International Journal of Environmental & Science Education
Vol. 7, No. 1, January 2012, 3-18

The influence of neurobiology on lifelong ecological literacy and ecological consciousness

Tom Puk

Received 11 March 2011; Accepted 27 May 2011

Since WW2, degradation of our global natural systems has been on the increase. Much of this degradation has been communicated to the general public via mainstream media and yet human behaviours do not seem to have changed significantly as a result. It is argued in this paper that the manner in which our brains and minds work, in particular in regard to the 'neuroplasticity' of the brain's pathways, may contribute to this lack of changed behaviour. Current research on neuroplasticity and more generally neuroconstructivism is examined. It is then postulated that we can take advantage of what might appear to be a limitation of neurobiology by a/ helping the developing mind create meta-values such as 'having a positive regard towards natural systems' that would then be defended by the adult brain and b/ applying the concept of embodiment during instruction. This paper will provide a growth sequence for lifelong ecological consciousness that incorporates the manifestations of neurobiology as well as current research involving nature-embedded, embodied experience. This growth sequence will provide educators at all levels (i.e. lifelong) with an enriched framework that will assist the learner at various stages of life in becoming a more ecologically discerning global citizen. The implication for educators is that we need to understand how each stage of life (i.e. early childhood to adult) is interdependent on preceding stages and interconnected with all stages as opposed to focussing only on individual stages of cognitive development.

Keywords: neurobiology, neuroconstructivism, nature-embedded embodied experience, stages of cognitive growth to acquire ecological consciousness, lifelong ecological literacy

Introduction

Three constant questions asked about the slow progress towards global ecological integrity are a/ "why aren't more people embracing ecological literacy and ecological consciousness, b/ why aren't individual lifestyle changes occurring more quickly" and c/ "how can education be more effective in creating an ecologically literate and conscious global society"? The answer in part to the first two questions may be that ecological literacy is often not a distinct component of schooling but is usually 'infused' (Knapp, 2000) or 'integrated' (Puk & Behm, 2003) into existing subject matter; or that most adults are not ecologically literate. Other reasons may include the role of media with its penchant to entertain rather than educate, or the slavish regard politicians give to ideology, or the profit motives of business and industry. These are all valid reasons why little progress has been made in regard to ecological consciousness. However, there may be additional

ISSN 1306-3065

http://www.ijese.com/

factors that would help us understand why adults find it challenging to modify their lifestyles in an ecologically consistent manner.

The genesis of this adult phenomenon begins during early childhood. In spite of this complexity, too often education is viewed in an atomistic rather than a wholistic manner i.e. studies may involve only early childhood, or elementary, or secondary or adult education. This paper will take a wholistic, lifelong view of cognitive development in regard to how neurobiology changes from stage to stage throughout life, thus providing educators with an interconnected framework of stages of growth for acquiring ecological conscious based on neurocognitive development. Thus, current research into cognitive neuroscience may shed light on the third question and provide use with some direction in regard to the manner in which teaching and learning can be better shaped to take advantage of how the brain (neural networks) and mind (cognitive processing) operate.

Neuroconstructivism

The essence of this theory involves a reciprocal relationship in which cognitive processes shape neural networks which in turn shape cognitive processes (Goswami, 2008; Mareschal, Johnson, Sirois, Spratling, Thomas & Westermann, 2007; Westermann, Mareschal, Johnson, Sirois, Spratling & Thomas, 2007). "[C]hanges to the brain's 'hardware' in turn change the nature of representations and their processing, which leads to new experiences and further changes to the neural networks" (Westermann, Mareschal, Johnson, Sirois, Spratling & Thomas, 2007, p.75).

Key components of this reciprocal relationship are the concepts of embodiment and grounded cognition (Barsalou, 1999; 2008; Calvo & Gomila, 2008). "Multiple levels of brain and body appear to continuously interact in cognition" (Stephen, Dixon & Isenhower, 2009, p.1811). It is now evident that sensory and motor dynamics cannot be separated from the cognitive processing of the brain as cognitive psychology has done in the past. Modality-specific systems are critical to conceptual and emotional processing (Niedenthal, Barsalou, Winkleman, Krauth-Gruber & Ric, 2005).

