Building on Shifting Sand
The Impact of Computer Use on Neural & Cognitive Development

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An exploration of the effects of technology in general and computer use in specific is presented, as they pertain to neurological maturation and cognitive development The role of neural plasticity is examined as it relates to how technology can change the structural-functional relationships in the nervous system and in turn effect the skills acquired during cognitive growth. Piaget's theory of cognitive development is briefly described as well as the challenges to the universality of this model. Implications for future research are presented in the light of the rapid proliferation of computers in education and the potential consequences of this expanded use in the developing cognitive systems of young children.

It is a commonplace that the influence of technology in the modern world is pervasive. The allure of finding easier, faster, better ways of accomplishing a task is compelling. Most people rarely stop to assess the potential negative consequences that technology may produce. If they do, such considerations are often coupled with a belief that technology can itself, ultimately, resolve the eventuate problems.

Nowhere is the seduction of technology more evident than in the increasing reliance placed on computers. Computers have moved from corporations to schools and into the home with little or no thought that they may have an aversive impact. The virtues of computer use are everywhere extolled. The sales pitch warns that to deny our children access to computer literacy is tantamount to keeping them from high-powered jobs in a future world that will surely be governed by those who have mastered the reigning technologies. Owen Barfield extended this idea when he observed that there are "quarters, where the sole motivation is the advance of technology and of the power over others that technology can confer."[1]

The consequence in education is that economic and political concerns take precedence over a pedagogy that supports the basic progress of children's development. An effort is needed to understand the processes involved in this fundamental growth. When this is done, it becomes clear that questions of appropriate usage and the timing of exposure to technology are critical to integrating computers into young lives. Computers are not demonic in nature. They are certainly useful tools and should be suitably and thoughtfully integrated within the educational system. However, exposing children to even a felicitous experience at the wrong time or in the wrong way may alter the manner in which they sense and perceive the world.

In this essay an overview of neurological maturation and cognitive development will be presented as they relate to the resulting outcomes of environmental manipulation. The intent here is not to call for an end to computer usage, but to suggest that at certain age levels computers warrant judicious use that considers neurological and cognitive readiness.

Neurological Maturation

Although one may observe dramatic differences among people overtime, the basic growth of the brain ("Brain" is shorthand for referring to the central nervous system that includes the brain and the spinal cord. These terms are used interchangeably throughout this essay.) proceeds in a similar fashion for all human beings both before and after birth. This dynamic is initiated by a genetic "blueprint" that provides material regarding both species specific information, such as having toes instead of webbed feet, and individual traits. The process of brain growth and differentiation is linked during prenatal life to specific ages and takes place according to a relatively fixed pattern.[2] Postnatal brain development does not occur in this uniform way, but tends to be episodic in quality. Episodic does not imply that maturation is haphazard. The ages at which certain changes occur remain constant and are inextricably conjoined to development in other domains. As shall become clear a curious relationship exists between the growth of the nervous system and the unfolding of cognitive facility.

In the last two decades substantial research attention has been given to the structural differences that emerge when the brain is exposed to divergent sensory experience. The changeability of the brain is evident because it can be demonstrated that external conditions can transform the course of its development This phenomenon, referred to as neural plasticity, is especially potent when exposure occurs at certain vital times. These sensitive, or critical, periods are the windows of opportunity when environmental influences will have their principal bearing. One can just as easily say inopportunity, since the result can often be disastrous. In order to understand the momentous character of this intervention, it is necessary to have a rudimentary understanding of how the nervous system is constructed and how it operates.[3]

The brain is made up of two classes of cells. These are neurons, “nerve cells”, and glial cells. The glial cells (from the Greek for “glue”) offer different types of support to neurons such as repair and insulation. Neurons, which number in the billions, “arrive in the world ready and waiting to connect themselves together in flexible networks to fire messages within and between parts of the brain.[4] Beginning at conception and continuing throughout gestation, these cells come together to form an organized whole with recognizable components and subdivisions. The brain is divided into systems primarily because of its anatomy. Richard Restak is careful to remind us that “the map is not the territory.” He states, “All proposed divisions within the brain are highly artificial and are based on our need to separate things into neat, easily understandable units. We must always remember that the brain functions as a whole”[5] This point is salient to comprehending how one segment of the brain is able to “step in” and take over a function that is normally associated with another part.

