness and reflection. We know from the neuroscientific research that emotional processes are a little bit quicker, faster, than our cognitive work; and sometimes, when we think that we have made a decision on a cognitive level, our emotions have prestructured our decision; what does it mean for learning and teaching?"

they can play a full part in our society. I am a teacher, I do not want to be a sorter, and I challenge the educational services of the world to separate out those two activities, to create two professions.

Third, and most important for me, is the implication that, knowing what we now think we know as a result of this forum, schooling as we know it (that curious 19th century invention based on the factory model of industrial production¹⁹) may be unsustainable as a strategy for raising and developing our young people in the next century. I draw here rather dramatically on Heinz Schirp's talk. And therefore, I end with the last question for the 21st century arising from this forum. We may need to bring all the skills and intelligence of this room together to bare on the question: how best are we going to raise our young in the next century, because the model we have inherited from the past simply is not working satisfactorily?"

5. Challenges Ahead

1. There is a paucity of research that links findings in neuroscience to associated findings about how adolescents *learn*. A first research and policy challenge emanating from this conference is to support an active research agenda into how findings in neuroscience and cognitive neuroscience can inform the learning of adolescents.

Reading and mathematics learning are being rethought because of important studies conducted using the lenses and tools of neuroscience

2. There is a paucity of research that links findings in neuroscience to associated findings about how to *teach* adolescents²⁰.

A second research and policy challenge is to support an active research agenda into how findings in neuroscience and cognitive neuroscience can inform the teaching of adolescents²¹.

3. Unfortunately, the paucity of research linking findings in neuroscience to findings in research and teaching *fails to act as an impediment* to those who wish to argue that they have a "brain basis" for their claims about how to teach or to learn. This observation, of course, echoes the caution of Dr. John Bruer, who repeated in this conference his invaluable caveat against amateurish claims about the assumed "brain-basis" for teaching or learning strategies.

¹⁹ Dr. Rod Cocking, as a respondent in Granada: "...how can we accomplish these [teaching] tasks when we know that the 19th century model of education doesn't work? We really need to focus on the new developments, and realise that, in throwing out this 19th century model, we have got to build on something else. We also need to recognise that we cannot build on just memorisation models: knowledge is growing so rapidly that we cannot teach everything; but, based on what we have been hearing here, we know that we have to work on problem solving, on thinking skills, thinking tools, learning strategies (...) or, as Guy Claxton presented it, [on helping] creative thinkers to develop a culture of knowledge of seekers".

²⁰ Dr. Schirp, again: "Don't forget the teacher as a learner! (...) [The teachers] hear a lot about their subjects, about mathematics or biology, or whatsoever, but they really have a big lack in neuroscientific and psychological learning theories. I think we should look into this direction and ask what young teachers could learn from neuroscience".

²¹ Mark Fletcher, during the Granada forum: "(...) this brain information is on the television, in the newspapers, in the magazines: what does it mean for the classroom teacher?"

A third research and policy challenge is to create a mechanism to educate policy-makers, parents, teachers, and others, about brain research as related to education. To be effective, this would need to meet several goals: (a) warn them against popular, but uninformed, ideas about brain science and learning²²; (b) encourage scientists to share well-informed principles that are relevant to learning, (c) in a way that clearly communicates the limitations involved in the evidence that supports these principles.

4. Evidence for the effectiveness of learning or teaching strategies need not (and in some cases will not) have a demonstrated basis in brain science at least in the short term. Rather, acceptable evidence for policy makers may involve judging student work portfolios, using classroom tests or standardized tests of learning or it may involve evidence on learning collected using strategies from cognitive psychology. However, mere anecdotal reports about effective learning and teaching strategies will not likely advance a science of learning and teaching. Progress in a science of learning or teaching will require the development of new, powerful measures of student learning not only to advance education, generally, but also to test the efficacy of “brain-based” claims for instruction.