> It is now clear that inside the brain as well, the causal factors that explain the patterns seen in any one modality may lie partly in the patterns of other modalities. In fact, recent work suggests that activity in various cortical areas (e.g., visual and motor cortex, or visual and auditory cortex) unfolds in a complex system of mutual causality. (Hutchins, 2010, p.710)

These are not independent, reductionist processes but rather represent an interconnected whole. The body acts as both a filter of experiences coming from one's surroundings, affecting and altering neural development and cognitive processing as well as an instrument with which the mind reaches out and manipulates the external surroundings (one's environment) in order to affect the experiences which affect learning. This in turn affects the development of neural networks (Goswami, 2008; Mareschal, Johnson, Sirois, Spratling, Thomas & Westermann, 2007; Westermann, Mareschal, Johnson, Sirois, Spratling & Thomas, 2007). In this way, the brain and mind attempt to construct their surroundings and in turn one's surroundings influence and construct the development of neural networks and cognitive processes. Experience is the key. "With every new experience, your brain slightly rewires its physical structure" (Blakemore & Frith, 2005, p.133).

Neuroplasticity: An Inverse Relationship

The changing nature of the neuroplasticity of the brain may also have implications for lifelong ecological literacy and provides direction towards the restructuring that schooling may require in order to influence global efforts to deal with ecological degradation. This involves the manner in which internal representations (the content of neural networks) are laid down in human beings during childhood and the resulting resistance to change during adulthood. Human beings have the longest period in which brain growth is shaped by their external surroundings, starting at birth (Rose, 2005). However because of the length of time involved being shaped by the external world, human beings alter their surroundings (i.e. culture, laws, beliefs, ecological systems) once they are adults to a degree unprecedented amongst animals (Doidge, 2008; Wexler, 2008). Because of this 'transgenerational shaping' of our surroundings and the resistance of the adult brain to change, adults are less capable of changing to the new realities that their own cultural artefacts helped initiate.

It has been well established that during the years leading up to puberty, the human brain is very "plastic" i.e. the external world directly influences the creation of the brain's neural networks with little resistance (Rosenzweig, Krech, Bennet & Diamond, 1962; Schwartz & Begley, 2003). These physical pathways (i.e. neural networks) and the content of these pathways are completely shaped by external stimuli during early childhood (Dennis, 2000). Neural networks must receive external stimulation in order to grow new brain cells and new synapses as the growth is not stimulated from within (Wexler, 2008). These networks are 'plastic' in the sense that they are malleable. In the very young, neural networks form and grow without resistance. However, increasingly over time the external stimuli (i.e. our surroundings) have become more human-created and less influenced by the natural world. The developing mind is being stimulated on a daily basis overwhelmingly by technology, by media, by transportation, by books and by words rather than by wind in the trees, the smell of the earth after a rain, the ever changing movement of water, the sound of silence in quiet meadows and the awe and majesty of ecological systems. The predominantly human-created external stimuli (the extreme being the synthetic images of virtual computer programs) result in the creation of human-influenced internal representations (the content) which is leading to a further disconnect with the natural world from which we came (Louv, 2006).

During young adulthood (post-puberty), the brain conducts "synaptic pruning" in the frontal cortex, eliminating synapses that have not been used extensively (thus the 'use it or lose it' behaviour of the brain) and begins to protect and strengthen representations that were laid down prior to puberty (Blakemore & Frith, p.113). The brain's internal representations (e.g. 'established perceptual, attitudinal and cognitive structures' (Wexler, 2008, p.4) which are translated into electrical patterns) become less capable of accepting new information because the brain is quite comfortable with the representations that it has built up for so many years. The young adult brain/mind becomes resistant to being shaped by the external environment and attempts to shape the external environment to its accustomed way of doing things. Synaptic pruning may also indicate the importance of practice in school instruction (Blakemore & Frith, 2005) and more generally the issue of depth vs. breadth in the curriculum. Without continuous practice and review, new learnings will eventually be pruned. The more topics that the modern assembly-line curriculum includes, the less time available to emphasize internalization and transformative/deep learning that require ongoing practice, application and review.

