Effects of Experience on the Brain: The Role of Neuroscience in Early Development and Education

Sandra Twardosz

Department of Child and Family Studies, University of Tennessee, Knoxville

Research Findings: Research on the effect of experience on the structure and function of the brain across the lifespan pertains directly to the concerns of professionals involved with children’s early development and education. This paper briefly reviews (a) the role of experience in shaping the developing brain, (b) individual adaptation to the environment through learning and memory, and (c) the effects of stress on the developing and adult brain. Controversies about applications of this knowledge to recommendations for parents and teachers regarding the care and education of young children are described followed by current neuroscience research and scholarship in early education.

Practice or Policy: Neuroscience perspectives and methods are currently contributing to research on children’s early environments and experiences. Thus, it is vital that early development and education professionals become knowledgeable about them.

The topic of brain plasticity encompasses numerous areas of neuroscience research, including the role of experience in shaping the developing brain and the changes in structure and function that accompany learning and memory throughout life. However, brain plasticity also refers to the brain’s response to the loss of sight or hearing, amputation of a limb, stroke, the ingestion of addictive substances, and other forms of brain injury. This capacity for change is an intrinsic and obligatory property of the nervous system. It is not even accurate to describe the brain as being capable of plasticity because, as a continuously changing system that is always in motion, it is always exhibiting plasticity (Robertson, Theoret, & Pascual-Leone, 2003). The impact of this relatively recent view of the brain can be seen throughout the social science and education literature as well as in the popular media.

This paper is divided into two major sections. The first section provides a brief review of three aspects of brain plasticity with examples from the developmental and neuroscience literatures that are closely connected with early development and education concerns. These include (a) the role of experience in shaping the developing brain and the concept of sensitive periods, (b) individual adaptation to the environment through learning and memory across the lifespan, and (c) the response of the developing and adult brain to stress. The second section reviews two major aspects of the integration of this knowledge into early development and education. The first aspect is the response of scholars in child development, early education, and neuroscience

Correspondence regarding this article should be addressed to Sandra Twardosz, Department of Child and Family Studies, College of Education, Health, and Human Sciences, University of Tennessee, Knoxville, 1215 West Cumberland Avenue, Room 115, Knoxville, TN 37996. E-mail: stwardos@utk.edu
to the misconceptions and overgeneralizations about early childhood brain development that resulted from media coverage and other events highlighting the importance of the first 3 years of life during the 1990s. The second aspect is current research and scholarship that applies neuroscience perspectives and methods to topics relevant to the early development and education field, such as self-regulation and the effects of poverty. This paper does not present an exhaustive review of any topic; rather, the intention is to bring a variety of topics and issues to the attention of diverse readers.

In presenting this material I do not presume that readers are comfortable with neuroscience or other biological sciences. Thus, basic terms that refer to brain anatomy and functioning are defined as needed, and many of the references cited are accessible for professionals in a variety of fields. However, because the integration of neuroscience perspectives and methods into early development and education fields has resulted in the need for many professionals to educate themselves about this topic, readers are encouraged to explore some of the resources available for this purpose (e.g., Drubach, 2000; Linden, 2007; Puce, 2005; Twardosz, 2007).

EFFECTS OF EXPERIENCE ON THE BRAIN

Prenatal Development

Brain development during the prenatal period is affected by experience with the outside world primarily in the form of maternal nutrition; stress; disease; and other teratogens such as alcohol, nicotine, medications, and illegal drugs (e.g., Hackman, Farah, & Meaney, 2010; B. L. Thompson, Levitt, & Stanwood, 2009; Uylings, 2006). Development is guided by gene expression and the interaction of parts of the developing brain with one another (Marcus, 2003). Although new neurons (nerve cells) are added in some areas of the brain, such as the hippocampus and olfactory bulb, even in adulthood (Sheridan & Nelson, 2009) almost all of an individual’s estimated 100 billion neurons are formed early in the prenatal period from neural stem cells in a process that involves overproduction and cell death; it is estimated that approximately twice as many neurons are produced as will survive. In the cerebral cortex, the thin outer layer of the brain that is essential for perception, cognition, and behavior, these newly born neurons migrate along radial glial (support) cells to form six layers, each serving a different function. Neurons differentiate into the various types of cells that make up the cerebral cortex and then form the axons (projections that transmit information to other neurons) and dendrites (projections that receive information from other neurons) that connect them to one another. Some of these connections (synapses) form during the latter part of the prenatal period, but most of them are formed after birth. Another process that begins at the end of the prenatal period is myelination, the encasing of axons in a fatty coating that makes communication among the neurons more efficient (Stiles, 2008).

Specific substances from the outside environment can be harmful or even devastating for normal prenatal brain development if they are present at specific times. An example is Accutane, a treatment for disfiguring acne, which can cause severe problems for the developing brain if taken early in pregnancy. Accutane is a form of retinoic acid derived from vitamin A. However, retinoic acid in the body acts as a regulator of genes that promote neuron production and other aspects of prenatal brain development such as the formation of the spinal column. Too much
or too little of this substance can result in spontaneous abortion, malformations such as microcephaly, and severe cognitive impairment (Stiles, 2008). Maternal diabetes is a risk factor for the developing brain during the third trimester. Too much sugar in the mother’s blood results in too much sugar and insulin in the fetus’s blood, which increases the rate of oxygen consumption beyond what can be transferred through the placenta. This lack of oxygen puts the hippocampus (a brain structure essential for memory) at particular risk, perhaps because of its high metabolic rate at this time. Furthermore, insulin taken by the mother to treat her diabetes may cause the glucose flow to the fetus to vacillate, which also affects the hippocampus (Nelson, 2007a). Another harmful substance is alcohol, which can interfere with neurogenesis and neuron migration and cause the death of neurons as well as a wide range of other effects depending on when and how much alcohol is consumed (Grossman, Churchill, Bates, Kleim, & Greenough, 2002; B. L. Thompson et al., 2009; Uylings, 2006).

After birth, the individual’s experiences with the environment play a critical role in continuing to form connections among the billions of neurons produced during the prenatal period, particularly in the cerebral cortex. However, this does not occur simply as a result of stimulation provided by caregivers and other aspects of the surroundings. Research in this area is typically described using a model developed by Greenough and his colleagues that includes two processes: experience-expectant and experience-dependent plasticity (Black, 2003; Black, Jones, Nelson, & Greenough, 1998; Bruer & Greenough, 2001; Greenough & Alcantara, 1993; Greenough & Black, 1999; Greenough, Black, & Wallace, 1987). This model is based primarily on research with nonhuman animals supported by more recent neuroimaging studies with humans. Given the abundant literature in which these processes are described, only a brief summary is provided here based primarily on the citations listed above.

