What Have We *Learned*?

The research presented at the June 1996 conference pointed to five key lessons that have the potential to reframe research, policy, and practice in diverse fields committed to improving results for children and families.

Human development hinges on the interplay between nature and nurture.

Much of our thinking about the brain has been dominated by old assumptions- that the genes we are born with determine how our brains develop, and that, in turn, how our brains develop determines how we interact with the world. These assumptions are not often stated in such explicit terms, but they underlie many conventional notions about why people and cultures are so different from each other. In some cases, they have been used to justify fatalistic and fallacious assertions that certain groups or individuals are bound to fail.[7]

Recent brain research challenges these assumptions. Neuroscientists have shown that throughout the entire process, of development - beginning even before birth - the brain is affected by environmental conditions, including the kind of nourishment, care, surroundings, and stimulation an individual receives. The impact of the environment is dramatic and specific, not merely influencing the general direction of development, but actually affecting how the intricate circuitry of the human brain is "wired" And because every individual is exposed to different experiences, no two brains are wired the same way. Of the nearly six billion people alive on the earth today, no two individuals have the same brain. Even identical twins, born with the same genetic endowment, will develop differently based on how and when various environmental factors effect the development of their brains.

Rethinking the Brain

Old Thinking	**New Thinking**
How a brain develops depends on the **genes** you are born with.	How a brain develops hinges on a complex **interplay** between the **genes** you're born with and the **experiences** you have.
The **experiences** you have before age three have a **limited impact** on later development.	Early **experiences** have a **decisive impact** on the architecture of the brain, and on the nature and extent of adult capabilities.
A **secure relationship** with a primary caregiver creates a favourable **context** for early development and learning.	**Early interactions** don't just create a context; they **directly affect** the way the **brain is "wired"**.
Brain development is **linear**: the brain's capacity to learn and change crows steadily as an infant progresses toward adulthood.	Brain development is **non-linear**: there are prime times for acquiring different kinds of knowledge and skills.

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A toddler's brain is much **less active** than the brain of a college student.	By the time children reach age three, their brains are **twice as active** as those of adults. Activity levels drop during adolescence.

The Impact of the Environment

To be sure, genes play an important role, endowing very individual with a particular set of predispositions. (Indeed, roughly 60 percent of genes in the human body are dedicated to brain development.) In recent years, geneticists have made significant Breakthroughs in their understanding of the relationship between genes and human behaviour. For example, they are beginning to identify specific genes that appear to predispose an individual award certain traits such as a bashful or outgoing social style. But they acknowledge that genetic endowment is only part of the equation; it is the dynamic relationship between nature and nurture that shapes human development.

Parents often notice that children have different temperaments. From birth, some appear to be more outgoing and adaptable; others tend to be more withdrawn and slow to warm up.[8] To be sure, genes play a role in determining temperament; but as researchers have shown, even before birth, the intrauterine environment can have a decisive influence on development, including temperamental differences in children. As infants grow, their predispositions are vitally influenced by a wide range of environmental factors, including not only the physical but also the social and emotional settings.

Neuroscientists stress the fact that interaction with the environment is not simply an interesting feature of brain development; it is an absolute requirement. It is built into the process of development, beginning within days of conception. From an evolutionary standpoint, there is a very good reason for this. The demands on the human brain are immense - one is tempted to say, unthinkable. In addition to controlling and monitoring all of the body's vital functions, this single organ must receive and process information about the world from the millions of sensory receptors reporting from the body surface and the internal organs; it must factor in past experience; it must then respond and adapt appropriately. In short, it must learn continuously and intensively. Carrying out these tasks requires billions of brain cells (or neurons), and trillions of connections (or synapses) among them. Because this challenge is so overwhelming, the brain has a unique way of developing that sets it apart from every other organ in the human body. Gradually creating and organizing billions of brain cells in a predetermined manner during early childhood would demand more information (in the form of genetic coding) than the body could possibly dedicate to this purpose. Nature solved this problem by evolving a more economical system. The developing brain produces many times more neurons and more synapses than it will eventually need. Most of the extra neurons are shed by the time a baby is born. The brain continues to grow in size, however, as each neuron expands; by adulthood, the brain will quadruple in weight. While the number of neurons remains stable, the number of synapses increases markedly in the first three years.

