

Play and Brain Development as Complementary Nonlinear

Dynamic (Chaotic/Complex) Systems

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Although non-linear dynamic systems (chaos/complexity) theory was initially embraced by theorists and researchers seeking to explain phenomena in scientific fields such as epidemiology, meteorology, physics, chemistry, astronomy, and evolutionary biology, in which phenomena often appear to be chaotic, but are really self-organizing (Waldrop, 1992), this theoretical perspective has now gained in importance with social scientists who study complex phenomena in human development and, more recently, with educators and psychologists who study learning processes (Van Geert, 2000). Developmental psychology, in particular, has often attempted to explain phenomena using linear theories (e.g., empiricist, rationalist), which attempt to discover universal variables that predict developmental trajectories (Case, 1999). However, human developmental phenomena cannot really be understood using theories based on linear systems thinking. Living systems typically have many interrelated parts, and the output, or behavior, of various subsystems, which may each show complex non-linear dynamics, also interact with other dynamical processes that are synergistically related, resulting in complex interactions (see Guastello, 1997, p.2). Chaos theory gives insight into how what appear to be simple systems engender complicated and often unpredictable behavior, while complexity theory focuses on how what appear to be complex systems may lead to well organized and often predictable behavior (Bloom, 2000). Thus, a major question for developmental psychology is this: How do simple inputs engender complicated developmental effects and complex systemic interactions result in well organized developmental outcomes for children over time?

One of the pioneers in the use of nonlinear dynamic systems theory to study human developmental change was Esther Thelen, who focused her work on the complex

interactions that characterized physical-motor and cognitive development of infants. She (and colleague Linda Smith) have stated that no single-causal model is sufficient to account for the “modular, heterochronic, context-dependent, and multidimensional nature” of human developmental processes (Thelen & Smith, 1994, p. 121). Similarly, Gilbert Gottlieb (2001), who created a model to explain ontogenetic change, asserted that such change arises not from either genetic or environment instructions but from an integrated system of dynamic interactions involving specific stimuli, the total environmental context, the status of anatomical structures and functions, the biochemical/biophysical conditions, and the developmental history of the individual. That is, ontogenetic change involves non-linear dynamic interactions.

The domain of interest in this paper is the system of dynamic interactions between the phenomena of *play* development and *brain* development during the first years of life. Because both play development and brain development involve integrated systemic change, the use of a non-linear dynamic systems perspective to analyze these phenomena may give insight into the complimentary inter-relationships between children’s early play and early brain development. It explores this question: Do changes in the developing brain serve as catalysts for changes in the organization and structure of children’s play and do the self-organizing changes observed in children’s play have a dynamic impact on developmental changes in the brain? While there is presently little direct research evidence of this inter-relationship, a comparison of the non-linear systems of play and brain development do suggest that such a non-linear dynamic relationship exists.

## **PLAY AS A NON-LINEAR DYNAMIC SYSTEM**

In any discussion about play, it is important to explain which elements of its ambiguous character are relevant to the discipline of human development for “each discipline has come to a different conclusion about the nature of play” (Gordon, 2009). As Goncu and Gaskins (2007) have noted, “Historically, play has proven to be a difficult topic to define and study” (p. 3). Rather, they assert that it is a “complexly determined behavior” that has posed a problem for researchers as they attempt to “integrate its multiple perspectives” (p. 4). Play is a pervasive behavior that humans exhibit throughout life, although adults often call their playful activities by other names (e.g., inventions, hobbies, creative art, theatricals). Nevertheless, the question of why the human species is so characterized by playfulness has been of interest to theorists and researchers for many years. In a seminal book, the sociologist Huizinga characterized the human species with the term, *Homo Ludens* (man the player) because, “civilization arises and unfolds in and as play” (Foreword, 1950). According to Ellis (1988), play has been important throughout human existence because it serves as a primary adaptive mechanism that has allowed humans not only to survive, but to flourish on this planet. Humans have always lived in changing, unpredictable (i.e, chaotic) environments, and over many centuries, their playful capacities may have been crucial in enabling them to survive and adapt to the chaotic and complex natural world.