A fourth research and policy challenge, therefore, is to provide professional development for teachers, parents and policy-makers to help them critically appraise a variety of chains of evidence for judging claims about how to improve teaching and learning among adolescents (i.e., not limited to “brain-based” claims). It is important to publicize effective teaching and learning strategies (i.e. “brain-based” and “non brain-based”) using new forms of information dissemination (e.g., television documentaries, multimedia www sites, multimedia e-journals)²³.

5. Pedagogical expertise is hard to codify, difficult to communicate, often associated with a few “good” teachers, and thus is a fragile commodity. Teaching is often, day-to-day, a solitary profession with many societal demands and often inadequate resources. These demands are particularly acute when the population of students is adolescent.

For these reasons, gains in knowledge about how to teach (at any grade level) are hard-won, and yet pedagogical strategies often remain at the level of craft knowledge. Teachers, of course, are not neuroscientists, but it is both understandable and desirable that they look to the work of neuroscientists to help them improve teaching²⁴.

A fifth research and policy challenge, therefore, is to strengthen pedagogical knowledge and strategies by inviting teachers to (a) share their knowledge among themselves and (b) share this knowledge with the neuroscientific community. Thus, the neuroscience community will be able to ground at least some of its research questions within the authentic experiences of good teachers (e.g., the work of Dr. Case and Dr. McCandliss).

²² It should be noted that neuroscience findings appear to attract much attention in the policy and educational circles. In this way, a few misguided claims from neuroscience may crowd out a large number of valid claims from cognitive psychology and cognitive science, and indeed ignore or devalue pedagogical expertise.

²³ But, in doing this, we have, as Mark Fletcher said, “[to be] aware of the danger that scientific findings are taken by the media and misconstrued, commercialised and abused”.

²⁴ Given the noted paucity of research findings linking neuroscience, learning and teaching, it is understandable that teachers might be tempted to too readily adopt so-called “brain-based” teaching strategies that are in fact not based on any evidence at all. The scientific community should be sensitive to these issues.

6. Pedagogical expertise supported by neuroscience findings can prove powerful. Although they are small in number, there is reason to celebrate recent studies conducted at the intersection on neuroscience and pedagogy. For example, reading and mathematics learning are being rethought because of important studies conducted using the lenses and tools of neuroscience. These studies include seminal work by Dr. Shaywitz in dyslexia, and as reported in this conference in reading difficulties (Dr. McCandliss) and mathematics learning (Dr. Alonso, Dr. Dehaene). Nonetheless, even here we must guard against a sort of “neuro-divide,” not unlike the “digital divide” currently serving to deny the underprivileged access to educational and communication technologies, in which the privileged gain first and best access to the fruits of a science of learning.

A sixth research and policy challenge, therefore, is to publicize on an ongoing basis the best educative research involving neuroscience, not simply in research journals, but to help the general public to understand the policy and learning implications of the new work. New forms of information dissemination (e.g., television documentaries, multimedia www sites) must be recruited in this effort.

7. Current research methods in cognitive neuroscience limit the types of questions that may be asked about teaching and learning. At least for the foreseeable future, research studies conducted at the intersection of neuroscience and education will be limited by the methods and tools of the field, as well as by the complexity of the questions. For example, questions like “how do individuals learn to recognize written words?” and more tractable than “how do individuals compare the themes of different stories?”, as the first question is more closely related to particular cognitive models available.

A seventh research and policy challenge, therefore, is to educate the public about both the gains due to cognitive neuroscience, but also the need to focus on “simple” questions about elementary processes first. There is of course a lot of work to do in order to integrate insights about elementary processes into the complex context faced by educators. Furthermore, educators can play a key role in helping identify such questions, that might be tractable for neuroscientists.

8. Schools are asked to support somewhat contradictory goals: to nurture students’ learning, but also to decide who goes forward for further education. These contradictory aims tend to have consequences for how society distributes resources, and how it uses tests of learning. Dr. Ball raised the issue: “Is the use of these insights gained from neuroscience somewhat akin to cheating, or is it more like a prosthesis?” The tension of these contradictory goals is clear in this question²⁵.