An infant is born equipped with au the neurons she will ever have in the cerebral cortex. Yet because of the way these cells connect, there are infinite possibilities in the way neural networks can form. The consequent whole, your brain, is created and recreated through this process. While the macroscopic features of the brain are, of course, essential, it is in the formation of neural networks that the wonder of plasticity lies.

Sir Charles Sherrington once described the nervous system as “. . . an enchanted loom where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern though never an abiding one.”[6] This eloquent portrayal readily applies to the ability of the brain to mold itself in response to the environment. The interplay of external conditions and internal modulation will have varying effects.

When the information received is a trauma or injury, the plastic nature of the brain enables it to compensate by shifting function from the site of the damage to other cells and structures surrounding that site. While this capability continues throughout the lifespan, it is at its prime efficacy from the prenatal era through early childhood.

The list of teratogenic factors, birth defect producing events, is woefully long. The risks of smoking, drinking and taking drugs are well known, but the subtleties involved in how these and other substances may alter development are alarming. Coming into contact with a substance or situation is not the only factor. Timing, duration of the contact and level of exposure in combination with genetic predisposition complicate the particulars. A fetus is unlikely to receive injury if exposed to mild radiation in the last months of pregnancy. When this exposure occurs between the ninth and tenth days of gestation during the germinal stage, the outcome may be a serious malformation such as spina bifida.[7]

In early childhood, language is one area where reorganization frequently occurs after injury. How this plays itself out depends on what portion of the brain is damaged. In some cases there is no apparent language deficit after injury while in other cases language may be saved, but at the expense of visuospatial functioning. Moreover, lesions in young children have far less impact on language function than do similar lesions in adults.[8]

There are also examples of early deprivations or injuries that no amount of compensation can rectify. Chronic malnutrition while in the womb or in the critical period shortly after birth can lead to brain damage. Mental retardation occurs with exposure to lead. The presence of cataracts or astigmatisms in the early years will lead to lasting vision impairments even after these conditions are surgically corrected.[9]

Conversely, there is an extensive experimental literature to demonstrate that early exposure to an enriched environment will alter the brain as well. It would be unethical, and immoral, to deprive children of experiences deemed as important and then measure the effects of the deprivation. The standard approach has been to enrich or add special experiences to the environment. These experiences take the form of interventions where there is increased stimulation of some kind. This is often done to compensate for perceived deficits in early life.[10] Since research began in this area in the late 1950s using rats, it has generally been assumed that being reared in an enriched environment is a desirable situation. The larger brain size and changes in neuroanatomy that flow from a stimulating milieu are viewed as benefits.[11]

The literature on enrichment creates an opening for the introduction of devices or techniques to “improve” development or “accelerate” growth of average children who have not been deprived. This tack is questionable for numerous reasons. One is that the assessment of what qualifies as improvement is highly subjective. At issue, too, is whether cognitive development, including language, memory, information processing, thinking, problem solving and related intellectual processes, can be accelerated in light of the existing biological constraints. Is demonstrating a bigger vocabulary indicative of anything other than simply knowing more words? Does improvement in test taking skills mean that a child’s thinking has improved?

The studies of language, mental retardation and visuomotor ability cited above illustrate that structural adjustments in the brain do bring about functional changes. There seems to be little doubt that experiences before birth and in early life can have lasting effects, for better or worse, in the capacity of the nervous system to learn and store information.[12] Understanding cognitive development together with the relationship between biology and cognition is the next step in evaluating the effects of environment on young minds.

Cognitive Development

Jean Piaget gives us the preeminent model of cognitive development.[13] Piaget was trained as a zoologist and his major interests were philosophical. His intense concern about how children develop their thinking began when he took a position administering early versions of the Binet Intelligence Test.[14] He became fascinated, not by the way children responded to questions that they knew, but by the wrong answers that they gave.[15] This concern was elaborated when Piaget began to observe the responses of his own children to everyday situations. When Piaget proposed his system in the 1920s,[16] the academic communities in Europe and the United States were dominated by either psychoanalytic, behavioristic or content-oriented psychometric paradigms.

The innovation introduced by Piaget focused on a view of the individual as a conscious, active participant in development. His model is neither a nativist nor empiric& one. It is an interactionist, or constructivistic, one. There is a tendency to perceive this model as nativist because of Piaget’s biological training combined with his argument that there are invariant stages through which individuals progress. Careful scrutiny reveals that the model draws on genetic influences (as in nativism) and environmental contingencies (as in empiricism), but the result in Piaget's system is that "the organism inherits a genetic program that gradually (through a process of "maturation") provides the biological equipment necessary for constructing a stable internal structure out of its experience with the environment.[17] The paradox in the model is that is the stable structures that allow for adaptation to changes in the environment.

