THE ENDOWMENT FOR
HUMAN DEVELOPMENT

1000 ELM STREET
MANCHESTER, NEW HAMPSHIRE 03101
(603) 621-0040
WWW.EHD.ORG
EHD@EHD.ORG

USER FRIENDLY: The Educational Implications of Brain Development

You may have heard it said that the brain is like a muscle that benefits from exercise. Though the brain is not a muscle, it does benefit from use. In fact, the brain grows not merely through the passing of time, but rather as a direct result of its experiences. From an educator's point of view, understanding the development of the brain has become essential. More and more we recognize that learning itself changes and improves the way the brain functions. Today this knowledge is being applied to improving the effectiveness of teaching. In recent years, increasing cooperation between scientists and teachers has begun to bridge the gap between cognitive research and educational application. Advances in noninvasive imaging technologies are now enabling neuroscientists to confirm long-standing theories of developmental psychology. This new knowledge provides answers on a physical level as to how behavior and learning relate to the development of the brain. The following introduction to the stages of brain development moves beyond explanation and extrapolates information relevant for improving strategies of learning.

Brain development begins during the early portion of the embryonic period. Neural ectoderm is present by about seventeen days after fertilization and gives rise to the entire nervous system. By day twenty-two, a neural ectoderm derivative called the neural tube develops.[1,2] The neural tube is the structure from which the brain and spinal cord are derived. Between three and four weeks after fertilization, the brain divides into three distinct vesicles named the forebrain, midbrain, and hindbrain.[3,4] Brain development begins so early and proceeds so rapidly that the embryo's head represents fully one-third of the total embryo length at four weeks.[5] By five weeks after fertilization, the brain has grown in size and divides into five secondary vesicles.[6] The cerebral cortex, the site of all higher brain function, appears by six weeks[7] and begins a period of rapid growth. The earliest reported brain wave activity was measured using an electroencephalogram (or EEG) in an embryo approximately six weeks, two days following fertilization.[8,9,10,11,12] At about eight weeks after fertilization, nerve cells within the brain called neurons begin a period of rapid multiplication which most researchers believe ends at eighteen weeks.[13] (Some report neuron multiplication continues until thirty-two weeks after fertilization.[14]) Evidence from controlled studies of newborns suggests complex brain functions such as learning and memory formation occur before birth.[15,16,17] These newborns exhibit preferences for certain music, voices and taste based on prenatal experience.

After birth, the physical structure of the brain continues to develop in part as a function of a child's interactions with his or her greatly expanded surroundings. "This interactive process renders moot such questions as how much depends on genes and how much on environment."[18] At the cellular level, neurons in the brain develop and continue to change in response to the interplay between internal chemistry and external experience. Each neuron is composed of a cell body with dendrites and an axon. The dendrites receive information from neurons or sensory organs, and the axon transmits the integrated information to either another neuron or a muscle. Where the dendritic spine of one neuron meets the terminal of an axon from another neuron, they form a synapse. In measuring the development of the brain, neurologists pay close attention to methods of synapse formation, or *synaptogenesis*.[19] At full-term birth, the brain has "only a relatively small proportion of the trillions of synapses it will eventually have."[20] The number of synapses help indicate the maturity and complexity of the brain. Interestingly, the newborn brain is about one-third the size[21] and one-quarter the weight[22] of the adult brain.[23] Subsequent growth largely results from an increase in blood vessels, support cells, and lipids rather than further neurons.

Development of the brain in the months following birth is marked by *synapse overproduction and selection*.

During this stage, the brain produces an excess of synapses. For example, in the visual cortex, the part of the brain responsible for vision, synapse density due to overproduction is greater in a six-month old child than in an adult. Experience now becomes critical in the selection and elimination of synapses. Frequently used synapses are retained while rarely used synapses degenerate. Only as the developing brain interacts with its visual surroundings does the visual cortex undergo synapse selection, reaching maturity around age two or three years. The rate of synapse overproduction and selection differs both in various regions of the brain as well as from neuron to neuron. Overall synapse density of the brain peaks around age five or six while the ongoing selection of synapses continues until early adolescence. Once synapse selection is complete, "what remains is a refined final form that constitutes the sensory and perhaps the cognitive bases for the later phases of development."[24] Although the brain will not repeat the overproduction of synapses seen after birth, it continues to produce synapses throughout life.

