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In recent years, revolutionary discoveries in neuroscience and developmental psychology have transformed our understanding of infant development. We now know that starting from conception, the infant brain is wired by the environment. Everything that the infant experiences in his mother's womb and after birth leaves a permanent imprint on his brain.

This book explains how even the most ordinary events, such as the words a mother speaks to her unborn son or the way a father holds his newborn daughter, evoke a cascade of biological changes—not only in the brain but also in the immune system and throughout the body. Every experience, from her trip down the birth canal to an afternoon in the park, shapes the health and personality of the child. Whether we intend it or not, everything we say and do teaches the infant a secret lesson about herself and us, her parents.

Tomorrow's Baby translates these scientific insights into practical advice for parents and parents-to-be. An internationally acknowledged expert in early human development, Dr. Thomas Verny draws on his knowledge of the latest scientific research to explain how, with planning and proper support, parents can create an ideal environment for their babies. Dr. Verny advocates "conscious parenting," which begins with the parent's or caregiver's informed acceptance of the enormous challenge of raising and nurturing a child. He offers a wealth of practical suggestions, from optimal prenatal communication to enhancing infants' empathic abilities, as well as advice for building language acquisition, enhancing intelligence, and developing other social skills. Now, for the first time, parents can learn how to help actualize their child's full potential, beginning with conception.

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1

Crossing the Amniotic Sea

In what amounts to a paradigm shift in our understanding of the human mind, we now know that interaction with the environment is not simply an interesting feature of brain development but rather an absolute requirement—built in to the process as the brain grows from one cell to 100 billion, from the moment of conception on. It is this requirement for brain building, says neuroscientist Myron A. Hofer of Columbia University and the New York State Psychiatric Institute, that explains why there is so much fetal activity so early in pregnancy; interacting with the environment through movement, the unborn child's experience provides a scaffold upon which the brain can form. No one doubts that the mother's diet is important to the developing baby, but today studies by Hofer and others point to an even greater influence: incoming signals—crystallized through the mother as a swirl of behavior, sensation, feeling, and thought—immerse the unborn child in a primordial world of experience, continuously directing the development of the mind.

IN THE BEGINNING

The spark of a new life is lit when a sperm fertilizes an egg. Containing the mother's genetic contribution to an offspring, eggs are released from the ovaries and travel down the fallopian tubes (the oviducts) to the uterus at the rate of about one a month.

Although eggs are few, sperm are plentiful. Produced in vast num-

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bers—as many as 300 million with each ejaculation—they propel themselves up the cervix and through the fallopian tubes in a race to reach the egg. Just one sperm will win that race, entering the egg and triggering the biochemical chain reaction that will most likely result in the birth of a baby nine months later.

The quest for individuality and survival starts in these earliest moments, before conception itself, when spermatozoon, one varying from the next, compete for access to the egg. While most of the contenders propel themselves toward the egg at about four inches an hour, a few speed demons make the complete journey in five minutes. In fact, biologists now tell us, sperm cells seem to fall into two groups: warriors and lotharios. The soldiers form a rear guard whose function is to prevent any unauthorized personnel—another man's sperm—from interfering with the amorous advances of their brothers.

In the recent past, experts thought that fertilization occurred when enzymes in the head of each sperm, acting like dynamite, blasted through the outer shell of the egg so that the sperm could lodge inside. Today we understand that each egg selects the sperm it mates with, making the first irrevocable decision in one's life. Indeed, rather than passively participating in this drama, the egg opens its shell and literally embraces the sperm it feels attracted to.

When maternal and paternal genes commingle in a single cell, a new entity, called the zygote, is formed. Over the next few days the zygote divides again and again, giving rise first to a morula (Greek for "raspberry") and then to a blastocyst.

After seven days the blastocyst floats down the oviduct to attach itself to the posterior wall of the uterus. But here it often runs into trouble. Because half the genetic material in the new organism derives from the father, the mother's immune system identifies the blastocyst as a foreign substance and mounts an attack, just as it would against a virus or a splinter. As a result, many early embryos are aborted. This life-and-death struggle will mark all survivors through the process of cellular imprinting, in some sense becoming the first experiential "memory" we have.