Challenges to internal representations in the adult brain can cause dissonance, discomfort and stress e.g. during mood disorders (Pittenger & Duman, 2008). The adult brain sees new information (that does not match existing structures) as being "foreign" (Wexler, 2008, p.6) and dissonant. The adult brain now attempts to preserve established representations in face of social/cultural challenges and "finds changes in structure difficult and painful" (p.9), which may explain in part why adults learn not to 'go there' in the first place but rather to accept the status quo- otherwise the resulting dissonance may not be pleasant. The neuroplasticity of the developing internal representations turns into a kind of neurorigidity or at the very least these internal representations become less plastic. [We need to differentiate here between the plasticity of the content (i.e. the meta-values) of the neural networks and the plasticity of the brain's ability to grow new neurons and networks, especially in injured brains. While the brain's ability to grow new physical pathways occurs throughout life (Schwartz & Begley, 2003) and even during older adulthood (Calero & Navarro, 2004), the content of the pathways becomes much more challenging to change post-puberty].

Through this lens, we see that young adults 'rebel' because they are acting on their internal structures (which are a combination of their own new experiences and established cultural environments created by adults) to change the external world to conform to their structures (Wexler, 2008). There is a struggle between adult and young adult for this change process. Depending upon how much ecological literacy is emphasized in the school curriculum, the young adult may have a strong belief system that 'society needs to change its ecological behaviours', only to have these beliefs confronted by the older, internal representations of the adult population representing the status quo. In the absence of a lifelong learning society that engages adults throughout their lives, this reduction of neuroplasticity may be an inhibiting factor in introducing some adults to ecological literacy as the concepts involved (e.g. 'everything is interconnected') are quite complex. Too much exposure to explicit images of ecological degradation may push the adult into a kind of "mourning mode" (e.g. viewing out-of-control oil spills from offshore drilling) during which neuroplasticity is impeded. It takes time and energy to modify internal representations to match the new, external stimulations. Certainly neural networks and cognitive processing in adults can still grow but the change is often modest. The overall effect of neurorigidity is "conservative" (Wexler, 2008, p.6) i.e., small changes done so grudgingly with a lot of effort and self-discipline in comparison to the effortless experience of the child's brain and mind.

Consequence for Ecological Change

The neurobiology of the brain may help explain in part the 'status quo' and the modest valuing that the global society appears to hold towards ecological integrity. The adult brain is more comfortable with small changes whereas the degree of ecological degradation is so great today that we require large changes in personal lifestyles and complex changes on the part of business, industry and governments (Flannery, 2006; Hansen, 2009; Monbiot, 2006; Puk, 2010). The Kyoto Protocol is a good example of modest change. After all the energy and debate that has gone into the Protocol since its inception in 1998, the Kyoto Protocol only requires a 5% reduction in global greenhouse gas emissions based on 1990 levels, far below what is required to reduce global degradation (Hansen, 2009; Intergovernmental Panel for Climate Change, 2007; Monbiot, 2006). However, the societal norm over the past half century has been one of evolutionary change, that is, slow steady progress. If we don't get something done today, we can do it tomorrow. If we don't accomplished a goal this year, we can do it next year (thus New Year's Resolutions). This is another example of the meta-values that our internal representations have been taught and have endorsed. Unfortunately evolutionary thinking may not be moving fast enough to keep up with the speed of ecological degradation. Because greenhouse gas emissions have constantly been increasing since the industrial revolution, globally we may need to reduce emissions by 60% rather than the modest Kyoto target of 5% (Hansen et al., 2008; Monbiot, 2006). This represents a huge gap between willingness to change and action to change. However, in Canada and the United States, the increase in emissions since 1990 has been even worse. Canadians and Americans produce more than 20 tonnes of CO2E emissions per person (Environment Canada Greenhouse Gas Emissions Inventory, 2009; Monbiot ,2006) compared to 6 tonnes in Great Britain. Thus, Canada and the United States may need to reduce their emissions by 94% based on