**Experience-Expectant Plasticity**

*Experience-expectant plasticity* refers to the overproduction of synapses in specific areas of the brain at specific times, which are then organized and pruned by experiences that are expected or common to the human species, such as patterned light, sound, language, opportunities to move and manipulate objects, and responsive caregivers. These experiences help build the structure of the brain in ways that support binocular vision, upright locomotion, eye–hand coordination, language, and emotional relationships. Although the experiences needed for typical human development are those that are generally available under a wide range of childrearing conditions, they may not be available if a child’s sense organs are not functioning properly or when the environment is not species typical, as can occur in cases of institutional rearing or child maltreatment.

Experience-expectant plasticity is associated with the concept of sensitive periods, times when specific parts of the brain require and are particularly responsive to a specific but widely available form of experience. As determined by analysis of human autopsy tissue, the overproduction of connections occurs in different parts of the cerebral cortex at different times, first in the visual and auditory systems and then in areas mediating higher cognitive functions such as the prefrontal cortex (e.g., Huttenlocher, 2002; Huttenlocher & Dabholkar, 1997). The number of connections reaches a peak and then begins to decline in response to experience until adult numbers are reached, a process that can take many years. For example, the peak number of synapses in the prefrontal cortex, the area of the brain associated with attention, working
memory, self-regulation, and planning, occurs during the preschool period, but the pruning of this area is not finished until late adolescence or early adulthood. The fact that sensitive periods do not occur in all areas of the cortex at once allows for neural circuits that process more basic types of information, such as combining visual stimulation from both eyes, to send reliable information to circuits involved in directing higher level cognitive processes (e.g., Knudsen, Heckman, Cameron, & Shonkoff, 2006). Note that sensitive period rather than critical period is used because it denotes a tapering off of the responsiveness of a brain area to the effects of experience over a more extensive period of time rather than an abrupt endpoint after which experience cannot have an effect. It is considered a more accurate way to describe human brain development (e.g., Thomas & Johnson, 2008).

In the development of the visual system patterned light guides the preservation and pruning of connections. Visual deprivation research with animals (e.g., Horton, 2001; Hubel & Wiesel, 1970) and studies with children who have experienced abnormal visual input indicate that normal visual experience is required for the development of numerous aspects of vision, including visual acuity, peripheral vision, and global motion, all of which have different sensitive periods (Lewis & Maurer, 2005; Tychsen, 2001). The extent to which these aspects develop in the absence of typical experience depends on a large number of factors, including when the deprivation began and ended, whether one or both eyes were involved, and type and extent of treatment. In some respects a unilateral cataract can be more damaging than bilateral cataracts because the eyes compete for cortical connections during infancy and early childhood as a part of normal development. Connections from the deprived eye may be pruned because they are not being stimulated by patterned light while those from the strong eye successfully compete for cortical space, so there is an uneven representation of the two eyes in the cortex. Patching the unaffected eye after the cataract is removed allows the weaker eye to form these connections with less competition.

In addition to affecting current visual development, typical visual experience may also serve to preserve neural structure that will be used for the development of skills that emerge later. For example, holistic face processing is severely affected in children with bilateral cataracts even when visual deprivation ended during the first few months of life (Maurer, Mondloch, & Lewis, 2007). Although many aspects of vision do not develop as they would have in the absence of visual deprivation, some plasticity for recovery is retained into later childhood and adulthood, perhaps because some synapses have been inhibited rather than pruned (Maurer, Lewis, & Mondloch, 2005).

Bell and Fox (1996) hypothesized that crawling develops in an experience-expectant manner and that the overproduction and pruning of connections could be measured using electroencephalography (EEG) coherence. Greater coherence between two scalp electrode sites can be interpreted as the presence of a greater degree of connectivity, or the presence of a greater number of synapses, between those sites. They compared groups of 8-month-old infants who either were prelocomotor or had 1–4, 5–8, or more than 9 weeks of crawling experience and found a curvilinear relationship between the amount of crawling experience and coherence between sites involved with locomotion and other parts of the brain. Prelocomotor infants and those with the most crawling experience exhibited less coherence or connectivity than those with 1–4 and 5–8 weeks of crawling experience, consistent with the process of the overproduction and pruning of synapses.

Another example is perceptual narrowing, a general term that describes the improvement in infants’ ability to discriminate among visual and auditory stimuli that they encounter in their
environment, accompanied by a decrease in their previous ability to do so for stimuli they do not encounter. The most familiar example of this process involves language development. During their first year, infants become better at discriminating the phonetic contrasts of their native language but less accurate at discriminating nonnative contrasts; however, some auditory sensitivity to those contrasts remains into adulthood (e.g., Kuhl, 2004; Kuhl et al., 2006; Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005; Werker, 1989; Werker & Tees, 1984). Exposure to a foreign language in infancy prevents the loss of accuracy with those phonetic contrasts (Burns, Yoshida, Hill, & Werker, 2007; Kuhl, Tsao, & Liu, 2003). Similarly, infants become less accurate in discriminating among monkey faces in the absence of experience with those faces while retaining the ability to discriminate among human faces (e.g., Pascalis, de Haan, & Nelson, 2002). Scott, Pascalis, and Nelson (2007) argued that the overproduction and pruning of synapses that occurs concurrently with perceptual narrowing could be the neural mechanism involved. The pruning or weakening of unused connections could be accompanied by the strengthening of others that are used frequently.

Studies conducted with typically developing children using magnetic resonance imaging (MRI), which can discriminate gray matter (neuron bodies and dendrites) from white matter (myelinated axons), have also provided support for experience-expectant processes. These studies have shown that development involves both progressive and regressive events and that there is some correspondence between brain changes and changes in cognition (e.g., Casey, Tottenham, Liston, & Durston, 2005; Sowell et al., 2004). Giedd (2006) summarized the results of the National Institute of Mental Health pediatric neuroimaging project, which involved 95 boys and 66 girls who were scanned twice at 2-year intervals between the ages of 4 and 20. White matter was found to increase in a linear fashion across brain regions throughout childhood, including in the corpus callosum, which links the activities of the left and right sides of the brain. Gray matter, however, increased and decreased in the different lobes at different times, perhaps reflecting the overproduction and pruning of connections. Gray matter loss in the cortex occurred first in sensorimotor systems and last in the prefrontal region, which corroborates the findings obtained from examining autopsy tissue.