Further development of the brain occurs in an ongoing process, called *synapse addition and modification* which affects both the structure and the function of the brain. The brain's ability to continually adjust its physical structure and function in response to internal and external changes is called *brain plasticity*. This plasticity allows people "to benefit from experience and to live a relatively long life with a brain that is largely unable to replace lost neurons."[25] Therefore, instead of creating new neurons in response to new experiences the brain modifies existing synapses and adds new ones. Because they form the foundation for learning and memory, synapse addition and modification play a vital role in optimizing brain function.

The modification of the brain through learning can take place by means of specific instruction or enriching experiences. Both of these change the brain, but in different ways. Evidence demonstrates that different types of learning restructure the brain differently and "can affect differentially the molecular and structural profile of neurons within the brain."[26] Instruction in specific tasks causes selective brain growth. For example "the training of animals to do specific behavioral tasks provides a model of selective dendritic growth."[27] Often, such selective growth is particular to the region of the brain associated with the given task. While specific instruction can stimulate one sector of the brain resulting in compartmentalized growth, enriching experiences stimulate widespread growth.

An enriching experience simply involves being in a stimulating environment. Professor Hebb at McGill University demonstrated the effects of enrichment when he brought home several laboratory rats. In contrast with control rats, these rats were provided with the enriching experience of running free in his home. His wife added further stimulus by chasing the rats out of her kitchen with a broom. When later compared with control laboratory rats, Professor Hebb's enriched home rats demonstrated far superior maze skills. His studies help show that enriching experience causes "increased density on the dendrites, increased dendritic length, and increased synapse size…thus, the enriched experience has built a brain with more synapses – in effect, a better brain."[28] Interestingly, this general experience increases overall brain weight: growth is not localized in any particular region of the brain. The unpredictable and varied nature of such enrichment brings about strengthening in multiple areas of the brain.

Through better understanding how different types of learning affect brain development, we can improve teaching techniques. We know that specific instructions or tasks alter isolated areas in the brain. Therefore, performing multiple tasks utilizing different areas of the brain at once may enhance overall learning. Language incorporates the separate abilities to speak, write, and hear: thought to be located in different regions of the brain. Therefore, "if these closely related skills have somewhat independent brain representation, then coordinated practice of skills may be a better way to encourage learners to move seamlessly among speaking, writing, and listening."[29] As we learned from Professor Hebb's rats, enriching experiences stimulate brain development. The classroom itself should therefore provide an enriching experience. Since environment can stimulate the brain, the classroom aids development even as lessons taught within the classroom increase knowledge. No longer merely a back drop for learning, classrooms providing an enriching experience become a vital part of the learning process.

Memory is another form of learning that impacts brain development. By understanding how memory changes the brain, we can further improve education. Research indicates storing and retrieving information continually changes brain structure. Through synaptic changes, short term memories are rapidly stored in the hippocampus. Long term memories form when synaptic changes in the hippocampus are repeatedly transferred to and slowly ordered in the neocortex.[30] This structural observation indicates the importance of repetition in increasing memory and improving learning. The benefit of organizing and structuring information when presenting it for memorization is also clear. "When a series of events are presented in a random sequence, people reorder them into sequences that make sense when they try to recall them."[31] Therefore teachers who present information in a logical order better enable their students to memorize the material. We also know the hippocampus is the area of the brain where facts are stored while the neostriatum, part of the neocortex, stores long term memory for skills.[32] This research reveals the importance of gathering skills rather than simply memorizing facts, and the importance of specifically instructing students in a way that promotes the acquisition of new skills.

Though neurological research does not provide a single most effective way to educate a child, current research on the developing brain has proposed many strategies for improving education. Throughout development, it seems "children's brains may be more ready to learn different things at different times."[33] This is suggested by the fact that the brain uses certain external information at specific times during development to internally organize the brain. Though research moves forward, we already know the human brain continues to develop in varying degrees throughout life. In fact, research shows stimulating brain development prolongs a person's life. A study of a group of nuns in Minnesota found that those "who earn college degrees, who teach, and who are constantly challenging their minds live longer."[34] Obviously the human brain thrives on stimulation. The good news for teachers is that the more we use them, the better they perform.