1990 levels in order to help achieve the global average reduction of 60% (Monbiot, 2006). As well, the time in which we have to achieve these dramatic reductions is short. Currently we have poured greenhouse gas emissions into the atmosphere to the point there are now 430 ppm CO2E. It is projected that once the atmosphere has reached 450 ppm, runaway irregular climate will occur in which our normal carbon sinks such as the oceans and soil will be so saturated with CO2 that they will begin to emit CO2 rather than sequester it. Once this happens, there will be less opportunity for successful human intervention. The rate of increase of greenhouse emissions into the atmosphere is 2-3ppm per year (Monbiot, 2006, p.16; Walker & King, 2008, p.17), thus that critical limit of 450 ppm may occur by 2020 if we don't make the significant reductions required starting now. Others such as Hansen (2009) believe we have already passed critical thresholds and need to reduce emissions even more drastically to 350 ppm CO2 from the present 391 ppm. In part because of the resistance to include ecological literacy as a distinct, compulsory subject-matter K-12 in most jurisdictions (Puk, 2010), in part because of the lack of lifelong ecological literacy for all citizens and in part because of the rigidity of internal pathways of current adults to change easily or quickly, these gaps between what is required (ecological integrity) and what is being done (ecological degradation) may be jeopardizing a healthy future.

So desperate is the brain to hold onto its pre-existing representations that change may cause anger or "denial" in an attempt to defend and protect these comfortable pathways (Wexler, 2008). Ecological literacy and ecological consciousness challenge current lifestyles, making many people uncomfortable with the assault on their internal representations. This in turn may provoke a backlash against this challenge and against those who threaten established internal representations.

There may also be a lack of congruency between "espoused levels of aspiration" and "de facto levels of aspiration" (Puk,1994). People may say they believe that ecological integrity is important and that they are making changes or are willing to make specific changes in their life-styles. However their de facto levels of aspiration, that is, their actions are not always congruent with their espoused beliefs. The espoused beliefs may exceed the plasticity of their internal representations (pre-puberty meta-values) and when push comes to shove those established pathways may resist the espoused beliefs and maintain the status quo. Neurorigidity also helps to explain the gap between ecological literacy and ecological consciousness. Ecological literacy provides the capacity to make changes "about the future of life based on a comprehensive, gestalt-like understanding of the reciprocal relationships among and between natural systems and human systems" (Puk, 2010) but ecological consciousness ("the human condition in which all daily behaviours are viewed through a lens of ecological literacy such that these behaviours form an ecologically beneficial lifestyle", p.115) requires acting on that capacity. The individual may know what needs to be done but their internal representations and the conservative nature of those representations may impede action. Because of the effort and self-discipline involved in change, people may avoid or abandon the attempt to significantly modify internal representations before enough time is given to the effort.

Implications for Lifelong Ecological Consciousness Implications for Schooling

To this point, four main principles of research into the nature of neurobiology in humans have been identified: 1/ throughout life, embodied experience shapes neural networks which shape cognitive processes in a reciprocal relationship; 2/ up until puberty, development of the human brain is largely influenced by the external world; 3/ post-puberty, the brain starts to protect the neural networks and cognitive processes that it has invested a great deal of energy in creating; 4/ while the physical and chemical structures of the adult brain are capable of growing in response to external stimuli, this occurs in a rather conservative manner. How might we utilize these findings in schooling and in lifelong learning?