Given the importance of play in human experience, the course of early play development has been of great interest to many researchers who study child development dynamics. In numerous studies of children’s play, researchers have identified qualities considered essential for an activity to be considered play in childhood, and these include

enjoyment (i.e., “fun”), internal motivation, ability to bend reality, and opportunity to engage in “safe” risk taking (see Fromberg & Bergen, 2006). Definitions of play in early childhood usually include discussions of distinctions between work and play, noting that play differs from work in that it is self-chosen rather than prescribed and does not have to result in a product or expected action (Wiltz & Fein, 2006). Characteristics that are essential for an activity to be considered play include a measure of personal inner control, ability to bend or invent reality, and a strong internally based motivation for playing (Neumann, 1971). That is, an activity can be experienced as play when these conditions are present but when they are missing (for example, in an activity labeled “play” in which all must participate is prescribed by a teacher), the playful element may disappear (Bergen, 2006). Young children can differentiate easily between play and work using these dimensions (Wiltz & Fein, 2006).

Barnett (1998) has identified five components of playfulness in young children, including cognitive spontaneity, physical spontaneity, social spontaneity, manifest joy, and sense of humor. The quality of playfulness also has been studied in relation to qualities of childhood creativity and innovation (Holmes & Geiger, 2002). Playfulness provides a predisposition toward certain types of creative acts, and enables players to organize their chaotic, complex experiences by imposing meaning and order on other aspects of their environment. These attempts are successful some times and unsuccessful at others, which is not surprising since most natural and human phenomena have non-linear dynamic qualities, and play exhibits many characteristics of such systems. Many of the qualities of non-linear dynamic systems are especially evident in the play of young children, which serves as the focus of this discussion.

For example, children's play is a *self organizing* system that may appear chaotic but in which complex patterns of behavior move toward order; this self-organizing process can be expected to occur but it cannot be predicted precisely. The capacity for self-organization uses multiple, mutual, and continuous interaction of all levels of the developing system. Theorists such as Case (1991) and Fischer (1980), who have studied children's cognitive change, have pointed out that periods of cognitive disorganization gradually become organized as children "construct" their knowledge, and Piaget (1945) has noted that play often serves as a medium through which these periods of disorganization and organization lead to development of complex cognitive schema. Play's self-organizing quality often involves spontaneously emerging patterns that create *attractor* states from initially chaotic behaviors. Play may appear to be disordered while it is evolving toward a stable "attracted" state, affected by strong elements that may organize and reorganize such patterns within varied environments. Vygotsky (1967) has noted that the self-organizing quality of play is especially apparent in the scripts enacted in pretense. However, self-organization is also evident in construction play with objects.

For example, a child may begin block play by arranging blocks in a random pattern, but as the play continues, the blocks become organized into a "garage," which then needs a "road" built to the garage, which then needs cars to drive to the garage, but when another child brings a fire truck to the play, the garage then becomes a fire house and needs a tower built and sirens added, and then....(play continues to be organized and reorganized by the players). Observers of children's play often note *phase shifts*, which appear to be abrupt changes in play patterns, often leading to higher levels of play, but really are the result of the confluence of many of these complex factors.

Thus, the play state also shows *disequilibrium*, because it is always capable of change, and its attractor states may be long or short. For example, the next phase shift of block play might be building a stable “city” of buildings that form a miniature world. Such “worldplay” is often engaged in over a long time and may include the writing of scripts, embellishing the world’s environment, and having miniature people engage in extended imaginative interactions (Root-Bernstein & Root-Bernstein, 2006). Conversely, children may build high block towers repeatedly only for the purpose of knocking them down and thus creating chaos. Play often has such *recursive* elements, with elaborations occurring both across contemporary situations and within each developmental age in *self-similar* patterns. These systems of repeated patterns (i.e., action going “back on itself”) is often characterized as “practice play” (Piaget, 1945), and its recursive nature may result in unanticipated outcomes. As an aid to moving to a higher level of development, children repeat these patterns in their play with slight variations, and the patterns become more elaborated. The *fractal* quality is clearly evident in block play, of course, since the medium is fractal; however, it is also evident in pretense, with small scale objects and actions showing self-similar patterns nested within larger size objects and actions.