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How are these connections formed? Neurons are designed for efficient connectivity. Every neuron has an axon, which sends electrical signals to other neurons, and numerous hairlike structures called dendrites which receive incoming signals.
A synapse is produced when the axon of one neuron connects with the dendrite of another. Transmission of an electrical signal across this hookup requires a neurotransmitter chemical such as serotonin, dopamine, or the endorphins. The resulting connections are profuse: in the early years of life, each neuron forms up to 15,000 synapses.

The brain development of infants and toddlers proceeds at a staggering pace. By the age of two, the number of synapses reaches adult levels; by age three, a child's brain has 1,000 trillion synapses-about twice as many as her pediatrician's. This number holds steady throughout the first decade of life. In this way a young child's brain becomes super-dense.

These conclusions are not based on mere speculation. As early as the 1970s-ancient history from the neuroscientist's perspective-Peter Huttenlocher at the University of Chicago began counting synapses in the frontal cortex. He observed that children's brains have many more synapses than adults' brains, and that the density of synapses remains high throughout the first decade of life.[9] After this, there is a gradual decline in synapse density; by the time a child reaches late adolescence, half of all the synapses in the brain have been discarded, leaving about 500 trillion – a number that remains relatively constant for the rest of the life cycle.

Brain development is, then, a process of pruning: the brain selectively eliminates excess synapses. In fact, the brain appears to be actively producing and eliminating synapses throughout life. In the first three years, production far outpaces elimination; for the rest of the first decade, production and elimination are roughly balanced; and beginning in early adolescence, elimination is clearly the dominant process. In this way, as a child grows, an overabundance of connections gives way to a complex, powerful system of neural pathways.

But how does the brain "know" which connections to keep and which to discard? This is where early experience plays a crucial role. When some kind of stimulus activates a neural pathway, all the synapses that form that pathway receive and store a chemical signal. Repeated activation increases the strength of that signal. When the signal reaches a threshold level (which differs for different areas of the brain), something extraordinary happens to that synapse. It becomes exempt from elimination - and retains its protected status into adulthood. Scientists do not yet fully understand the mechanism by which this occurs; they conjecture that the electrical activity produced when neural pathways are activated gives rise to chemical changes that stabilize the synapse.

These findings confirm that brain development is a "use it or lose it" process. As pruning accelerates in the second decade of life, those synapses that have been reinforced by virtue of repeated experience tend to become permanent; the synapses that were not used often enough in the early years tend to be eliminated. In this way the experiences-positive or negative-that young children have in the first years of life influence how their brains will be wired as adults.

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The dynamic process of producing and eliminating synapses offers clear benefits. For example, it enables young children to adapt readily to many different kinds of conditions and settings. It helps children who grow up in a setting where survival hinges on efficient hunting to acquire the necessary perceptual and physical skills, while enabling children who grow up in an urban environment to develop the capacity to filter out certain kinds of stimulation.

To be sure, maintaining large numbers of synapses requires considerable energy. Using PET scan technology, Harry Chugani and his colleagues at Michigan Children's Hospital, Wayne State University, have documented the fact that in the early years, the human brain has a significantly higher metabolic rate (as measured by its utilization of glucose) than it will have later in life, presumably due to the profusion of connections being formed in the brains of young children.

Indeed, based on measurements of glucose utilization, Chugani has found that the brain development that takes place before a baby's first birthday is more rapid and extensive than neurobiologists previously suspected. A newborn's brain is in a largely subcortical state; its cerebral cortex - the part of the brain responsible for complex cognitive functions like language and spatial orientation-is relatively dormant. By the time the candle is lit on the baby's first birthday cake, the brain has achieved a highly cortical state. But the cortex is not the only region of the brain to mature quickly. PET scans show that by the age of one, a baby's brain qualitatively resembles that of a normal young adult. This transformation corresponds to the dramatic changes that parents and other people who care for babies witness in the first year, as newborns progress with incredible speed from virtually helpless beings to children who are starting to reason, to walk and talk, to form intentions and carry them out, and to enjoy interactions with a variety of people, pets, and objects.