The strengths and limitations of our neural networks may help to explain why outdoor, experiential learning is so valuable to brain development (Louv, 2006). By influencing the development of neural networks and cognitive representations during the early years and in particular in the years leading up to puberty, in regard to being able to accept and promote change as a meta-value, particularly when dealing with change involving the reciprocal relationship between natural systems and human systems, hopefully once adulthood is reached those meta-values will kick in naturally. The weather and the biota of the outdoors changes continuously moment by moment , day by day and our neural networks are shaped by these "real-time interactions with a changing world" (Westermann, Mareschal, Johnson, Sirois, Spratling & Thomas, 2007, p.78). The brain-body-surroundings unified system is influenced by multiple real-time adjustments, continually coordinating with the internal and external worlds (p.78). Whereas, the conditions in the classroom remain relatively the same day after day, year after year and our cognitive processes become accustomed to this sameness and try to protect it as a meta-value. We need to consider developing dynamic, ecological curricular growth routes for the different ages and brain complexities as a way to take advantage of neurobiology. Post-puberty, these growth routes should take into consideration the degree of neurorigidity of the learner.

Schooling in many parts of the world has been very much influenced by Piagetian influences. Our grade system is based mostly on his stages of cognitive development of the learner. Neurobiology however now provides us with a more complete picture of human ontogeny. We need to consider adjusting schooling based on these findings. While the brain and mind have a plastic component to them throughout life (Dennis, 2000; Schwartz & Begley, 2003; Blakemore & Frith, 2005), the quality of this plasticity in regard to internal representations begins to erode very quickly and post-puberty, the brain is attempting to alter the external world and protect its internal representations (Wexler, 2008). Figure 1 provides a developmental model for how we might shape the brain's capacity to influence the development of cognitive processes during schooling and lifelong.

Stage 1: Pre-Puberty: birth to grade 3

At this stage of brain development, the internal representations are almost totally influenced by external stimuli. By creating the conditions from birth for the young child to spend significant amounts of time outdoors in natural settings, we would create the potential for ecological systems to lay down 'ecological internal representations' through embodied experience rather than just human-made representations. By creating curricular activities that allow the young child to playfully explore natural systems and to emphasize the innate beauty of these systems, we can provide the learner with the context to experience ecological, experiential reasoning at an early age. Calling for exploration and play in natural settings in young children is of course not new as many such as Dewey (1963) and Vygotsky (Pass, 2004) advocated play and inquiry many years ago. Through outdoor play, "new strategies and behaviours can be developed with minimal costs and these strategies can, in turn, influence evolutionary processes" (Pellegrini, Dupuis & Smith, 2006, p.262). However the latest research on the role of neuroplasticity may provide us with a different foundational understanding as to why exposure to the natural world is so important to the future of the young child. The implication is that cognitive processes and meta-values laid down by the developing mind will then be protected by the adult brain as the mind attempts to alter its surroundings. If these internal representations are devoid of ecological representations, Birth to Grade 3 PRE-PUBERTY MATURATION

-external world stimulates the creation of internal neural networks
-neuroplasticity
-need to lay down ecological neural representations

Grade 4-9 (5-7) BOUNDARY SPACE

-introduce nature-embedded, embodied experience (conceptual processing)
-need to embed ecological cognitive seeds (meta-frameworks for discernment)

Grade 10-Lifelong POST-PUBERTY MATURATION

-internal representations seek to alter the external world
-neural networks become less plastic
-develop surveys for adult readiness
-develop growth routes to emphasize embedded seeds
-introduce complex issues through nature-embedded, embodied experience

Figure 1. Stages of Growth to Acquire Ecological Consciousness Based on Neurocognitive Development

the adult mind will seek to alter the surroundings based predominantly on human-made influences. If these internal representations are formed from stimuli in the natural world, the adult's cognitive processes should attempt to protect these representations and alter the external environment accordingly.

The Primary Emphasis of Stage 1: laying down ecological internal representations.