This adaptation is a biological function. As children mature, the functions within this system remain constant while the structures change systematically. The change in structures is development. According to Piaget there are two basic functions which he calls adaptation or "the accord of thought with things [18] and organization which he says is "the accord of thought with itself."[19] Adaptation is subdivided into assimilation and accommodation. In assimilation the organism reacts to the environment in keeping with knowledge or activities that are present at birth or have already been learned. In accommodation there is a change in understanding because the organism is unable to deal with a situation based on existing knowledge. An example of this interweaving of activity is the infant's ability to suck which is present at birth. Piaget would say that an infant has a sucking scheme. This can be thought of as an individual structure or mini-system within the larger organization of cognition. The sucking scheme allows the infant to assimilate a nipple to the behavior of sucking. When the infant encounters her fingers or toes, the newborn sucking scheme becomes inadequate. Accommodation is necessary to respond to the changes in information and behavior. Assimilation and accommodation are called functional invariant because they are representative of all biological systems despite the divergent content of those systems.

In essence, Piaget's theory addresses two questions. "(1) What are the characteristics and capabilities of children that allow them to adapt to the environment? and (2) What is the most useful way of classifying or ordering child development?"[20] Adaptation and its attendant channels of assimilation and accommodation address the first question. Piaget's description of an ordered sequence of development into invariant stages is the rejoinder to the second question.

It is in Piaget's stages that the relationship between the physiological structure of the nervous system and cognitive function are seen most clearly.[21] KoIb and Whishaw point out that after birth, "Significantly, the first four brain-growth stages coincide with the classically given ages of onset of the four main stages of intelligence development described by Piaget."[22] Each of the Piagetian stages forms a structural whole where the preceding stages are incorporated as necessary substructures. Adaptation shows that maturation occurs because of the interaction of genetic predisposition and dynamic participation with the environment.

The criticisms of Piaget are largely concerned with dimensions that are excluded from his overall model. In every stage theory there is a de-emphasis of individual variability in favor of "average" performance. Anthropological research examines the influence of culture on Piaget's system and on analogous models to determine if, in fact, they are universal.[23] The effects of schooling on performance of specific cognitive tasks is another area that has received substantial attention.[24] There have been challenges to specifics within the theory as well. It has been charged that the information processing capabilities of infants and young children were underestimated by Piaget.[25] This claim has more to do with the instrumentation that was available in the early decades of this century than to theoretical weakness, but it serves as a good illustration of the nature of the criticisms leveled against the theory.

When all the data is analyzed, it is hard to deny that there are stages of cognitive development that unfold in a characteristic sequence - to quibble over whether a certain skill emerges at age three years or three years and two months or that an infant may have more elaborated memory abilities misses the point. The types of intervention that typically occur in educational settings are not fine tuned. They are aimed at broad developmental levels. In the last eleven years, three major reviews of Piaget's work illustrate the validity and applicability of these categories and the continued heuristic value of the theory.[26]

This explication of Piaget's theory now allows for a discussion and evaluation of the effects that environmental regulation can have on a child's development. Keeping in mind that the child's neurological growth is part of this synthesis, the issue of calculated manipulation takes on a more ominous cast.

Environmental Manipulation

The stimulation that a child receives from the environment modifies development in two overlapping areas. The child's neurological structures and cognitive productiveness are interdependent and each is sensitive to environmental influence. Since his death in 1980, there have been a variety of attempts to challenge Piaget's constructivist model. This work, largely done in educational settings, focuses either on ways to accelerate the movement of a child through the Piagetian sequence of cognitive development or is aimed at verification, or nullification, of the system itself.