The specific types of experiences involved in the pruning and elaboration of connections in some human brain areas remain far less clear than those involved in other areas. For example, although it is reasonable to suppose that the development of the prefrontal cortex depends on experiences that are widely available in typical human environments, there does not appear to be neuroscience research that specifies what those experiences are. Similarly, experiences that would be atypical or harmful for the development of this area, analogous to the absence of visual stimulation from one eye for the development of the visual cortex, have not been specified.

Experience-Dependent Plasticity: Learning and Memory

In contrast to the organization and pruning of overabundant connections that requires general forms of species-typical experiences, experience-dependent plasticity involves the modification of existing synapses or the generation of new ones on the basis of experiences that are individually specific. One can contrast basic sensory, motor, and cognitive skills such as binocular vision, walking, distinguishing one face from another, and communicating with language with
remembering the events of one’s own life; learning culturally specific skills such as eating with a fork, reading and writing, and playing specific sports; and acquiring adult expertise in occupation and leisure activities. Experience-dependent plasticity, most commonly equated with learning and memory, occurs throughout life and is not associated with sensitive periods; however, there are differences across the lifespan in the way these processes occur that are associated with the development of the hippocampus and cortical areas (e.g., Bauer, 2009).

More than 50 years of experimental work with juvenile and adult nonhuman animals demonstrated that living in enriched or complex environments filled with a changing variety of objects to manipulate and the opportunity for social interaction resulted in differences on a wide variety of brain measures compared with living in the standard laboratory cage. More synapses per neuron, increases in brain weight, differences in brain chemistry, and better performance on learning tasks resulted from experience with the enriched environment (e.g., Rosenzweig, 2007; van Praag, Kempermann, & Gage, 2000).

It is tempting to view the research on enriched environments with rodents as a model for differences in brain development that could be occurring in high-quality compared with more mediocre child care environments. However, Greenough and Black (1992) cautioned that these enriched rodent environments should instead be viewed as complex because they are meant to approximate the experiences available to rodents who are living in the wild outside of the standard laboratory cage, which is a sterile environment with little social or physical stimulation. Thus, it is more likely that this research is a model for investigations on the deprivation that can be associated with institutional or orphanage rearing.

Research comparing complex with minimally stimulating environments has highlighted the role of opportunities to move and explore, sensory stimulation, and social interaction on numerous aspects of brain functioning. The brain also changes in response to specific training. These changes include increased synapses per neuron, compared with a greater density of blood vessels that resulted from repetitive activity, as demonstrated by Black, Isaacs, Anderson, Alcantara, and Greenough (1990) in a study comparing acrobatic training and repetitive physical exercise on the rat cerebellum (a structure involved in motor learning). These effects occur for adult as well as young animals, although effects are not as great for the older animals, and the effects occur not only for neurons and their connections, but for support cells such as glia, the vascular system, and myelination (e.g., Grossman et al., 2002).

Research with human adults using neuroimaging methods has provided abundant support for the effect of individual learning experiences on the structure of the brain. In laboratory studies, participants in experimental groups learned complex finger movement patterns and were compared with control groups whose participants simply moved their fingers. Changes were found in the cortical maps of people who learned the patterns but not those who simply moved their fingers. That is, the practice that led to learning increased the amount of space in the cortex that was innervated by the axons of brain cells from their fingers (e.g., Karni et al., 1995; Robertson et al., 2003). These changes are interpreted as increases in gray matter; however, neuroimaging cannot provide information on numbers of synapses.

Studies in more natural situations have shown changes in cortical maps or brain structures that are associated with specific learning experiences such as mastering the spatial layout of a major city as part of training to become a taxi driver (Maguire et al., 2000) or playing a stringed instrument, in which the differential involvement of the left and right hands is reflected in the measured amount of cortex devoted to each hand (Elbert, Pantev, Wienbruch,
Rockstroh, & Taub, 1995). Of course, factors other than the training experiences could be wholly or partially responsible for the differences.

Learning to read is another example of experience-dependent development because it occurs only under specific conditions and usually involves structured learning experiences that are not bound by a sensitive period. Carreiras et al. (2009) investigated changes in brain anatomy among former Columbian guerrillas who were learning to read for the first time in their early 20s. They compared participants’ MRI scans to those of a matched control group of individuals who had not yet learned to read. Increases in gray matter occurred in areas involved in visual, phonological, and semantic processing, and there were increases in white matter (myelinated axons) in the corpus callosum. These differences were interpreted as consequences of learning to read because the groups were well matched in terms of cognitive ability and the differences were observed in brain areas already identified as functional for reading in individuals who had learned to read in childhood. Petersson and Reis (2006) found similar results when they compared the brains of literate and illiterate adults in a fishing village in southern Portugal.

Experience-expectant and experience-dependent plasticity occur concurrently until early adulthood, and then the adult brain continues to change in response to individual experience and learning. A key distinction between these two types of brain plasticity is that, in the former case, the synapses are overproduced and then shaped by experience, whereas in the latter case, experiences occur and modify existing connections and produce new ones.

Institutional or orphanage rearing during the early years of life can put brain development at risk in terms of both experience-expectant and experience-dependent plasticity (Nelson, 2007b). Recent studies from the Bucharest Early Intervention Project, a randomized trial of foster care as an intervention for early institutional deprivation in Romania, provided information relevant to this issue. Because children were assessed and then randomly divided into foster care or continued institutional care groups, it is more likely that differences in behavioral and brain measures can be attributed to deprivation rather than to other variables such as initial differences in health. A comparison group consisted of children living with their families who had never been institutionalized. Children in the foster care group experienced varying lengths of institutionalization before placement (Zeanah et al., 2003).

Although the quality of the environment and caregiving varied across institutions (e.g., Smyke et al., 2007), sensory stimulation, touch, speech, and personal caregiving were usually minimal compared with what is typically available in a family environment. Smyke, Zeanah, Fox, Nelson, and Guthrie (2010) found attachment disturbances (disorganized or unclassified attachment) in the majority of the institutionalized children, indicating that institutional care did not provide the species-typical experiences required for the formation of an attachment to a primary caregiver. Placement in foster care resulted in a large increase in secure attachments compared with remaining in the orphanage. Differences were also found in lexical and grammatical performance at 30 months, with the institutionalized children as a group producing one half the number of utterances, one third the number of words, and a smaller number of two-word utterances than the family-reared children. However, compared with a group of children who were in foster care an average of only 2 months, previously institutionalized children who had spent an average of 18 months in foster care resembled the family-reared group on these language variables (Windsor, Glaze, Koga, & BEIP Core Group, 2007). Several studies using EEG methodology (e.g., Moulson, Westerlund, Fox, Zeanah, & Nelson, 2009; Parker & Nelson, 2005) found evidence of cortical hypoarousal in the institutionalized children, indicating...
that there was less brain activity in these children. This finding is consistent with the decreased metabolic activity found by Chugani et al. (2001) using positron emission tomography for older children who had been adopted after institutionalization.