Stage 2: Boundary Space: grades 4-9 with particular attention to grades 5-7

At this stage, the learner would continue the experiences from the Stage 1, that is, playful explorations through embodied experience in the natural world. In Stage 2 these playful explorations would be extended to introduce conceptual understanding and take advantage of "emotional memory" (Rose, 2005, p.164) through "nature-embedded, embodied experience" (Puk, 2010; Puk & Stibbards, 2011a). "Ecological macro models" are "representations of ecological systems or components of ecological systems in which the learner actively plays a role in order to better understand and internalize how these systems work" (Puk, 2010, p.27). These activities are based around three foci that characterize natural systems and the reciprocal relationship between natural systems and human systems (Puk & Stibbards, 2011a; Stibbards & Puk, 2011) complexity and the non-linear elements of life (Davis & Sumara, 2005; 2007), emergent properties (Kauffman, 2010) and embodied experience (Barsalou, 1999; 2008; Niedenthal, Barsalou, Winkleman, Krauth-Gruber & Ric, 2005).

An example of an ecological macro model is the honey beehive (Puk, 2010, p.302). An outline of a "honey beehive" and its different chambers are laid out on the ground with ropes.

Students randomly choose different coloured t-shirts each of which represent honey bees with different roles (e.g. nectar foragers, receiver bees, pollen foragers, nurse bees, a queen bee, etc). Students are taught three kinds of dances (waggle, shake and tremble) that honey bees utilize to communicate with each other when gathering pollen and nectar (Jacobsen, 2008). Students are also provided with the basic instructions and parameters of the activity. Once the activity begins, each student plays the role of the honey bee they represent. Some go searching for flowers (stations with buckets of water) in order to collect nectar and pollen (water carried in a container), others search for water (which is carried in a container), while others receive pollen and nectar back at the beehive (transfer of water as pollen and nectar), etc. The beehive as a superorganism (Holldobler, & Wilson, (2010) is an example of complexity in the natural world as there is no linear sequence to follow in this behaviour and macro model. Outcomes emerge dependent on the actions of the bees/students, e.g. how successful they are at finding nectar and pollen and how much pollen and nectar they can carry back to the beehive without spilling any. Ecological macro models provide a rich context and an expanded 'zone of proximal development' that Vygotsky referred to (Vygotsky, 1987, p.209; Pass, 2004), as the multiple real-time interactions between the parameters of the activity (e.g. roles of each bee interacting, spatial characteristics of the area), social peers and the natural world (e.g. weather conditions, topography and natural fauna) challenge the learner to solve problems inherent in the activity and acquire conceptual understanding beyond their current capacity. The parameters of the macro model (having been set by the adult/teacher) and the complexity of the natural surroundings expand the role of Vygotsky's adult in this zone of proximal development and combine the human cultural influences central to human ontogeny (Vygotsky, 1987; Tomasello, 1999; Blakemore & Frith, 2005) with that of natural systems. These activities also emphasize imagination (i.e. thus the development of new neural networks) by developing enhanced imagery of the activity (e.g. the honey beehive) that students internalize and retain as "enhanced memory" (Blakemore & Frith, 2005) and emotional memory for future retrieval, e.g. debriefing back in the classroom with images created from embodied experience rather than from virtual experiences of textbook and media. McGaugh (as cited in Rose, 2005) has demonstrated that "emotional memory is more powerful than purely cognitive memory" (p.164) and that people remember "emotion-laden information" better than purely cognitive ones e.g. classroom-based learning from textbooks. For the learner, moving around in a natural setting, negotiating the parameters of the macro model, as if they were a honeybee (or a photon of light in understanding photosynthesis or a water molecule in water treatment, etc.) creates a rich mixture of emotional and conceptual influences. The honey beehive macro model and other macro models can then be further adapted for Stage 3 learners by adding the heavier anthropogenic issues, for example in the case of the honey beehive, of colony collapse disorder including multiple, complex influences of irregular climate, synthetic chemicals, EMF and urbanization (see further discussion on adding heavy issues to nature-embedded, embodied experience in Stage 3).