By the age of two, toddlers' brains are as active as those of adults. The metabolic rate keeps rising, and by the age of three, the brains of children are two and a half times more active than the brains of adults-and they stay that way throughout the first decade of life. Compared with adult brains, children's brains also have higher levels of some neurotransmitters, which play an important role in the formation of synapses. All of these factors - synapse density, glucose utilization, and the level of some neurotransmitters - remain high throughout the first decade of life, and begin to decline only with puberty. This suggests that young children - particularly infants and toddlers - are biologically primed for learning.[10]

The pruning process proceeds at a rapid pace in the second decade of life, but does not occur at the same rate in all parts of the brain. Fewer changes are seen in the nature of "hard-wired" areas of the brain, such as the brainstem, that control such involuntary functions such as respiration. In contrast, the most dramatic pruning has been observed in the cerebral cortex. As this part of the brain develops, roughly 33 synapses are eliminated every second – suggesting that the developing brain responds constantly and swiftly to ongoing conditions that promote (or inhibit) learning.[11]

Connectivity is a crucial feature of brain development, because the neural pathways formed during the early years carry signals and allow us to process information throughout our lives. How, and how well, we think and learn – both as children and as adults – has a great deal to do with the extent and nature of these connections.

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Researchers have measured the level of brain activity required for different tasks, and have found that when individuals address more difficult problems, brain activity surges. But if a problem is solved easily, changes in brain activity are virtually undetectable.[12] This reflects the role of connectivity: when experience and learning have created efficient neural pathways, signals travel easily among them and the processing of information requires relatively little effort.

Pasko Rakic and his colleagues at Yale University have found that the cerebral cortex is vulnerable to environmental influence from its earliest stages of development – within days of conception. By studying macaque monkeys, whose brain development closely parallels that of humans, Rakic and his colleagues have found that as a fetus develops, brain cells have to find their way up the cerebral wall, sliding up elongated cells called glial fibers until they reach their precise position within the cerebral cortex. The sequence and timing of this process must adhere to a very precise schedule if normal development is to occur. As a cell climbs this cortical "ladder", it comes into contact with the numerous cells that it passes on its rise to the top. This contact activates various genes that define the cell's identity, location, and mission. But if anything interrupts of sidetracks this journey – such as expose to adverse environmental conditions or a lack of nutrition – the effects can be devastating.

Often cells that go astray will die before any harm is done. But, as Rakic observes, if cells end up in the wrong place at the wrong time and for inappropriate synapses, the result may be a neurological disorder such as infantile epilepsy, autism, or schizophrenia. The delicate nature of this cell migration process explains, in part, why substance abuse, poor nutrition, or exposure to radiation can have a long-lasting or permanent impact on a developing fetus.[14]

By elaborating processes such as cell migration, neuroscience has given us a much more specific picture of the risks that threaten early brain development, and we know precisely when those risks are highest. For example, a fetus that is exposed to cocaine or to radiation on the fourteenth day after conception is likely to have a different (and worse) outcome than a fetus exposed on the thirtieth day. These findings have far-reaching implications for prenatal preventative care. Indeed, they suggest the need for early parent education, since many expectant mothers do not know that they are carrying a child until well after the days of highest risk have passed.

Humans and Other Primates

Some of the research cited thus far comes from animal studies, and to be sure the neurobiology of animals-even other primates-differs significantly from that of human beings. But compared to the brains of other species, the human brain is even more primed to respond to experience and the environment. Bradd Shore of Emory University emphasizes, in a recent book on cognition and culture, that compared with other species, humans are born with remarkably undeveloped brains-"a curious state of affairs for the brainiest of the primates."[15] Other primates, including the macaque monkeys studied by many neuroscientists, come into the world with brains that are much further along in their own development trajectories: at birth, their brains are closer to their eventual adult weight and show less dramatic growth. Among primates, only the human brain enters the world in such an unfinished state. Indeed, in humans the great preponderance of brain development takes place outside the womb, in direct relationship with the external environment. In short, to a greater extent than other species, humans have brains that are dependent on environmental input.