On the question of intervention to accelerate the stages of development, some neo-Peagetians stand firm, stating that, "1) if a child is not ready to change, no teacher can help him; 2) if he is ready, the change will occur without intervention; 3) therefore, intervention [to accelerate the stages of development] is superfluous."[27] Piaget held a negative attitude toward attempts to quicken development and even challenged the very idea of intervention on the basis that this might actually be harmful to the child in the long run.[28]

Different studies explore this problem, but one stands out because of its disquieting results. Several researchers assessed the abilities of four-year-old children attending academic or nonacademic pre-kindergarten programs. While the children in the academic program performed better on tests of academic skill such as recognizing letters or numbers, there were no differences in general measures of intelligence or social competence among the children. There was a further difference though. Children in the academically oriented program were judged as showing less creativity. The authors conclude, "that the effort spent on formal, teacher-directed academic teaming in preschool may not be the best use of children's time at this point in their development."[29] This outcome seems to indicate that there is a reason for apparent cognitive immaturity.

One extensive review of the research in this area concludes that, "a consideration of the adaptive aspects of slow maturation cautions us to provide children with intellectual experiences tailored to their capabilities rather than trying to endow them with skills ill suited for their biologically determined cognitive systems."[30] David Elkind puts it more plainly when he argues that the academic pressure placed on young children is "miseducation".[31]

Recently, a more radical view suggests that, "there is a cerebral primacy in the development of knowledge: that developed neurobiological and inchoate neurocognitive systems not only predispose individuals to specific knowledge domains, but actually drive human knowledge toward those specific domains.[32] This assertion has sparked a vociferous debate regarding whether different educational practices must be tailored to fit the specific domains of knowledge.

The underlying consideration in this and in many of the acceleration through intervention studies is a tacit challenge of the universality of Piaget's stage model. Here, the methodological approach is one that presumes that if acceleration is possible, then the existence of stages must be doubtful. This is where the relationship between neural plasticity and cognitive function becomes paramount. In Piaget's system, the timing of the stages is of equal importance to the sequence involved. The seemingly unhurried and inefficient operation that occurs during infancy and childhood may be the essential ingredient in the intellectual plasticity that human beings display. This permits cognitive flexibility in young children that allows for thorough integration of new schemes. It also gives way to the construction or reorganization of neural networks that, as has been discussed, can compensate for deprivation or injury.

While this appears beneficial at first glance, it also follows that changes in brain development may actually be detrimental to the child. When stimulation is presented at an inauspicious time or in an inappropriate manner the growth of neural connections may move in directions that are at odds with a propitious course of development.

Terry Winograd and Fernando Flores point out that the whole context of an event is a vital concept. Their caveat is that the relationship between changes in structure and the causative experience is “historical”. “The structure of the organism at any moment determines a domain of perturbations - a space of possible effects the medium could have on the sequence of structural states that it could follow.”[33] Humberto Maturana’s position is that, “learning is not a process of accumulation of representations of the environment; it is a continuous process of transformation of behavior through continuous change in the capacity of the nervous system to synthesize it.”[34] When these ideas are considered together, it is now palpable why technology can become an intrusive participant in this developmental ballet.

Among the varieties of disorganized thinking explored by Jane Healy, “attention deficit” disorder serves as a potent example of this difficulty. There has been an exponential increase in the number of cases of Attention Deficit and Hyperactivity Disorders (ADHD) reported and treated in recent years. Healy argues that the clinical symptomatology for ADHD is a manifestation of a broader “mental restlessness” exhibited among students. She states, “Inability to persist in solving problems, reading “hard” books, or doing work perceived as “boring” are even more serious symptoms” than “focusing and maintaining internal control of attention.”[35] Healy goes on to present a strong case that problems in thinking like AND are grounded in neurological disruptions that may be the result of environmental factors. She explores the proposition that children are being raised in “toxic environments”.

The latest culprit is any endeavor that inhibits the child’s physical activity. This includes television, video games and sitting in front of a computer screen. All of these undertakings severely limit the child’s use of her body. Phyllis Weikert addresses this point by stating, “Children used to play in natural ways, with kids of different ages, outside, basically unsupervised by adults. Visual and auditory attention, body coordination - all were gained through that kind of play. This physical learning must take place before children start dealing with abstractions; it doesn’t happen if children don’t have those experiences.”[36]

The attendant problems associated with using computers, principally in early childhood, go beyond a lack of physical fitness or failure to engage in physical learning. Although these difficulties can be inferred by extension, the central concern is the effect of computer use on brain function and how such effects influence cognitive ability.