Play also exemplifies the characteristic of *sensitive dependence on initial conditions* because small inputs into children’s play situations may cause a range of disparate results. For example, the types of materials, the time available for play, the settings in which it can occur, and the materials available all influence its initial character. As these conditions change, the play may also change. A parent may make a comment about the play or add an item to the play equipment or a peer may join the play and such conditions may entirely change the direction of the play. At the present time,

initial conditions also include a great deal of media availability, and play researchers have noted how children often portray media characters in their play. Computer-generated play materials that promote virtual play also are having an impact on the themes of play and how they are enacted. Play always demonstrates *openness* because the players continue to receive energy from sources outside the “playframe” (Bateson, 1956). Indeed, players can draw upon all of their experiences and incorporate them in some form during play.

There are, of course, *control parameters*, which include differences in play patterns due to the age and skill of players, limitations on experience, and types of settings available for play. Control parameters set boundaries that affect patterns of interaction and the timing of phase shifts. Young children will not demonstrate play that is as physically demanding or cognitively detailed as that of older children, children from different socioeconomic backgrounds may have different play scripts in family pretend, and large scale fort building or outdoor games with rules will not occur if neighborhood play spaces are not available. Play shows *interdependence* because all levels of play are interrelated and children often move back and forth between types of play and levels of difficulty, while building on the overall experience. Because of its great flexibility, that is, its *soft assembly*, play has both stable and dynamic alternating periods and thus is not “hard-wired.” Because the capacity for change is always present, play epitomizes *plasticity*; plasticity within constraints leads to patterns, and patterns and order emerge from interactions of the components of the complex system; thus, play is truly a non-linear dynamic system.



## THE BRAIN AS A NON-LINEAR DYNAMIC SYSTEM

Brain research has made exceptional progress in recent years and a greater understanding of the brain's "pluripotentiality" has resulted in clear evidence that brain development follows a non-linear systems model (Bates, 2005). Researchers have identified many characteristics of the brain that are congruent with a non-linear model of development. Even in the prenatal period, the brain shows *self-organization*, with patterns that spontaneously emerge from chaotic appearances. For example, during this period, the cortex is being built by neurons climbing "ladders" of glial cells to create the higher brain centers (Bergen & Coscia, 2001). There are periods of both *attractor* states and of *disequilibrium*. As each area of the brain develops, there is extensive synaptic growth, but then there is a period of pruning that results in greater stability of that area and more efficient processing. Thus, over the childhood years various areas of the brain exhibit evidence of movement from disorder to order. Although stable individual differences in brains can be observed by late childhood, researchers have found that the brain is always capable of some change and may even produce new neurons at later life ages. *Recursion* is also present in the brain because brain development is repetitive, with elaborations both across brain areas and across developmental ages in *self-similar* patterns. The *fractal* quality can be seen in the repeating patterns of development as each area of the brain becomes activated, and in the nested quality of many brain functions. Behavioral evidence of *phase shifts* in brain development can be seen in many ways. For example, the greater organization of infant emotion and language once myelination begins to connect the limbic system with the frontal lobe is readily observed in the later part of the first year of life (Eliot, 1999).

*Sensitive dependence on initial conditions* is an extremely important characteristic of brain development, as research on harmful teratogenic influences on the prenatal brain and disruption in brain development when children are exposed to conditions of abuse or severe neglect has documented (Perry, 1996; Carlson & Earls, 1997; Elliot, 1999). Small inputs into the brain from genetic, hormonal, or environmental conditions often cause disparate results in brain development. However, the brain also shows *openness*, receiving energy from outside sources as well as having *control parameters* that guide the developmental patterns of various parts of the brain. Some parameters are invariant (sensory locations), some change with age (frontal lobe development), and some change with experiences (synaptic connections) (Thompson & Nelson, 2001). Although the brain is modular, with certain areas having some primary roles, it is also *interdependent*. All levels of the brain are interrelated and brain activity requires interactions among many components (Bates, 2005).

Neuroscientists are demonstrating how maturation of neural connections within the brain is related to ability to solve problems, use language, and understand emotional meanings, and these abilities when exercised also interact to strengthen certain neural connections (Thompson, et. al., 2000). *Soft assembly* is also a characteristic of the brain; it is flexible, with stable and dynamic qualities alternating rather than being “hard-wired.” Thus, a primary characteristic of the brain is that of *plasticity*, because the capacity for brain system change is always present. According to Bates (2005), the brain’s “neural plasticity” results in “pluripotentiality;” that is, cortical structures can be configured in many ways, depending on types and timing of experiences. The brain can adapt to a variety of different “brain plans” in early childhood. If brain trauma occurs, the young

child's brain can reconnect itself so that necessary functions can be performed, even for abilities such as language, which in the past had been judged "domain specific." Research on the nature of play has shown that it also exemplifies pluripotentiality, continually adapting to environmental conditions and developmental changes (Vandervan, 2006). Perhaps it is possible to define play as a state of *plasticity* of the brain!