Children placed in foster care showed some cognitive recovery compared with children who remained in the institution, and the differences were the greatest for children placed in foster care earlier (Nelson et al., 2007). The authors discussed these results in terms of a possible sensitive period of about 2 years within which placement in foster care would have its greatest effect, but stated that further study with additional participants would be needed to support that conclusion. Instead, they stated that there was a continuing cost to the child in terms of cognitive development the longer he or she remained in institutional care.

Effects of Stress on the Developing and Adult Brain

Stress is another type of experience that affects brain development and functioning throughout the lifespan through the action of cortisol, a glucocorticoid that is released as part of the human stress response. Teicher et al. (2003) and Meaney (2004, 2010) argued that there appears to be a sensitive period when experiences such as child maltreatment or other trauma, and perhaps more typical chronic childhood stress, help guide brain development along a path that results in a heightened level of responsiveness to threat. The absence of such intense experiences allows development to follow a path that results in lower stress reactivity. It is possible that these two pathways evolved in response to environments that varied in resources and danger. Heightened responsiveness to threat might increase the chances of survival and reproduction in dangerous environments with scarce resources; however, the resulting high levels of cortisol also make it more likely that the individual will succumb to anxiety disorders related to dysregulation of the highly complex human stress system.

Decades of developmental research with nonhuman animals has demonstrated that the stress produced by maternal deprivation and other atypical early social experiences results in the dysregulation of the stress system and increased risk for psychopathology (e.g., Higley, Suomi, & Linnoila, 1992). The current most prominent line of research on early experience and stress responsivity is the rat model of variation in maternal care (e.g., F. A. Champagne & Meaney, 2007; Francis, Diorio, Liu, & Meaney, 1999; Meaney, 2004, 2010; Parent et al., 2005). Many mother rats provide abundant amounts of licking, grooming, and arched-back nursing (lying on their backs so pups can nurse easily), which is considered high-quality maternal care. However, all rat mothers do not provide the same amounts of this care, which provides the basis for programs of highly controlled laboratory research. Numerous studies have shown that the amount of high-quality care experienced by pups during a short sensitive period of postnatal life results in differences in their stress reactivity in adulthood. Moreover, their own levels of stress reactivity translate into how they care for their own pups. Rat mothers who received high-quality care from their own mothers are more likely to be less anxious and to provide abundant licking, grooming, and arched-back nursing to their own pups than the more anxious rats do for theirs. Consequently, their own pups will be more likely to be relaxed or anxious, respectively. Cross-fostering studies indicated that these differences are not the result of the genetic relationship between mothers and their pups because the offspring of anxious mothers are likely to become relaxed rats if they are raised by relaxed foster mothers. However, characteristics of
the current environment, such as food shortages, can affect a relaxed rat so that she is more likely
to provide lower quality care.

There are additional benefits to pups of high-quality rat mothering, including enhanced pro-
duction of synapses in the hippocampus (the structure involved in memory formation) accompa-
nied by enhanced spatial learning (Liu, Diorio, Day, Francis, & Meaney, 2000; Meaney,
2004; Parent et al., 2005). However, adult rats that had experienced low levels of licking and
grooming showed better memory in the stressful context of a fear conditioning task that involved
foot shock (D. L. Champagne et al., 2008) compared with rats who experienced higher quality
care. This may be an illustration of the advantages of high stress reactivity in some contexts.

The biological mechanism by which the early experience of varying levels of licking, groom-
ing, and arched-back nursing is translated into lower or higher stress reactivity is methylation
(the biochemical marking of a gene that reduces or prevents its expression). This process oper-
ates on a gene that contributes to the termination of the stress response because it guides the
production of cortisol receptors on the hippocampus. More receptors for circulating cortisol
means that the hippocampus sends feedback to the hypothalamus to stop producing stress hor-
mones. If the gene is marked, fewer cortisol receptors are produced, negative feedback is not as
efficient, and the stress response is prolonged (e.g., Meaney, 2010).

The extent to which gene methylation mediates the effects of good- and poor-quality caregiv-
ing in the early development of humans is unknown. One recent study, however, indicated that
child maltreatment may result in gene methylation. McGowan et al. (2009) compared hippocam-
pal autopsy tissue from 36 adults who either committed suicide and had a history of severe child-
hood abuse, committed suicide and had no history of childhood abuse but were matched for
psychiatric diagnoses with the abuse group, or died from causes other than suicide (control
group). The suicide victims who had been abused were found to have fewer glucocorticoid
receptors in their hippocampal tissue than either the control or suicide nonabuse groups, which
did not differ from each other. These results are consistent with the fact that individuals with
major depression have fewer receptors and increased stress reactivity, and may point to some
developmental origins of anxiety-related disorders. Further information can be found in Parent
et al. (2005), who explored the connections between the stress reactivity research and the study
of the familial transmission of mental illness.

In a related line of research, investigators have found that cortisol can affect the processes of
neurogenesis, synaptic overproduction and pruning, and myelination in the developing brain.
Such research involves the comparison of groups of children with or without the experience
of various types of maltreatment, studies of adults who were maltreated as children, and experi-
mental studies with animals. The most convincing evidence exists for possible effects of mal-
treatment stress on the developing corpus callosum. High levels of cortisol can interfere with
the myelination of corpus callosum axons by suppressing the division of the glial (support) cells
that produce the myelin. This results in axons that are less efficient in conducting impulses
across the brain hemispheres. Reduced corpus callosum area has been found in several regions
of the corpus callosum for children who suffered neglect or sexual abuse compared with children
who were admitted for psychiatric care but had not been abused or neglected and control group
children (e.g., Teicher et al., 2004). (See Twardosz & Lutzker, 2010, for further information on
maltreatment and brain development. See Tarullo and Gunnar, 2006, for a review of research on
the development of the hypothalamic–pituitary–adrenal axis in early childhood and the function
of secure attachments in buffering an infant from the effects of stressful experiences).
The experience of stress not only influences brain development; it impacts the experience-dependent processes involved in memory as well. The previous section on learning and memory across the lifespan highlighted the more positive aspects of this plasticity, including the beneficial effects on the brain of complex environments and the learning of specific skills. These activities are associated with the production of additional synapses and even new neurons in specific parts of the adult brain such as the hippocampus. Experience-dependent plasticity, however, has what Sapolsky (2003) called “a dark side” (p. 1735). Exposure to sustained stress can lead to the death of neurons, loss of connections, and inhibition of neurogenesis. The hippocampus is a prime target for these effects because of its abundant cortisol receptors. These biological events lead to the disruption of declarative memory, which depends on the functioning of the hippocampus. In contrast, the mild, short-term stress of stimulation and challenge can enhance declarative memory.