Stage 2 also connects the externally influenced developing mind of Stage 1 with Stage 3 when the newly-created internal representations attempt to alter one's external surroundings and resist the influence of the external world. This Stage 2 Boundary Space provides the staging area for post-puberty when plasticity begins to erode. Grades 5-7 may be the key grades to prepare cognitive processes for this future (this will vary depending on the age of sexual maturation). Therefore, in addition to nature-embedded, embodied experience, students would be taught meta-frameworks that emphasize learning how to learn (which Rose 2005 points out is an inherent quality of the developing brain), in particular about the reciprocal relationships between human systems and natural systems. *In particular, we need to provide 'ecological cognitive seeding*' that will help create these meta-frameworks (or what Case 1996 referred to more generally as 'central conceptual structures'), and that empower students with strategies for self-directed learning, "critical evaluation of transmitted knowledge and meta-study skills" (Blakemore & Frith, 2005, p.121) in regard to ecological literacy and ecological consciousness. These ecological cognitive seeds (e.g. "learning how to view human and natural systems from a life-cycle perspective" and "understanding the reciprocal relationship between human systems and natural systems") would thus be laid down pre-puberty after which neuroplasticity begins to decay.

One example of these meta-frameworks that might provide ecological seeding for the higher grades in this stage (that is grades 8-9) is the following set of questions that the young learner would be taught to invoke whenever they are presented with statements and assertions about ecological issues:

1. Who is making the claim and why?
2. Are these claims accurate (how ecologically literate are these claims)?
3. Is there something missing from the claim (what are these claims not telling me)?
4. Is this about protecting natural systems or about money (is this ultimately an ecological benefit or a perceived economic benefit)?
5. Will this protect natural systems and human health in the long term (is this claim consistent with ecological integrity)?
6. Although this might look good to me now, do we really need this and will others be harmed as a consequence (is this about convenience or about need and if a convenience will it be harmful for others later)?
7. Do I know enough to determine the claim is valid (am I ecologically literate enough to know if the claim is ecologically responsible)?
8. If not, where can I go for more information?

(the bracketed sections represent adapted wording for Stage 3 learners)

As the world becomes more aware of the consequences of ecological degradation, the danger is that there is a great deal of misinformation, misunderstanding and at times deliberate obfuscation. In the latter case, billions of dollars are spent to deliberately sow doubt in the minds of the unsuspecting public (Beder, 2002). Michaels (2008) suggests that claims about possible solutions or assertions that question the validity of ecological degradation are made that purposely distort the science underlying the claim, with the general public not knowing which to believe. By teaching young students how to ask questions, about their own beliefs and knowledge base and that of claims made in the media or in text, we would be providing them with the tools of discernment (Puk & Stibbards, 2011b). Moon (1999) describes five stages of meaning making from a/ surface learning composed of noticing, making sense, and making meaning stages, to b/ deep learning composed of stages involving working with meaning and transformative learning (p. 139). Transformative learning is characterized by being meaningful, reflective and most importantly, restructured by the learner (p.139) as opposed to the noticing stage of surface learning when memorization is paramount. Meta-frameworks for discernment/transformative learning such as the set of questions found above would become internal representations for students in grades 8-9 before brain plasticity begins to decline. Later as adults, the brain/mind would hopefully attempt to protect these meta-values (e.g. "question all knowledge thoroughly").

This set of questions should not be taught as a formula in which universal answers would automatically be produced. Rather, it would teach the older boundary learner a process for asking questions about ecological issues which the adult brain/mind might then later protect as a meta-value. This should serve the future adult well as issues about ecological degradation and ecological integrity become more and more complex and simple solutions become more elusive.

The Primary Emphasis of Stage 2: a/ nature-embedded, embodied experience; b/ ecological cognitive seeding with meta-frameworks for self-directed learning.

Implications for Adult Learning

As Vance and Crowe (2006) suggest, “researchers need to develop a better understanding of how lifelong lifestyle habits affect brain plasticity in older age” (p.74) in order to take advantage of neurobiology. The major implication of neurobiology as it applies to ecological literacy and ecological consciousness is that what occurs during schooling has a major impact on the adult brain’s ability and the mind’s willingness to change and learn quickly enough to meet the challenges of ecological degradation.