An eighth policy implication of this work is to ask how testing and assessment may also change as a result of insights gained by work in cognitive neuroscience. If our psychometric theory and testing technologies (which help us apportion scarce educational resources) do not similarly advance, we run the risk of devaluing brain-based approaches to learning because current standardized testing approaches are based on outmoded models of learning and are likely to prove insensitive to detecting the effects on learning of these models²⁶.

²⁵ This discussion seems now more relevant than ever, considering the fact that, as stated by Dr. Alain Michel (acting as a respondent in the Granada forum), the number of students who reach high school level and higher education increased dramatically in the last four decades; using Dr. Pilar Ballarin’s words, we are shifting from a “selective system” to a “generalized (i.e., more democratic) education system”. “Sorting” students will hence increasingly become a main challenge for the school of the 21st century.

²⁶ See the NRC report: <http://www.nap.edu/books/0309072727/html/>

9. Evidence was presented in a number of talks about the genetic basis for learning. For example, deficits both in focusing behavior and in mathematics abilities were linked to genetic roots.

A ninth research and policy challenge rests on how to inform the public about the interpretation of these data. How should people think about the relative contributions of genetic and environmental factors? In particular, policy-makers should be informed about cognitive strategies and technological prostheses that can overcome learning deficits, whatever their basis. For example, if the findings related to attention deficit / hyperactivity disorder are borne out, they have clear policy implications for psychopharmacological interventions (Dr. Swanson).

10. Communication problems will exist among neuroscientists, educators, and policy-makers. Neuroscientists and educators, generally, do not share a similar professional vocabulary²⁷; they apply different methods and logics; they explore different questions; they pursue different goals. They are perceived differently in the policy arena. Neuroscientists scientifically study the seat of learning itself: the brain. They carry with them the authority and aura of an arcane science. They are relatively few in number and employ expensive technology. By contrast, teachers of adolescents work in a complex social milieu in which the objects of their work (i.e., their students) may not share their goals. Their tools typically comprise chalk, talk, and textbooks.

A tenth research and policy challenge, therefore, is to be aware of the cultural differences between these two professions, and work to reduce misunderstandings and miscommunications and to promote understanding. Policy-makers must promote the professional sharing of resources, particularly the insights gained at the respective levels of analysis (i.e., classroom learning and brain function), so that the findings of this emerging field may inform both our understanding of the brain-machine, and the brain-in-action: that is, human learning.

11. It was argued that a new science is being born: the science of learning. There was a palpable feeling in this conference that the intersection of the fields of neuroscience, cognitive science, and education could help bring forth a new discipline that could strengthen each field²⁸. A science of learning could provide neuroscience with testable hypotheses about learning and venues in which to test them. Neuroscience could provide tools, techniques and evidence to disambiguate cognitive theories of learning. Neuroscientists could begin to provide a scientific basis for the art of teaching.

An eleventh research and policy challenge, therefore, is to provide the leadership and resources, particularly at the university level, necessary to grow a science of learning²⁹. Interdisciplinary work among educators, cognitive scientists, psychologists, and neuroscientists must be supported, notably through research funding. New professional development structures must be established and supported so that the gains, and insights of an emerging science of learning are not

²⁷ "It is very difficult to ask a neuroscientist what he recommends for learning in the classroom. But we have to ask" (Dr. Schirp).

²⁸ Echoing Mark Fletcher's wish in Granada: "I would ask, not so much challenge, but ask, that we create a culture of encouragement, where teachers can experiment with ideas and models, and refer to scientists for information on quite small things as well as the big things (...). I believe that not only it can be done, but it must be done".

²⁹ Asking about the contribution of neuroscience to education, Dr. Claxton, speaker in Granada, stated: "The challenge for neuroscience is to help understand how the learning capacities of the brain can be amplified and transformed to maximum effect".

lost³⁰. Supporting interdisciplinary work is particularly difficult since it tries to combine different methods, problems, technologies, and world-views; progress may require the application of new explanatory models such as complexity theory (cf. the remarks by Dr. Jean-Claude Ruano-Borbalan) and will certainly require the active involvement of policy-makers.