## **BRAIN AND PLAY DEVELOPMENT AS COMPLEMENTARY NON-LINEAR PROCESSES**

Although it is difficult to find archeological evidence, the evolution of the human brain and the evolution of playfulness are likely to have occurred in concert. Recent brain research on animals has disclosed that there is a strong relationship between the playfulness of a species and the brain's proportion of body size. Iwaniuk, Nelson, & Pellis (2001) have reported that animal species whose young play more and play for a longer period as they develop have larger brains in proportion to their body size. The brain of the human child, of course, accounts for a great proportion of the child's body size and weight, and brain size and weight remains proportionally high throughout human life, making playfulness a lifelong human quality. During the first 5 or 6 years of life, however, play development and brain development seem to show symbiotic non-linear qualities. That is, brain development and play development both seem to demonstrate complementary features of non-linear dynamic systems, which may have emerged simultaneously during the evolutionary period.

In their observations of young children, early childhood educators have noted what appear to be these complementary non-linear dynamic processes occurring in both early brain development and play development. Although the confirmation of these

complementary relationships awaits further psychological research using brain imagining techniques, it is possible to hypothesize on this complementarity by comparing presently known information about brain development with observed developmental changes in play behaviors and noting parallels that seem to exemplify their complementary non-linear dynamic nature.

For example, although most of the neonate's 100 billion neurons are not linked in networks, during the first year of life these connections begin to be made rapidly through the process of synaptogenesis. From birth to age three, synapses increase greatly, and by the end of first year, the brain looks more similar to the adult brain (all areas actively functioning) than to the newborn brain (Chugani, 1999). These *self-organization* and *soft assembly* qualities of the brain are also observed in infant play. Infants' early play appears to be reflective of the development of various brain areas; that is, as certain areas of the brain become more active, child play reflects those actions and possibly influences which synaptic connections are made stronger. For example, the major sensorimotor areas of the brain develop quickly during the first year and infants' actions may enhance that development as they look and reach for objects, hear and make a range of sounds, and engage in exploratory physical play during that same time period.

*Recursive* play (repeating and elaborating on similar actions) is prominent, especially during the second half of the first year, as myelination of the frontal lobes of the brain begins. Piaget (1945) has termed this "practice play," in which infants exhibit their thought in actions. Social-emotional game play, such as peek-a-boo and other turn-taking games are initiated as the lower brain centers begin to connect with the brain's frontal lobe, and as the brain centers where language and conceptual thought are

primarily located develop, play with language and pretend play begin in earnest (Ratner & Bruner, 1978). Brain researchers have noted that human actions are interrelated to brain network development (Shore, 1997). As experiences change, groups of neurons *self-organize* in patterns of firing in response to these changes (Masterpasqua & Perna, 1997). That is, within *control parameters*, humans appear to “grow their own brains” through their experiences, and since play is a such pervasive experience during early childhood, the *control parameters* governing play development and brain development seem to be dynamically related.

As synaptic connections increase during the toddler age period, brain synapses continue to expand and reach about 1,000 trillion—twice the density of the adult brain. The rapid expansion of synapses in some areas results in “overproduction” of synaptic connections, and those areas that are the first to reach this dense stage are the ones in which pruning (eliminating unused or little used connections) begins (Lichtman, 2001). Pruning makes the brain more efficient and faster in thought but less flexible and active. In comparison to the adult brain; the child’s brain has more “plasticity,” and this flexibility of thought is seen in the expansion of pretend play, which also may reflect the beginnings of “theory of mind” (ability to imagine what others are thinking) and the use of simple scripts (two or three elements). The *phase shift* into extended pretense may be an indication of a new *attractor* state in the brain, when new patterns of play are formed but never repeated exactly. This ability to imagine in pretense remains with humans throughout the rest of their lives.