Another function of prolonged stress is to enhance the types of memory that do not depend on the hippocampus, including the implicit memory involved in fear conditioning, which is mediated by the amygdala. Stress enhances the connections in this area at the same time that it is causing damage to the hippocampus. This research has major implications for adults who have undergone extreme stress, such as war veterans and adults who suffered abuse in childhood (e.g., Bremner, 2005).

In summary, stress is a form of experience that affects the developing and mature brains through the action of cortisol. Experiencing the stress of childhood maltreatment and perhaps some more typical variations in parenting may affect the development of specific brain areas as well as set the individual along a developmental path of high stress reactivity. The experience of intense or chronic stress may also affect aspects of memory through the action of cortisol on the hippocampus and amygdala.

NEUROSCIENCE IN EARLY DEVELOPMENT AND EDUCATION

The previous section provided a brief review of three aspects of brain plasticity involved in typical human development, illustrated with research on perceptual, motor, language, and socioemotional development as well as reading, child maltreatment, institutional deprivation, and learning during adulthood. In this section research on brain plasticity is related specifically to issues in early development and education. Two separate sets of literature are reviewed. The first emerged in response to the media-inspired public interest in neuroscience during the 1990s that resulted in advice for parents and teachers on promoting early brain development. Current research and scholarship that applies neuroscience perspectives and methods to topics in early education, including self-regulation, early intervention, music training, and the effects of poverty, is then described.

Neuroscience and Early Development—Setting the Record Straight

During the 1990s, “The Decade of the Brain,” a variety of events led to high public enthusiasm about brain plasticity and the possibility that certain types of experiences during early childhood could ensure favorable outcomes in later life, and thus ameliorate social ills. These events included media coverage of neuroscience research; concern about the quality of child care
and children’s school readiness; White House conferences on early childhood; and public information campaigns about the importance of the first 3 years of life, such as the “I Am Your Child” campaign (e.g., Shore, 1997; R. A. Thompson & Nelson, 2001). The most prominent journalist involved in this effort was probably Ronald Kotulak of the Chicago Tribune, who won a Pulitzer Prize for his interpretive coverage of research on early brain development. Kotulak was motivated by the possibility that answers could be found in neuroscience for the increasing crime and violence of inner city youth. After spending 2 years reading scientific articles and interviewing 300 researchers, he concluded that society needed to focus on improving experiences during the first 3 years of life in order to prevent that outcome (Kotulak, 1996). His writing conveys the excitement about neuroscience that was characteristic of this period.

The positive and negative consequences of these events for early childhood programs, and public understanding of the relevance of neuroscience research for guiding the early care and education of children, have been discussed in depth by R. A. Thompson and Nelson (2001), Bailey (2002), and Zigler, Finn-Stevenson, and Hall (2002). Briefly, these consequences included greater public appreciation for the role of experience in brain development that helped modify beliefs in a fixed genetic program, the beginning of preschool initiatives in several states, and the formation of the National Research Council Committee on Integrating the Science of Early Childhood Development. This committee published From Neurons to Neighborhoods (National Research Council and Institute of Medicine, 2000), a book that reflected the efforts of this multidisciplinary group to understand the role of experience on aspects of development ranging from neural circuitry to social relationships.

However, there were also some negative outcomes, such as persistent oversimplifications and misunderstandings about brain development that influenced recommendations for parents and teachers. Of particular concern was the intense focus on the first 3 years of life as the critical period during which the preponderance of significant brain development occurred, and the responsibility of parents and teachers to provide experiences that would stimulate the formation of connections in the child’s brain during “windows of opportunity” (e.g., Swierk & Moore, 2000). This use-it-or-lose-it viewpoint seemed to portray adults as being involved in a race against time in providing stimulation to infants and young children so that synapses were not lost. Such an image appeared to play into the hands of manufacturers who could profit from the sale of stimulating educational toys and materials (e.g., Quart, 2006). Implications such as these could not be fully justified by the results of the neuroscience research available at that time.

Prominent child development, neuroscience, and early education scholars collaborated to address these misunderstandings and to present a more accurate view of current knowledge on the effects of early experience. These efforts resulted in a rich literature that described the contributions of specific types of experiences to perceptual, language, cognitive, and socioemotional development and delineated what neuroscience research could and could not say about early development, including what was known about critical and sensitive periods and how this knowledge might apply to early intervention (e.g., Bailey, Bruer, Symons, & Lichtman, 2001; Fox, Leavitt, & Warhol, 1999; Jones & Zigler, 2002). In addition, they highlighted the dangers of translating basic neuroscience research directly into recommendations for parents and teachers.

Several important themes pervaded this literature. The first theme involved the need to recognize that the brain can be modified by experience throughout life and that highly significant brain development also occurs during childhood and adolescence. Thus, an overemphasis on
the first 3 years could divert attention and resources from other parts of the life cycle, such as the prenatal period, when adverse events can be very damaging for early brain development, with lifelong consequences (R. A. Thompson & Nelson, 2001).

The second theme related to the concept of sensitive periods in early development. There was extensive discussion of the differences between critical and sensitive periods (Bailey, 2002); the difficulty of demonstrating their existence for many aspects of human development, such as musical expertise (e.g., Bruer, 2001); and the fact that there is not just one such period for the entire brain. In addition, the importance of ensuring that children do not experience deprivation and maltreatment and that their sense organs are functioning normally was emphasized, as was the fact that pruning is essential for typical brain development and should not be viewed as a process that can or should be prevented (Bruer & Greenough, 2001). R. A. Thompson and Nelson (2001) advocated for the availability of consistently high-quality environments and care as a means of ensuring that experiences needed during sensitive periods are present for each child.