Human beings process information using sequential and parallel processing. In sequential processing one piece of information is processed at a time: If A, then B, therefore C and so on. In parallel, or simultaneous (i.e., distributed) processing, many pieces of information are sorted, classified and connected by different modular components all at the same time: If A, then B, and K, don’t leave out 6 and 14, is it time for lunch yet?, etc. It is this latter method of divergent thinking, associated with the right hemisphere of the brain, that creative thinkers draw upon when problem solving. Computers rely on sequential methods of analyzing data. As John Searle states, “The reason that no computer program can ever be a mind is simply that a computer program is only syntactical .. .. Minds are semantical, in the sense that they have more than a formal structure, they have a content.”[37] Computers are lifeless, “What we embed [in them] is the inert and empty shadow, or abstract reflection, of the past operation of our own intelligence."[38]

Once a child is placed at a computer terminal the full panoply of cognitive function is curtailed. In word processing, programming and data base manipulation, the only operational demands are those involved in sequential, analyatical thinking. Again to quote Jane Healy, "Most agree that computers are a tool with almost unlimited potential, but until they engage in parallel as well as simultaneous processing, they will not only be a poor match, but also a poor model for most forms of human reasoning."[39]

Directions for Future Research

Although the precise way in which computer use shapes the brain is, as yet, unknown, it is clear that computer use has the potential to bring about change. As Jerome Bruner writes, The only thing I can say with some degree of certainty . . . is that the evolution of human brain function has changed principally in response to the linkage between human beings and different tool systems."[40] The infiltration and proliferation of computers within education constitute a profound "tool system". The unknowns involved give rise to a frightening prospect. Given what is understood about neural plasticity and cognitive function, there is no reason to assume that the computer will have a benign effect. Computers may be helpful instruments when they are operated by individuals whose cognitive structures have already matured. Limiting computer use appears to be a wise choice until the long-term impact on preschoolers and early school age children is thoroughly assessed.[41] The threat of potential harm to developing young minds would seem to be enough of a deterrent in the absence of the necessary research data.

Yet, the startling aspect of this inundation of technology is how quickly computers have been accepted by educators at all academic levels despite the lack of evidence to substantiate their effectiveness. Institutions of learning have invested their faith, and their fiscal budgets, into a pursuit that may be at odds with the task of education. Steve Jobs, the man who hastened this spiraling revolution, offers some sobering reflections on this point. Jobs confesses, "I used to think that technology could help education. I've probably spearheaded giving away more computer equipment than anybody else on the planet. But I've had to come to the inevitable conclusion that the problem is not one that technology can hope to solve."[42]

School systems are searching for a solution to the apparent decline in student performance, and earnest search for a "quick fix", or panacea. The present-day shortcomings in writing, reading skills and mathematical ability will not be resolved by a software package or CD-ROM program. In the same interview, Jobs states an obvious point that bears repeating when he says, "Historical precedent shows that we can turn out amazing human beings without technology. Precedent also shows that we can turn out very uninteresting human beings with technology."[43]

By accepting the seemingly easy solution, the deeper issues involved in flagging school performance have been skirted. The problems in education are cultural problems. The academic failures that arouse dismay can be seen throughout society. Illiteracy and innumeracy are not limited to the classroom. They are present in the boardroom, at the doctor's office, in the judge's chambers and in the state house. There is a recognition dawning that something has gone awry. The reliance on technology as a substitute for engaging in a careful reappraisal of thinking and knowing accompanied by diligent research shortchanges everyone, particularly the youngest members of this society.

Sven Birkerts sums this up poignantly when he writes, "There is.. . a tremendous difference between communication in the instrumental sense and communion in the affective, the soul-oriented, sense. Somewhere we have gotten hold of the idea that the more all-embracing we can make our communications networks, the closer we will be to that partaking that we long for deep down .... our technologies have not yet eradicated that flame of desire."[44]

In the lives of young children, imagination and creativity may be replaced by the dull, lifeless contact that often occurs with computers. Children are transformed from active seekers of information bursting with curiosity into passive receptacles to be filled with bits of information. The dynamic potential of neural plasticity and cognitive development seems abandoned in this scenario. The task, then, is to avoid uncritical reliance on technology until the questions of outcome are resolved. Computers are here to stay, but we have an obligation to demand they be used judiciously.

Notes

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[1] Owen Barfield, *History, Guilt, and Habit*. (Middletown, Connecticut: Wesleyan University Press: 1981), page 91.

[2] Bryan Kolb and Ian Q. Whishaw, *Fundamentals of Human Neuropsychology*, 3rd edition. (New York: W.H. Freeman and Company, 1990).