Social games with peers and adults become more elaborate and involve following one or two “rules,” which are often adapted by the child to improve the odds in their

favor. The development of games with rules may illustrate the brain's *sensitive dependence on initial conditions*, because these games promote *self-organization* as they apply stress to the system. As parents know, following the rules of game play can be very challenging to young children, but the experiences of game play may have a role in children's later ability to follow rules. During these early years, practice play is still highly evident but it usually elaborates into construction play, which involves planning and creating organized systems from chaos; thus, its synergy with brain frontal lobe development may promote a period of well-organized behavior.

During the 3 to 6 age period, the refinement of motor, sensory, and language areas of the brain begins and pruning of some "oversupplied" areas starts. In this age period there is an expansion and elaboration of many types of play. During the same age period, synaptogenesis of the brain's frontal lobe is reaching its greatest density and the P300 wave, which improves processing speed, begins to be evident in the brain (Hale, 1990). This continuing brain *self-organization* is accompanied by the behavioral appearance of sociodramatic play, which involves extended complex social and pretense acts. Theory of mind is clearly exhibited in such play as script narratives become very elaborate, and they often have *recursive* elements as the script progresses over extended time periods. Pretend play that involves much symbolic language use is a major factor in developing *self-regulation* and it may promote synaptic growth of the symbolic areas of the frontal lobe. Games with rules also reach higher levels of precision and elaboration, and children begin to play board games with symbolic elements (e.g., Candyland). There is a *phase shift* at the end of this age period as the synaptic density of the frontal lobe reaches its peak and pruning begins. The complex and often chaotic dynamics linking expansions of

synaptic connections and pruning of the brain and the elaboration and organization of play are highly evident during this period. Although research is needed to confirm the hypothesis of non-linear dynamic interactions between play and brain development, observable evidence suggests pluripotentiality and complementarity in their development.

### **SUGGESTED RESEARCH TO EXPLORE THIS HYPOTHESIS**

Unfortunately, many of the presently available techniques for monitoring brain processes require the participants to be relatively quiet motorically so that motor actions do not cloud the brain activity that is being studied. For example, if activation of neural networks in memory areas is the subject of research, the subject is usually required to sit or lie quietly using only a finger movement to respond to stimuli. Thus, with present techniques, it is difficult to study what brain activity is occurring during children's active play. As future research techniques develop, however, microgenetic analysis of brain/play dynamic interactions may be possible. Other research techniques used to analyze dynamic psychological systems, such as structural modeling, sensitivity analysis, or cybernetics may also be investigated as possible models useful for investigation play/brain dynamics (see Levine & Fitzgerald, 1992). There are two areas of research on play/brain dynamics that are of special interest to early childhood educators.

The first is whether the non-linear dynamic complementarity of brain and play development can be observed and analyzed to map out the process of chaotic transformation that may be occurring. This research would be of interest both to those interested in typical child development and also to those studying problems in development. For example, exploring the dynamic links between autistic children's lack

of pretense development and its potential connections to their atypical brain development would be of great value.

Another area of research interest is related to the presence of new but increasingly pervasive “initial condition” affecting play: the presence of technology-enhanced (augmented) toys (Bergen, 2001, augmented). Much of what is hypothesized about the complementarity of play and brain development is based on observational research reported before the advent of such augmented toys. An interesting issue related to non-linear dynamic change is how this new ‘initial condition’ will interact with play and brain development. If the augmented play environment creates novel play behaviors within the play chaotic system, sensitive dependence on initial conditions, recursion, control parameters, and other non-linear qualities of brain development may result in novel brain self-organization. By examining the effects of augmented play materials through the lens of non-linear dynamic systems theory, researchers may gain insight into how the plasticity of children’s play and brain development is affected by these newer play materials.

### **SUMMARY**

Research on brain development has clearly indicated that the brain has many of the qualities of non-linear dynamic systems exemplified in its growth, especially during infancy and early childhood. Researchers who have studied the development of play, especially during the early childhood years, also have amassed evidence regarding its non-linear dynamic and often chaotic characteristics. Because both of these developmental processes have complimentary characteristics of nonlinear dynamic systems, their self-organizing and plasticity qualities appear to create attractors and phase



shifts in both play and brain development during this age period. Aspects of brain development appear to be fostered in playful activity, and the advancing complexity of the brain seems to be reflected in the characteristic development of play. Thus, it is important to approach research through non-linear dynamic systems theory in order to understand how children's play is complementarily involved in creating the brains that will determine civilization's future.

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