THE BRAIN MAKES A DEBUT

After successful implantation of the blastocyst, the cells grow and differentiate, forming the beginnings of the skeleton, the kidneys, the heart, and the lungs. The first traces of the unborn's brain emerge with the appearance of the "neural groove" along the growing but still tiny em-

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bryo some 17 days after conception. By day 21, ridges called neural folds develop along the groove, and by day 27 the folds have wrapped around the groove to form the neural tube, precursor to the spinal cord and brain.

When the neural tube closes off at day 27, cells from its anterior end start dividing so rapidly that they double in number every hour and a half. As they divide they also differentiate, giving rise to the major brain structures—including the cerebral hemispheres, the cerebellum, the diencephalon, the midbrain, the pons, and the medulla oblongata. In these early days of gestation, primitive brain cells continue their rapid division, migrating from the original "zone of multiplication" at the anterior of the tube to the more distant regions of the flowering brain.

It is during this migratory voyage that brain cells, guided by a still obscure string of chemical messengers, begin to forge a true network. Because the system is multiplying so rapidly and because it is so complex, it is extremely vulnerable to damage by inappropriate concentrations of hormones or toxins and a host of outside disturbances. And consequences may be dire.

In one early mechanism, primitive cells form what scientists now call cortical ladders. Neural cells use these ladders to "climb" from the zone of multiplication to the outer regions of the cerebral cortex—the center of thought. If disrupted, cells may fail to get off the ladder and move to the side, so that the path for new climbers is blocked. In the case of gridlock, developmental abnormalities may result.

Two species of mutant mice, called reeler and staggerer because of their bizarre motor behavior, are believed to result from this type of developmental abnormality, says Arnold B. Scheibel, professor of neurobiology and psychiatry and former director of the Brain Research Institute at the UCLA Medical Center. In humans, similar problems may contribute to schizophrenia, temporal lobe epilepsy, dyslexia, and some types of character disorders. Preliminary studies suggest that the most intractable sociopaths may have suffered damage during the "ladder" sequence in the development of the brain.

But "climbing the ladder" is just one challenge facing embryonic brain cells. As the young network evolves, neurons must connect with specialized "target cells" in distant brain regions. If the targets have not yet developed, then proxy target cells are spawned. Without the target cells or their proxies, neurons end up in the wrong place or simply wither and die. If things go well, the proxy cells are destroyed and the real target cells take their place in the architecture of the brain.

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"This remarkable sequence of processes, culminating in a 'change of partners' and the establishment of permanent connections, is subject to error," says Scheibel, "and the results may include a number of major and minor cognitive and emotional disorders that show up at various stages in the life of the individual. We are only at the beginning of our understanding of these complex phenomena, but certain types of dyslexia may be one of the results of problems during this change of cortical connections."

THE NATURE OF THE NETWORK

Finally, after migrating nerve cells reach their destination, they commence the process of networking by growing branches, or "dendrites." The dendrites deliver messages to the nerve cell's long, slender axon, which in turn carries the information to other receptive cells.

From the middle of the second trimester—about midway through gestation—an elaborate network of neurons, their projected axons, and their lush dendritic branches start communicating through connections known as synapses. A synapse is not a point of literal connection between two nerve cells but rather a microscopic gap. One cell communicates with the next by sending a chemical messenger (known as a neurotransmitter) across the synapse. The neurotransmitter released from the first cell provokes an electrical signal known as an action potential in the second. If the action potential is strong enough, it will cause the second cell to release its own neurotransmitter, thus passing the signal on. A single neuron may have tens of thousands of synaptic connections. At the present time about 150 unique neurotransmitters and trillions of synaptic connections have been identified in the brain of an unborn child.

The profusion of primitive neurons is great: at least fifty thousand cells are produced during each second of intrauterine life. So immense are the challenges involved in brain building that at least half our entire genome (the full catalogue of human genes on all the chromosomes) is devoted to producing this organ that will constitute only 2 percent of our body weight.