[3] Neurological development is a complex, lifelong process. It is necessary, without getting too technical, to understand several features of this process in order to grasp the implications of neural plasticity. For a complete discussion of prenatal and postnatal neurological development, see Richard Restak. *The Brain*. (New York: Bantam Press, 1984) or any standard pediatric textbook; and for neural plasticity see Richard M. Lerne, *On the Nature of Human Plasticity*. (New York: Cambridge University Press, 1984).

[4] Jane M. Healy, *Endangered Minds: Why Children Don"t Think and What We Can Do About It.* (New York: Touchstone, 1990), p. 51.

[5] Richard Restak, *Receptors*. (New York: Bantam Books, 1994), p. 12.

[6] As quoted in Ashley Montagu, *The Direction of Human Development*, revised edition. (New York: Hawthorne Books, 1970), p. 59.

[7] The germinal stage marks the first two weeks of gestation between fertilization and the implantation of the organism into the wall of the uterus. It is characterized by increasing cell division and structural complexity. Spina bifida is a defect where the vertebral arches are absent. The result is that the spinal cord and membranes will protrude through the spinal column. This is sometimes so severe that these tissues distend from the back of the infant.

[8] There is a vast literature that addresses the effects of brain trauma on language. Oliver Sacks offers several highly accessible essays on this topic.

[9] Research on the detrimental effects of environment on brain development and function has an extensive history. Two classic examples are J.A.L. Singh and R.M. Zingg, *Wolf Children and Feral Men*. (New York: Harper and Row, 1940) and Harry Harlow. *Learning to Love*. (San Francisco: The Albion Publishing Company, 1971).

[10] Project Head Start is one example of an intervention program that has had mixed results. The intent of the more than 2000 different Head Start projects, many now defunct, is to eliminate the disadvantages that emanate from being raised in a deprived environment. This situation is defined as coming from a home that is less advantaged economically, socially and intellectually.

[11] Marian Diamond"s *Enriching Heredity*. (New York: The Free Press, 1988) is one example.

[12] A thorough discussion of this point is presented in M.C. Wittrock, "Learning and the Brain" in M.C. Wittrock, editor, *The Brain and Psychology*. (New York: Academic Press, 1980).

[13] Kurt Fischer and Louise Silvern point out in their seminal review of cognitive development. "Stages and Individual Differences in Cognitive Development" in Mark R. Rosenzweig and Lyman W. Porter, editors, *Annual Review of Psychology*, volume 36. (Palo Alto, California: Annual Reviews Inc., 1985). There are two main frameworks that inform many of the theoretical approaches in developmental psychology. The mechanistic model views people like machines and sees them as reactive. The organismic model views people like active organisms and sees them as active. Piaget's theory is an organismic or constructivistic model. Since 1985, a third approach, the contextual model, has rapidly gained influence. The contextual, or ecological model, shares characteristics of the organismic and mechanistic models, but moves away from the emphasis on specific stages.

[14] This is now called the Stanford-Binet Intelligence Test for Children.

[15] In his "Autobiography", in *History of Psychology in Autobiography*, edited by E.G. Boring et. al. (Worcester, Massachusetts: Clark University Press, 1952), pp. 237 - 256, Piaget's excitement about finding his domain of study is apparent. He says, "At last I had found my field of research." p. 245.

[16] The original French edition of Piaget's *The Language and Thought of the Child* appeared in 1923, followed by *Judgment and Reasoning in the Child* in 1924. His more comprehensive and elaborated volume, *The Origins of Intelligence in Children*, appeared in 1936. These editions were translated into English and published in 1924, 1926 and 1952, respectively.

[17] John L. Phillips, Jr., *The Origins of Intellect: Piaget's Theory*, second edition. (San Francisco: W.H. Freeman and Company, 1975), p. 7.

[18] Jean Piaget, *The Origins of Intelligence in Children*, translated by Margaret Cook. (New York: International Universities Press, 1952), p. 8.

[19] Ibid.

[20] Guy Lefrancois, *The Lifespan*, fourth edition. (Belmont, California: Wadsworth Publishing Company, 1993), p. 59.

[21] For a complete discussion of Piaget's stages of cognitive development, see Howard E. Gruber and J. Jacques Voneche, editors, *The Essential Piaget*. (Northvale, New Jersey: Jason Aronson, Inc., 1995).

[22] Kolb and Whishaw, *Fundamentals of Human Neuropsychology*, p. 686.