The third theme was a response to the fact that most public interest in early brain development was focused on stimulation that occurred during personal interaction between caregivers and young children, whereas powerful variables related to poverty and low-income status, such as poor nutrition and stress, were not given much attention (e.g., DiPietro, 2000). Similarly, it was emphasized that skepticism was required when considering the effects of short-term stimulation on brain functioning. The classic example of the lack of such skepticism was the overgeneralization to very young children of several laboratory studies with adults in which listening to music by Mozart produced short-term effects in spatial-temporal reasoning (e.g., Rauscher, Shaw, & Ky, 1993). Ultimately, several states spent large amounts of money to put classical music CDs in the homes of every newborn with the intent of affecting cognitive development (R. A. Thompson & Nelson, 2001). The current marketing of various forms of media stimulation for infants and young children (e.g., DeLoache et al., 2010) and untested brain-based learning programs to school systems (e.g., Goswami, 2006) can be seen as a continuation of this phenomenon.

Several scholars expressed strong opinions about whether neuroscience research was even relevant to early education. Hannon (2003) stated that there were few implications of the findings from developmental neuroscience for education or intervention from birth to age 8 because they did not challenge current practice. For example, the deleterious effects of stimulus deprivation on child development were already known from research in other fields, as were the effects of failure to remove cataracts in early childhood on later vision. He did concede that future neuroscience research will probably result in knowledge that does challenge what is currently known about best practices.

Others feared that programs such as Head Start would lose their credibility when they did not produce the effects on intelligence and academic achievement that the public had been led to believe would occur, or that the public would conclude that such intervention was futile after the age of 3. Jones and Zigler (2002) were particularly critical of the fact that interest in long-term and intensive programs for children in poverty was being replaced by public support for quick fixes, such as the purported results of listening to classical music. After reviewing research on the effects of experience on brain development, they concluded that it was simply too early for such research to inform public policy given the difficulty of generalizing from animal models to human circumstances. They also criticized the narrow focus on cognitive development and the comparative lack of attention to socioemotional development and motivation.
Bailey (2002) rejected the idea that information about critical and sensitive periods should be used to justify the importance of early education; rather, early education should be justified by the fact that learning begins at birth. Learning opportunities should be presented in a way that considers a child’s readiness to learn a particular skill or concept and the moments when teaching is most likely to have an effect. This is the timing that is important, not the timing implied by critical or sensitive periods. Bailey appeared to be focusing on the response of the brain to individually relevant experience rather than on species-wide experience-expectant plasticity. Although he argued that the early childhood years are important because they provide the foundation for future learning, this is a different argument than stating that they comprise a critical period.

In contrast, Lombroso and Pruett (2004), in a chapter relating brain development to the politics of Head Start, stated that there do appear to be some critical periods in human development beyond which later experience cannot compensate for earlier deprivation and that the brain does respond to some types of experience with more ease during early childhood than it will later. Public policy should be based on what is necessary for development during these periods.

Knudsen, Heckman, Cameron, and Shonkoff (2006) combined the perspectives of neuroscience, economics, and developmental/behavioral science to argue that investing in the early environments of disadvantaged children was the most efficient strategy for strengthening the future workforce of the United States, with a greater return on investment than providing remediation in adulthood. In their argument they drew upon neuroscience research on the effects of experience in sculpting brain regions related to sensory and language development as well as stress reactivity, an aspect of temperament. Most of this research involved animal models. They discussed this information in conjunction with evidence about the effects of early compensatory education such as the Perry Preschool Program. The importance of the availability of appropriate experiences during critical and sensitive periods was emphasized. However, in addition to the fact that cellular and molecular processes function to take advantage of certain types of experiences at specific times, which is one facet of the sensitive period concept, they described another facet. That is, during the early childhood years, learning does not need to compete as much with the prior learning represented in neural circuits as it will later.

The literature described above reveals disagreement about the ramifications and usefulness of neuroscience research for the early development and education field, and some of it can leave the impression that neuroscience was being rejected as a source of information. However, the reactions of these scholars stemmed from what was perceived as the overgeneralization and misuse of the research that existed at that time. Lombroso and Pruett (2004) stated that neuroscience is not irrelevant to the early childhood field, it is just incomplete. This statement is probably the most reasonable way to conclude this section and move on to more current literature.

Current Neuroscience Research in Early Education

The integration of neuroscience perspectives and methods into the early education literature appears to be occurring at a slow pace. Articles on topics such as the efficacy of early intervention, the transition to kindergarten, early literacy practices, parent education and involvement, socioemotional competence, comparisons of curricula, and so forth that appear in journals such as Early Childhood Research Quarterly, Early Education & Development,
Research in Childhood Education, and the Journal of Applied Developmental Psychology rarely mention neuroscience findings as part of the rationale for conducting studies or include neuroimaging methods. Books of readings on early education topics may include a chapter on brain development, but such information is usually isolated and not integrated into the rest of the content (e.g., Fusaro & Nelson, 2009). This state of affairs probably reflects the difficulty involved in acquiring expertise in neuroscience after graduate school, the time it takes to revise graduate curricula to include neuroscience material, particularly when resources are scarce; the few professional opportunities available to interact with neuroscientists; and perhaps the opinion that neuroscience methods would not add to the quality of the research.

Recent literature pertaining to early education that does incorporate neuroscience approaches does not appear to continue or even reference the debates that were the focus of so much attention until the middle of the last decade. Rather, scholars are now elucidating the contributions of neuroscience to understanding early development, investigating the effects of educational experiences on behavior and on the structure or function of specific brain regions, and conceptualizing ways in which neuroscience can contribute to analyzing and intervening with societal problems. These interdisciplinary approaches involve the application of knowledge about the brain’s plasticity and the use of neuroimaging methods in conjunction with behavioral measures. Although this work acknowledges the existence of sensitive periods, most of it concentrates on learning.

One example is the research being conducted at the Institute for Learning and Brain Sciences at the University of Washington, which involves the disciplines of psychology, machine learning, neuroscience, and education. The purpose of this institute is to characterize the learning that occurs very early in life in language and social understanding by drawing on the insights and methods of the participating disciplines. Eventually it should be possible to apply the principles by which this learning occurs to improve education. An ongoing project is the design of a social robot that may be able to help toddlers learn a foreign language (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009).

Several examples of applied research and ideas for research programs that involve neuroscience perspectives and methods are discussed below. This research is quite new, and some of the studies appear to stand alone rather than represent a body of work. Thus, it is important to view them as exploratory and awaiting replication.