12. Scientific findings, in almost all disciplines, raise more and more ethical questions, and ethical questions are to be dealt with, at least in democracies, in the political arena. As Dr. Michel pointed out in Granada: *"(...) we all know that scientific results can be badly used; as far as brain science is concerned, we all think about the danger of eugenics, for example. If we are to use neuroscientific research results in the field of education, we will need a code of ethical conduct, so that some excesses can be avoided. Remember, as Rabelais said, in the 16th century: "Science sans conscience n'est que ruine de l'âme"*.

A twelfth research and policy challenge, therefore, is to encourage a large international debate about all the ethical questions addressed in this work; to do this, it is necessary to inform public opinion in order to allow the persons to discuss these extremely important issues³¹.

³⁰ *"(...) Teachers have questions and neuroscientists have questions; both questions together could lead to a common question; and then, perhaps, we will be able to give some answers to common questions"*, as Dr. Schirp underlined, thus coming back to one of the main ideas which lead to this OECD initiative.

³¹ An international debate is here not only desirable, but necessary, and this is one of the reasons why OECD's CERI embarked on this high-risk venture. As Dr. Cocking (NSF) said in Granada: *"Why OECD? Because I think we really need to have the international focus"*.

Addendum

Looking toward the Tokyo conference, Dr. Masao Ito noted four ways to think about brain science, each with clear policy implications:

- fundamental studies to understand how the brain works and generates cognition and consciousness;
- medical studies for preventing and curing neurological and psychiatric diseases and delaying ageing of the brain;
- efforts to develop brain-friendly information technology and to build a brain-like computer and a human-like robot; and
- studies of the development of the normal brain to better nurture the brain.

Annex I

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

Agenda

Venue: Centro Manuel de Falla, Paseo Martires s/n, Granada, Andalusia, Spain

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 José Moratalla Molina, Mayor of Granada
David Aguilar Peña, Rector of the University of Granada
Pilar Ballarin, General Director of Education, Region Andalusia
Julio Rodriguez Lopez, President, General Savings Bank of Granada
Rosario Quesada, Responsible for Youth, Diputacion 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 Pilar Ballarin
General Director of Educational evaluation and teacher training
Junta de Andalusia (regional government), Seville, Spain
on "Main policy questions at high school level"

19:15 – 20:15 Plenary discussion

Friday, 2 February 2001

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

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

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

16:00 - 16:15	Pio Tudela Professor University of Granada, Spain on "Implicit and Explicit Learning: A cognitive neuroscience point of view"
16:15 - 16:30	Jose Manuel Rodriguez Ferrer Professor University of Granada, Spain on "Specificities of post-puberty period: harnessing hormones?"
16:30 - 16:45	Stephen Kosslyn Professor Harvard University, Cambridge, 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	<i>Break</i>
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"

Saturday, 3 February 2001

Session 4: 10:00 - 12:30 / Numeracy, Literacy and Creativity

- 10:00 - 10:15 Diego Alonso
Professor
University of Almería, Spain
on "Brain Mechanisms of Youth acquiring mathematic skills"
- 10:15 - 10:30 Bruce McCandliss
Assistant Professor
Sackler Institute, New York City, USA
on " Brain Mechanisms of Reading Skills: from novice to expert"
- 10:30 – 10:45 Guy Claxton
Professor
University of Bristol, UK
on "How brains make creativity,
and how schools strengthen or weaken young people's creative birthright"
- 10:45 - 11:15 Plenary discussion
- 11:15 - 11:45 Mark Fletcher
Academic Director,
English Experience, Folkestone, UK
on "A classroom challenge to neuroscience (and to education):
The Brain-friendly revolution - Reality or Neuro-babble?"
- 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 Professor, Director RIKEN- Brain Science Institute, Tokyo, Japan on "Scientific reflections on the results of the forum and opening to Tokyo"
12:30 - 12:40	Jean-Claude Ruano-Borbala Director "Sciences Humaines", Auxerre, France 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, Mayor of Granada Julio Iglesias de Ussell, Secretary of State for Universities, Ministry of Education Candida Martinez, Regional Minister for Education / Science, Region Andalusia Jarl Bengtsson, Head of CERI/OECD Bruno della Chiesa, Administrator, CERI / OECD "Concluding words"