[23] Richard A. Shweder's "0n Savages and Other Children", *American Anthropologist* 84, pp. 354-366, is but one example of the harsh criticisms that have been directed toward Piaget from the field of anthropology regarding the need to include culture as a variable.

[24] See Jacqueline J. Goodnow, “The Socialization of Cognition: What’s Involved” in James W. Stigler, Richard A. Shweder and Gilbert Herdt, editors, *Cultural Psychology: Essays on Comparative Human Development.* (New York Cambridge University Press, 1990), pp.259-286.

[25] John H. Flavell has spent more than a decade examining the pros and cons of Piaget’s model. For a thorough discussion of this work see *Cognitive Development*. (Englewood Cliffs, New Jersey, 1985).

[26] Kurt W. Fischer and Louise Silvern, “Stages and Individual Differences in Cognitive Development” (cited above, note 13); Robert S. Siegler “Mechanisms of Cognitive Development” in Mark R. Rosenzweig and Lyman Porter, editors. *Annual Review of Psychology*, volume 40. (Palo Alto, California: Annual Reviews Inc., 1989); and Henry M. Wellman and Susan A. Gelxnan, “Cognitive Development Foundational Theories of Core Domains”, in Mark K Rosenzweig and Lyman W. Porter, editors, *Annual Review of Psychology*, volume 43. (Palo Alto: Annual Reviews Inc., 1992).

[27] John L Phillips, *The Origins of Intellect: Piaget’s Theory*, p. 175.

[28] Ibid

[29] M.C. Hyson. K. Hirsh-Pasek and L. Rescorla, *Academic Environments in Early Childhood: Challenge or Pressure?* (Chicago, Illinois: The Spencer Foundation, 1989), p. 15.

[30] David F. Bjorklund and Brandi L. Green, “The Adaptive Nature of Cognitive Immaturity, pp. 104 iii, in *Human Development* 95/96. edited by Karen L Friedberg. (Guilford, Connecticut The Dushkin Publishing Group, 1995), p. 109.

[31] As quoted in Bjorklund and Green, ibid.

[32] Michael Glassman. “The Argument for Constructivism”, *American Psychologist* 51(3), March 1996, p. 264. Glassman is paraphrasing David Geary in this passage. While Glassman is a constructivist in the spirit of Piaget, his challenge to Geary lies not in the presumed neurological basis of cognition, but in the way educational systems should address this issue, especially in the domain of mathematics education.

[33] Terry Winograd & Fernando Flores, *Understanding Computers and Cognition: A New Foundation for Design*. (Norwood, New Jersey: Ablex Publishing Corporation, 1986), p.43.

[34] As quoted in Winograd and Flores, Ibid., p. 45.

[35] Healy, *Endangered Minds: Why Children Don’t Think and What We Can Do About It*, p. 153.

[36] As quoted in Healy, ibid., p. 171. For a complete survey of Weikert’s views see *Round the Circle: Key Experiences in Movement.* (Ypsilanti, Michigan: High Scope Press, 1986).

[37] John Searle, *Minds, Brains and Science*. (Cambridge, Massachusetts: Harvard University Press, 1984), p. 31. Searle illustrates the semantic shortcomings of computer programs in his famous “Chinese Room” problem contained in this same volume.

[38] Stephen L. Talbott, *The Future Does Not Compute: Transcending the Machines in Our Midst*. (Sebastopol, California: O’Reilly and Associates, Inc.. 1995), p. 360. Talbott offers a profound

explication of the broader social and cultural implications of computer use. His insights regarding ways of knowing add a deeper philosophical dimension to this general discussion.

[39] Healy. *Endangered Minds: Why Children Don't Think and What We can Do About It,* p. 325.

[40] Quoted in Healy, ibid., p. 334.

[41] There is a great deal of very good work being done to evaluate the effects of interactive media. A summary of research in this area is presented in Patricia M. Greenfield and Rodney R. Cocking, editors, *Interacting With Video,* (Ablex Publishing Corporation, 1996).

[42] Gary Wolf, "Steve Jobs: The Next Insanely Great Thing", *Wired* 4(2), February 1996, p. 158.

[43] Ibid.

[44] Sven Birkerts, "The Fate of Reading in an Electronic Age," pp. 107- 112, excerpted from *The Gutenberg Elegies*, in New Letters 60(4), 1994, p. 112.