Adele Diamond and her colleagues focus specifically on executive functioning and the role of the prefrontal cortex as it relates to cognitive development, considered within the context of how the functioning of that brain area can be affected by social, emotional, and physical experiences. For example, Diamond and Amso (2008) described the role of neuropharmacology in explaining why children with phenylketonuria were being diagnosed with cognitive deficits related to prefrontal cortex functioning despite following the prescribed dietary guidelines. Animal models of phenylketonuria and a longitudinal study of children revealed that the dietary guidelines were not keeping the level of phenylalanine low enough to allow another amino acid, tyrosine, to cross the blood–brain barrier in sufficient quantities for unimpaired functioning of the prefrontal cortex. This knowledge led to a change in these guidelines. Diamond (2010) has also related the sensitivity of the prefrontal cortex to emotions, stress, sleep, and exercise to issues in early education, such as the heavy focus on academics with minimal attention to the social, emotional, and physical experiences that support academic functioning. (See Diamond, 2010, for an extensive list of definitions and references related to research on executive function and self-regulation.)
Given that the prefrontal cortex has a protracted period of development that can be influenced by experience, and that some children enter school hampered by a lack of skills connected to prefrontal cortex functioning (e.g., Blair & Diamond, 2008), it is logical to try to intervene during the preschool years. Neuroscientists and early education scholars collaborated in a comparison of the Tools of the Mind curriculum with a balanced literacy curriculum that covered the same academic content but, unlike Tools of the Mind, did not include an executive function component that addressed inhibitory control, working memory, and cognitive flexibility (Diamond, Barnett, Thomas, & Munro, 2007). Low-income children and their teachers were randomly assigned to these curricula and received equivalent support and teacher training. Executive function was promoted by 40 activities, including the encouragement of self-regulatory private speech and teacher coaching in dramatic play. Children who participated in the Tools curriculum performed better than those assigned to balanced literacy on tasks that required inhibitory control, whereas both groups performed equally on a task that did not require such control. Computer-based interventions for preschool children that have targeted executive attention have also found improvement on cognitive tasks; a brief review of these can be found in Rueda, Checa, and Rothbart (2010).

A potential application of knowledge about brain plasticity and neuroimaging is in the evaluation of early intervention programs. Raizada and Kishiyama (2010) suggested that EEG measures might be useful in detecting neural changes in children that occur in response to early intervention. Changes in the functioning of neural networks may not be accompanied by differences between experimental and control groups on behavioral measures at a specific time. However, they may be correlated with longer term outcomes. Thus, the use of neuroimaging as one component of the evaluation process might help explain the fadeout and reemergence of the effects of early intervention as occurred with the Perry Preschool Program. The authors called on neuroscientists to become involved in current evaluations of interventions such as Head Start and the Harlem Children’s Zone, a program that operates to promote cognitive development from birth through middle school.

Another area of interest to early educators is the function of children’s involvement with music. Neuroimaging has been incorporated into investigations with both adults and children on the development of musical skill and the possibility that the benefits of music training transfer to other aspects of cognitive development. Although there is much public and media interest in the possibility that involvement in the arts can be a vehicle for improving academic performance, such interest is based primarily on correlational research linking participation in the arts with higher test scores (Hatva, 2010). The two studies described below are the first to investigate the effects of music training on brain development in early childhood.

Hyde et al. (2009) measured behavioral responses and structural brain changes after 15 months of weekly half-hour keyboard lessons that began at 6 years of age for an experimental group; a control group participated for an equivalent time in school music activities. They used deformation-based morphometry, an MRI technique, to search throughout the brain for size and shape changes. The keyboard training group had greater relative size in motor areas, the corpus callosum, and the auditory region. Moreover, these children performed better than the control group on a melody and rhythm test battery and a four-finger motor sequencing test. Differences were not seen in visual-spatial or verbal measures. Changes associated with typical brain development were found in the control group. The authors stated that this is the first longitudinal investigation to show differences in performance and brain structure in the developing brain.
as a result of specific music training. The results pertain to the question of whether differences seen in the brains of adult musicians compared with controls could be the result of practice rather than or in addition to putative genetic differences. The study also sheds light on the issue of whether learning to play an instrument has cognitive effects beyond those specifically related to music.

Another recent study (Moreno et al., 2009), in which 8-year-old children received training in either music or painting, showed that music training resulted in improvements on both a reading task and a discrimination test of small pitch variations in speech. Moreover, the amplitude of some of the EEG components elicited by the music and speech tasks was greater for the music training group. This difference was thought to reflect greater efficiency of the neural networks involved in these tasks; that is, more neurons may have been active or more highly synchronized. Considered together, the results of these two studies indicate that music experiences that result in learning can cause changes in the structure of the developing brain, and these can be distinguished from those occurring as a result of typical development.

Kraus and Chandrasekaran (2010) reviewed the literature that relates intensive music training to the auditory skills of musicians and argued that there were also differences in speech and emotional processing, perhaps because such music training improves a person’s ability to extract relevant information from incoming sound. Because brain plasticity related to music training seems to depend on the early onset of music instruction and active engagement through practice, they advocated that school systems take responsibility for such training so that the benefits are not confined to the few children with resources for intensive instruction. An argument for such an investment is possible improvement in academic performance; improved auditory abilities that might result from such programs may help children listen and extract relevant information in noisy classroom environments. The authors concluded that school music programs should be improved and evaluated for effects on academic performance that may occur as a result of brain plasticity in auditory areas.

A final topic to be considered is the relationship of neuroscience to research on the effects of poverty on children and families, which have been associated in numerous studies with cognitive and socioemotional deficits and difficulties across the lifespan as well as differences in brain structure and function (e.g., Lipina & Colombo, 2009). For many children intervention is necessary because circumstances in the environment promote deficits in areas such as language, executive functioning, and self-regulation.

There is evidence that children’s language environments and some aspects of their language-related skills differ by socioeconomic status (SES); (e.g., Hart & Risley, 1995; Hoff, 2003). However, the biological mechanisms involved in such differences are generally unknown. One study provided preliminary evidence that the left hemisphere, on average, may be less specialized for language in children of lower SES families than in children of middle-income families. Raizada, Richards, Meltzoff, and Kuhl (2008) obtained standardized language measures and functional MRI scans during a rhyme task from fourteen 5-year-old children from a range of socioeconomic levels before the children entered kindergarten. They found a correlation between SES and rhyme task left minus right activation in the inferior frontal gyrus, which includes Broca’s area, indicating that greater activity in the left hemisphere during the rhyme task increased with SES. This correlation was greater than that obtained between SES and some of the language measures. Neuroimaging thus provided information beyond what was available by correlating SES and test performance. The authors are now investigating the richness of children’s language environments as a possible cause of these SES differences.
Noble, Norman, and Farah (2005) administered cognitive tasks to 60 African American kindergarten children, half of low-income and half of middle-income status. Tasks were selected based on neuroimaging and lesion studies so that they taxed five neurocognitive systems that are involved in academic performance. The results indicated that there were no significant differences between the income groups for the visual, spatial, and memory systems. However, SES differences were especially great in the areas of language and executive function, with indications that some of the difference in executive function was associated with individual differences in language ability.