The complexity of the human brain far exceeds the instructional capacity of our genes. When all is said and done, the adult human brain will consist of about a hundred billion neurons, or nerve cells, embedded in a scaffolding of up to a trillion glial, or support, cells. Although genes may provide the blueprint for basic brain development, the final

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location, pathway, and interrelationships of individual neurons are determined, to a large degree, by early environmental input: nutrition, states of wellness or disease, presence of toxins like cigarette smoke or alcohol, persistent sounds or movements, maternal mood and associated neurotransmitters, and intrauterine conditions, such as the presence of twins. Such input is always idiosyncratic, different for each unborn child; as surely as our genes, it accounts for the diversity of personality and style, for the unique nature of each individual on the planet today.

BRAIN EVOLUTION

This new way of thinking is bolstered by findings from evolutionary science itself. For most of the past hundred years, evolutionary biologists instructed by Darwin believed that one elegant mechanism could explain the diversity of life on Earth. According to this prevailing view, all species evolve through random mutation of the genes. Populations with new traits arise when mutations produce organisms especially good at finding food, avoiding predators, or producing offspring. After generations, these successful mutants may replace earlier organisms within their species or even form whole new species. In this view of natural selection, nature selected the organisms with the genes most likely to survive but, other than that choice, had no impact on the expression of the genes.

A convincing challenge to Darwin, however, has been made with the theory of "directed evolution," spearheaded by scientists such as the molecular biologists John Cairns and Barry Hall. Cairns and Hall are hardly creationists; instead, their research shows that the mutations driving evolution are not always random. In experiment after experiment, they find, microorganisms are whipping up mutations especially suited to their surroundings—as if some inner molecular scientist were helping the cells adjust to environmental requirements and needs. In light of such studies, scientists have come to recognize living organisms as "dynamic systems" capable of actively reprogramming gene behaviors to accommodate environmental challenges.

Now that we have cracked the human genome, we are learning that within the staggeringly long sequences of DNA, only a small percent codes for proteins. More than 95 percent of DNA is "noncoding," made up of on and off switches for regulating the activities of genes. Robert Sapolsky, professor of biological sciences and neurology at Stanford,

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notes, "It's like you have a 100-page book, and 95 of the pages are instructions and advice for reading the other 5 pages."

What triggers these switches? Many things, including messengers from inside the cells and the body, and external factors from nutrients to chemical toxins. Carcinogens may enter a cell, bind to a DNA switch, and turn on the genes that cause the uncontrolled proliferation that eventually leads to cancer. Through the act of breast-feeding, a mother initiates a train of events that activates genes related to infant growth.

The "malleable aspect of gene expression is an extremely important point in terms of fetal development," says cellular biologist Bruce H. Lipton. "In the uterus, the fetus is constantly downloading genetic information required for development and growth. But when compromised, it will modulate the instructions, enacting behavioral programs that enable it to stay alive."

Every living organism has two categories of behavior for survival: those supporting growth, and those supporting protection. Growth-related behaviors include the search for nutrients, supportive environments, and mates for species survival. Protection behaviors, on the other hand, are employed by organisms to avoid harm. In single cells, survival behaviors related to growth and protection can be distinguished by movement toward or away from a given target or source. But in more complex organisms—the human prenate, for instance—behaviors result when cells act in concert. There's a kind of "gang" reaction, Lipton notes, in which patterns of development are shunted toward growth or protection, depending on the environment outside. As with every living system, the selection of growth or protection programs by the unborn child is based on his perception of his environment.

Such perceptions reach developing children in myriad ways, but for the unborn child, the only channel is the mother. She serves as the baby's conduit to the outside world.

"Initially, one might think that free passage of maternal signals through the placenta represents a 'defect' in nature's mechanism," Lipton says. "But far from being a design flaw, the transfer of maternal environment–related signals to the fetal system is nature's way of providing the baby with an advantage in dealing with the world she will soon enter. The old axiom, being forewarned is being forearmed, is appropriate to apply to this situation."

In the best of all worlds, a mother's ability to relay environmental information to the developing offspring will directly affect the selection of gene programs best suited to survival. The downside of the story is

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