[1] Keith L. Moore, *Before We Are Born* (Philadelphia, W. B. Saunders, 1993), 63.

[2] Yozen Fuse, "Development of the Hypothalamic-Pituitary-Tyroid Axis in Humans," *Reproductive Fertilization Development*, Vol. 8 (1996), 9.

[3] Moore, 63.

[4] Keith L. Moore and T. V. N. Persaud, *The Developing Human* (Philadelphia, W. B. Saunders, 1998), 91.

[5] J. Laffont, "Embryology of the Brain," *J. Neuroadiology*, Vol. 9 (1982), 5.

[6] Moore, 64.

[7] Miguel Marin-Padilla, "Structural Organization of the Human Cerebral Cortex Prior to the Appearance of the Cortical Plate," *Anatomy and Embryology*, Vol. 168 (1985), 21.

[8] Hannibal Hamlin, "Life or Death by EEG," *JAMA* Vol. 190, No. 2 (12 Oct. 1964), 112.

[9] L. G. R. Van Dongen, "Fetal Movement Patterns in the First Trimester of Pregnancy," *British Journal of Obstetrics and Gynaegology*, Vol. 87 (March 1980), 193.

[10] Mayumi Fujii, Noboru Goto, Susumu Onagi, Akira Okada, and Akinori Kida, "Development of the Human Lateral Vestibular Nucleus: A Morphometric Evaluation," *Early Human Development*, Vol. 48 (1997), 23.

[11] L. G. R. Van Dongen and Elizabeth G. Goudie, "Fetal Movements Patterns in the First Trimester of Pregnancy," *British Journal of Obstetrics and Gynaegology* Vol. 87 (March 1980), 193.

[12] Bork / Bern, 362+

[13] J. Burn, J. A. Birbeck, D. F. Roberts, "Early Fetal Brain Growth," *Human Biology,* Vol. 47, No. 4 (Dec. 1975), 511.

[14] R. J. Robinson et al, "The Central Nervous System in the Newborn," *British Medical Bulletin*, Vol. 22, No. 1 (1966), 49.

[15] Jean-Pierre Lecanuet and Benoist Schaal, "Fetal Sensory Competencies," *European Journal of Obstetrics and Gynecology and Reproductive Biology* (1996), 16.

[16] M. Cheour-Luhtanen et al. "The Ontogenetically Earliest Discriminative Response of the Human Brain," *Psychopsysiology*, Vol. 33 (1996), 480.
[17] J. L. P. de Vries, G. H. A. Visser and H. F. R. Prechtl, "The Emergence of Fetal Behavior," *Early Human Development*, Vol. 7 (1982), 301.
[18] National Research Council, *How People Learn*, J. D. Bransford, A.L Brown, & R.R. Cocking, eds.(Washington, D.C.: National Academy, 2000), 115.
[19] Peter R. Huttenlocher and Arun S. Dabholkar, "Regional Differences in Synaptogenesis in Human Cerebral Cortex," *The Journal of Comparative Neurology*, Vol. 387 (1997), 167-178.
[20] NRC, 116.
[21] NRC, 116.
[22] Robinson et al, 49.
[23] NRC, 116.
[24] NRC, 116.
[25] Bryan Kolb, *Brain Plasticity and Brain Behavior*, (Mahwah: Lawrence Erlbaum, 1995), 167.
[26] Jeffrey A. Kleim, E. Lussnig, E. R. Schwarz, et al., "Synaptogenesis and FOS Expression in the Motor Cortex of the Adult Rat after Motor Skill Learning," *The Journal of Neuroscience*, Vol. 16, No. 14 (1996), 4523.
[27] Kolb, 169.
[28] Kolb, 13.
[29] NRC, 122.
[30] James L. McClelland, Bruce McNaughton, & Randall C. O'Reilly, "Why There Are Complementary Learning Systems in the Hippocampus and Neocortex: Insights From the Successes and Failures of Connectionist Models of Learning and Memory," *Psychological Review*, Vol. 102, No. 3 (1995) 420-421.
[31] NRC, 124.
[32] Charles R. Noback et al, *The Human Nervous System: Structure and Function*, 5th ed. (Baltimore: Williams and Wilkins, 1996), 365-366.
[33] NRC, 122.
[34] Kolb, 12