Annex II

LEARNING SCIENCES AND BRAIN RESEARCH:

POTENTIAL IMPLICATIONS FOR EDUCATION POLICIES AND PRACTICES

Third High Level Forum

Tokyo, Japan, 26/27 April 2001

Brain Mechanisms and Learning in Ageing

Agenda



Venue: RIKEN Brain Science Institute, WAKO Campus, Japan

Thursday, 26 April 2001

Session 1: 09:00 - 10:45 / Introduction and Scientific Overview

Chair: Jarl Bengtsson

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|---------------|--|
| 09:00 - 09:15 | Teiichi Sato, Director General, JSPS, Japan, CERI Governing Board
Member Masao Ito, Professor and Director of RIKEN-Brain Science
Institute, Japan
Jarl Bengtsson, Head of CERI/OECD
Opening - Welcome |
| 09:15 - 09:30 | Eamonn Kelly
Professor
George Mason University, Fairfax VA, USA
Consultant CERI / OECD
on "Synthesis of the Main Results of the two First Fora" |
| 09:30 - 10:15 | Raja Parasuraman
Professor
Catholic University of America, Washington, DC, USA
on "Attention, Ageing, and Dementia:
Extending and Enhancing Cognitive Function in Adulthood" |
| 10:15 – 10:35 | Plenary discussion |
| 10:35 - 10:45 | <i>Break</i> |

Session 2: 10:45 - 12:45 / Interdisciplinary Issues related to Learning in Ageing

Chair: Sir Christopher Ball

- 10:45 – 11:05 Jarl Bengtsson
Head of CERI / OECD
on "Ageing Populations: New Policy Challenges"
- 11:05 - 11:25 Shinobu Kitayama
Professor
University of Kyoto, Japan
on "Cultural Variations in Cognition: Implications for Ageing Research"
- 11:25 - 11:45 Yasumasa Arai
Professor
Juntendo University, Tokyo, Japan
on " Gender issues: is there a sexual brain?"
- 11:45 - 12:05 Rod Cocking
Program Director, Human Cognition and Perception
National Science Foundation, Arlington, USA
on "Crossing Disciplinary Boundaries
to Understand the Cognitive Neuroscience of Ageing"
- 12:05 – 12:35 Plenary discussion
- 12:35 - 12:45 Hideaki Koizumi
Senior Chief Scientist, Research Director
Advanced Research Laboratory, Hitachi, Ltd.
on "Reflections on Sessions 1 &2 "
- 12:45 - 14:00 *Lunch break*

Session 3: 14:00 - 16:00 /Brain Plasticity over the Life Cycle, Memory & Lifelong Learning

Chair: Hans Stegeman

14:00 - 14:20	Andrea Volfova Cognitive Neuroscience Laboratory Harvard University, USA on "What could Brain Plasticity mean for Lifelong Learning?"	Bruno della Chiesa Administrator OECD / CERI
14:20 – 14:40	Yasushi Miyashita Professor University of Tokyo, Hongo, Bunkyo, Japan on "Memory: Encoding and Retrieval"	
14:40 – 15:00	Itaru Tatsumi Professor Tokyo Metropolitan Institute of Gerontology, Japan on "A PET Activation Study on Retrieval of Proper & Common Nouns in Young and Elderly People"	
15:00 - 15:20	Lynn Cooper Professor University of Columbia, USA on "Age-related Effects on Dynamic Properties of Dissociable Memory Systems "	
15:20 – 15:50	Plenary discussion	
15:50 - 16:00	<i>Break</i>	