In a systematic replication, Farah et al. (2006) administered cognitive tasks to 60 African American children between the ages of 10 and 13 years, half of low-income and half of middle-income status; the children in the two groups were equivalent on health measures. Tasks were designed to provide information about abilities connected with seven specific neurocognitive systems. The results indicated that for the visual cognition, spatial cognition, and reward processing systems there were no significant differences between the groups. However, there were large differences in the areas of language and memory, including working memory, with a smaller difference in cognitive control. An explicit goal of this research group is to design more efficient interventions for low-income preschool children by targeting the neurocognitive systems that seem to be differentially impacted by variables that make up SES. For this purpose, it is better to use measures that are more specific than IQ or achievement tests. Thus, their goals are similar to those of Diamond et al. (2007).

Hackman, Farah, and Meaney (2010) stated that neuroscience can make an important contribution to society and human welfare by synthesizing the information that has resulted from decades of research on socioeconomic differences in mental health, emotional functioning, and cognitive functioning in children and the environmental conditions related to those differences. The three studies described above are a few of the latest examples of those that have focused on cognition. The next step would be to identify the underlying cognitive and affective brain systems that are influenced by SES, as illustrated by those studies, and then to identify the biological mechanisms by which environmental circumstances affect those brain systems. Hackman et al. (2010) discussed three such mechanisms, that is, influences on prenatal development, parental care, and cognitive stimulation in the home. For example, SES differences in parental care have been identified in a vast social science literature that associates family stress with harsh childrearing methods, conflict, insecure attachment, and decreased parental involvement as well as in studies indicating that high-quality parenting can promote resilience for children in poverty. This literature was then compared with what is known about high- and low-quality maternal care in rats and nonhuman primates; the results of introducing stress, such as food shortages, into their environments; and the consequences for offspring in terms of stress reactivity and learning. However, the authors were careful to stipulate that the link between low SES and differences in gene methylation in humans has not yet been investigated. They also made a case for the relevance of the enriched (complex) environments rodent research (e.g., Rosenzweig, 2007) as a model for conceptualizing the effects of differences in home cognitive stimulation.

Despite the fact that neuroscientists are just beginning to become involved with issues of SES and poverty, Hackman et al. (2010) outlined a number of policy implications. Given what is known already from social science and neuroscience research about the impact of stress on parenting and cognitive stimulation in the home, they concluded that priority should be given to policies and programs that reduce parental stress and focus particularly on women’s well-being.
These, of course, are familiar objectives, and it remains to be seen whether the addition of neuroscience approaches to the investigation of poverty will make it more likely that they can be accomplished.

**SUMMARY AND DISCUSSION**

This paper has provided a brief review of three aspects of brain plasticity and the relationship of this knowledge to issues and research in early development and education. It is encouraging that current research appears to address the issues that scholars were most concerned about in their commentaries about the misinterpretation and overgeneralization of neuroscience information in past decades. That is, current research addresses socioemotional as well as cognitive development. Attention is being paid to well-designed and intensive educational interventions rather than quick fixes, and research is not limited to interpersonal stimulation but to larger societal variables such as those related to the experience of poverty. Recent research is interdisciplinary and involves human participants.

The literature reviewed in this paper is only a sample of what is available on the effect of experience on the brain, and that topic is only one of many in the developmental, cognitive, and social neurosciences that is relevant to early development and education. For example, studies describe the links between specific brain activity and skills such as mathematics (e.g., Nieder, 2005), and there is a well-developed area of research on dyslexia that uses neuroimaging to measure the impact of interventions on brain areas involved in reading (e.g., Gabrieli, 2009; Temple et al., 2003). The links between moral development and neuroscience (Killen & Smetana, 2008) and a neuroimaging approach to the possible effects of cultural experiences on the brain (e.g., Han & Northoff, 2008) may also be of interest to some readers.

Caution must be exercised when drawing conclusions about human experience from research using animal models; several authors have discussed this issue specifically. Knudsen et al. (2006) explained that animal research is relevant not because of its direct applicability to humans but because of its role in identifying neurobiological processes that can operate across species. Thus, the results of the complex environments literature can provide a model of the effect of stimulation on the brain but cannot be equated with more and less stimulating home environments. Teicher, Tomoda, and Anderson (2006) stressed the importance of animal models for investigating the effects of abuse and neglect on brain development because retrospective correlational studies with humans cannot eliminate competing explanations for the proposed impact of stress on the development of brain structures. However, they also emphasized the difficulties of modeling all effects of childhood abuse, especially with rodents, because of differences in the way experiences are encoded in the brain across species. Thus, corroboration from human studies is essential. Hackman et al. (2010) reiterated these points, indicating that it is difficult to capture the social and cultural aspects of poverty in animal studies, correspondence between parental care and cognitive stimulation across species may be low, and animal models for measures of language and executive functioning do not exist. The full range of nonexperimental social science methodology, however, can be used in conjunction with experimental animal models.

Currently, the application of neuroscience perspectives and methods to research in early development and education is proceeding slowly and focuses on children. It does not appear that information about adult brain plasticity in response to learning or stress has been integrated into
research on teacher training, professional development, or parent education. This would be a fruitful area for research because insights about early development and education practices that come from collaboration with neuroscientists, and that lead to the development of interventions for children, will be ineffective unless teachers and parents implement them. Stress experienced from poor working conditions and personal circumstances may make it very difficult for adults to learn and maintain new ways of interacting with and teaching children. It is possible that a consideration of the literature on adult brain plasticity can contribute to more effective professional development practices and environments for adult learning. In turn, neuroscientists who are studying topics pertinent to early development and education are dependent on the deep knowledge base on the implementation of curricula and interventions that exists in the early development and education field.

It is apparent that one of the primary outcomes of the study of brain plasticity is increased appreciation for the importance of the environment, beginning with prenatal conditions and continuing with the wide range of settings individuals encounter throughout their lives. It is critical that early development and education professionals understand what neuroscience perspectives and methods can bring to the study and improvement of these environments in conjunction with the knowledge and methodology of the social sciences and education.

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