But experience does not begin at birth. A growing body of evidence (from studies of humans) confirms that even before birth, brain development and perceptual learning are affected by experience, including a fetus' own sensory and motor experiences. Ultrasound recordings show that the neurons that develop in utero begin driving an infant's limbs as early as at seven weeks of gestation. In his remarks at the conference, Myron A. Hofer of Columbia University and the New York State Psychiatric Institute, wondered aloud why there should be so much fetal activity so early in pregnancy, in view of the fact that this activity is not needed to help the fetus adapt to the perfectly suitable intrauterine environment. He concludes that a key function of early fetal activity is to aid the process of constructing the brain, so that from the very start, experience can act on the brain's development. Experimental data confirm that learning can take place in utero. Studies have shown, for example, that newborns will show a preference (by sucking on a pacifier more intensely) for sounds that mimic the mother's voice as it was heard in utero.[16]

All of this evidence-and a great deal more that is beyond the scope of this report-leads to a single conclusion: how humans develop and learn depends critically and continually on the interplay between nature (an individual's genetic endowment) and nurture (the nutrition, surroundings, care, stimulation, and teaching that are provided or withheld). The roles of nature and nurture in determining intelligence and emotional resilience should not be weighted quantitatively; genetic and environmental factors have a more dynamic, qualitative interplay that cannot be reduced to a simple equation. Both factors are crucial. New knowledge about brain development should end the "nature or nurture" debate once and for all.

Day-to-Day Care of Young Children's Brains

Recent research on early brain development and school readiness suggest the following broad guidelines for the care of young children:

- Ensure health, safety, and good nutrition -Seek regular prenatal care; breast feed if possible; make sure your child has regular check-ups and timely immunizations; safety-proof the places where children play; and use a car seat whenever your child is travelling in a car.
- Develop a warm, caring relationship with children -Show them that you care deeply about them. Express joy in who they are. Help them feel safe and secure.
- Respond to children's cues and clues -Notice their rhythms and moods, even in the first days and weeks of life. Respond to children when they are upset as well as when they are happy. Try to understand what children are feeling, what they are telling you (in words or actions), and what they are trying to do. Hold and touch them; play with them in a way that lets you follow their lead. Move in when children want to play, and pull back when they seem to have had enough stimulation.
- Recognize that each child is unique -Keep in mind that from birth, children have different temperaments, that they grow at their own pace, and that this pace varies

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from child to child. At the same time, have positive expectations about what children can do and hold onto the belief that every child can succeed.

- Talk, read, and sing to children -Surround them with language. Maintain an ongoing conversation with them about what you and they are doing. Sing to them, play music, tell stories and read books. Ask toddlers and preschoolers to guess what will come next in a story. Play word games. Ask toddlers and preschoolers questions that require more than a yes or no answer, like "What do you think...?" Ask children to picture things that have happened in the past or might happen in the future. Provide reading and writing materials, including crayons and paper, books, magazines, and toys. These are key pre-reading experiences.
- Encourage safe exploration and play -Give children opportunities to move around, explore and play (and be prepared to step in if they are at risk of hurting themselves or others). Allow them to explore relationships as well. Arrange for children to spend time with children of their own age and of other ages. Help them learn to solve the conflicts that inevitably arise.
- Use discipline to teach -Talk to children about what they seem to be feeling and teach them words to describe those feelings. Make it clear that while you might not like they way they are behaving, you love them. Explain the rules and consequences of behavior so children can learn the "whys" behind what you are asking them to do. Tell them what you want them to do, not just what you don't want them to do. Point out how their behavior affects others.
- Establish routines -Create routines and rituals for special times during the day like meal time, nap time, and bed time. Try to be predictable so the children know that they can count on you.
- Become involved in child care and preschool -Keep in close touch with your children's child care providers or teachers about what they are doing. From time to time, especially during transitions, spend time with your children while they are being cared for by others.
- Limit television -Limit the time children spend watching TV shows and videos as well as the type of shows they watch. Make sure that they are watching programs that will teach them things you want them to learn.
- Take care of yourself -You can best care for young children when you are cared for as well.

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