Session 4: 16:00 - 18:00 / Skills Acquisition, Later in Life

Chair: Yasushi Miyashita

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| 16:00 – 16:20 | Masao Ito
Professor, Director
RIKEN-BSI, Japan
on "Roles of the Cerebellum in Skills Acquisition & its Dependence of Age" |
| 16:20 – 16:40 | Pio Tudela
Professor
University of Granada, Spain
on "Cognitive Skills Acquisition, Later in life: Attention and Automaticity" |
| 16:40 – 17:00 | Wolfgang Schinagl
Professor
IHK Steiermark, Austria
on "New Learning of Adults in the Information and Knowledge Society " |
| 17:00 – 17:20 | Bruce McCandliss
Assistant Professor
Sackler Institute, New York, USA
on "Brain Mechanisms Influencing Adult Learning:
the Case of Persistent Difficulties in Learning Non-native Speech Sounds" |
| 17:20 – 17:50 | Plenary discussion |
| 17:50 - 18:00 | Kenneth Whang
Program Official
National Science Foundation
on "Reflections on Sessions 3 & 4" |

Friday, 27 April 2001

Session 5: 09:00 - 11:00 / Diseases, Learning and the Power of the Ageing Brain

Chair: Masao Ito

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| 09:00 - 09:20 | Shigenobu Kanba
Professor
Yamanashi Medical School Japan
on "Characteristics of Senile Depression:
Importance of Prevention and Treatment" |
| 09:20 - 09:40 | Akihiko Takashima
Professor
RIKEN Brain Science Institute
on "Understanding the Ageing Brain from Studies of Alzheimer's Disease" |
| 09:40 - 10:00 | Art Kramer
Professor
Beckmann Institute - University of Illinois
on "Enhancing the Cognitive Vitality of Older Adults:
The Role of Fitness and Cognitive Training " |
| 10:00 – 10:20 | Yoshiko Shimonaka
Professor
Bunkyo Women's University, Faculty of Humanity, Japan
on "Creativity and Ageing: Does Creativity Decline in the Adult Life Span?" |
| 10:20 – 10:50 | Plenary discussion |
| 10:50 - 11:00 | <i>Break</i> |

Session 6: 11:00 - 12:40 / Learning and Education: research policy perspectives

Chair: Eamonn Kelly

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| 11:00 - 11:30 | Akito Arima
Professor
Former Japanese Minister of Education and Science
on "Education and Research in Japan" |
| 11:30 – 11:50 | Denis Ralph
Professor, Executive Director
South Australian Centre for Lifelong Learning and Development
on "Learning Across the Lifespan - Linking Research, Policy and Practice:
An Australian Perspective" |
| 11:50 - 12:10 | Eric Hamilton
Director
Research, Evaluation and Communication / Education Division
National Science Foundation
on "NSF Policy and Programmes on Brain Research and Learning Sciences" |
| 12:10 - 12:30 | Plenary discussion |
| 12:30 - 12:40 | Barry McGaw
Deputy Director
DEELSA/OECD
on "Reflections on Sessions 5 & 6" |
| 12:40 - 14:00 | <i>Lunch break</i> |

Concluding Session: 14:00 - 16:00

Chair: Jarl Bengtsson

14:00 - 14:20	Masao Ito Professor Director RIKEN Brain Science Institute, Japan on "Scientific Reflections on the Work"
14:20 - 14:50	Sir Christopher Ball Chancellor of the University of Derby, UK on " Policy Reflections on the Work and General Conclusions of the "Phase 1" Fora"
14:50 - 15:20	Plenary discussion
15:20 - 15:40	Bruno della Chiesa Administrator OECD / CERI on "Next Steps: Towards "Phase 2"
15:40 - 16:00	Plenary discussion
16:00-17:00	<i>Brain Science Institute Laboratory Tour</i>