Stage 3: Post-Puberty: grade 10-lifelong

During this stage, the young adult learner and the lifelong learner would continue the experiences from the first two stages: a/ significant time exploring the natural world through nature-embedded, embodied experience and b/ extending their ability to employ meta-frameworks. As well, we now need to gradually add the heavy <u>issues</u> of ecological degradation (e.g. “increased emissions will cause increased melting of glaciers which will cause rising water levels which will displace millions of people around the world”). [By placing these kinds of heavy issues on the shoulders of young children (Stages 1 and 2) who do not possess significant power to affect these issues can lead to ecophobia (Sobel, 1995). Thus delaying heavy issues to Stage 3 is preferable]. Stibbards and Puk (2011) found that teacher candidates, after an academic year-long course in ecological literacy featuring twenty-six ecological macro models (e.g. topics such as natural and anthropogenic greenhouse gases, nuclear energy, hydrogen and microbial fuel cells, plastics, organochlorines, virtual water, etc.), rated their experiences and beliefs about ecological macro model learning (i.e. nature-embedded, embodied learning) very highly. This study involved teacher candidates rating 15 statements about their experiences with macro models including statements such as: “I believe the em2s [ecological macro models] resulted in a deeper integration of material than would have been achieved through the traditional lecture style of instruction”; “I believe that em2s can be an effective form of instruction in university education”; “I am confident I can develop effective em2s as a future teacher as a result of participating in the models in this course”; “I believe I will retain the content of these em2s longer than if I had read about the content or had been part of a lecture”; “My attitude towards ambiguity and uncertainty used as a form of instruction changed and became more positive during the course through the use of em2". On a Likert scale of 1-5 (1 agree not at all, 5 agree extremely), “86.84% of the ratings were either 4 or 5, with a mean score of 4.34 on all items” (p.25). The study also found that self-efficacy measures in regard to beliefs and attitudes about embodied, emergent learning increased significantly from pre-course ($M=73.54$, $SD=11.93$) to post-course ($M=84.24$, $SD=5.87$, $t(14)=3.322$, $p=.006$), an increased confidence of $M=10.70$ (p.25) (not withstanding the possibility of pre-course false self-efficacy explained below).

In a second study with the same class of teacher candidates, Puk and Stibbards (2011b) found that there was significant growth ($p<.001$) between pre-course and post-course testing in the teacher candidates’ ability to develop mature definitions for key ecological concepts. On a scale of 1-4 (1 meaning either no definitions or incorrect definitions, 4 meaning mature, robust definitions), pre-course means ranged from 1.00 to 1.40 while post-course means ranged from 2.6 to 4 (p.35)! This improvement was attributed to the embodied experience embedded in the macro models. Although these are small scale studies, nevertheless we do have some evidence that instructional strategies that feature embodied, modality-specific systems can take advantage of the reciprocal relationship between cognitive processes, neural networks and surroundings with significant results.

Secondly, recognizing the natural resistance the post-puberty mind has to accepting the external world is an important reason why during adult learning we should emphasize the asking of questions over statements. When the adult learner is making statements, the brain/mind is attempting to alter its external surroundings to conform to its pre-existing internal pathways- thus very little change may occur. Adults are often more comfortable in making statements that simply reinforce their current internal representations which in turn provide internal reassurance and comfort rather than restructuring their meaning-making through deep reflection. In a study that assessed the ability of teacher candidates to develop definitions for key ecological concepts at the beginning of their teacher education program (Puk & Stibbards, 2011a), these teacher candidates were also asked how well they thought they could define these concepts and how capable they were of teaching these concepts. The results of the study found a false sense of efficacy as their past experiences in higher learning (all the subjects had undergraduate degrees and some even had graduate degrees) negatively correlated with their perceived ability to define these concepts. While there has been little research on false self-efficacy, it is possible that this is another example of how the adult brain/mind attempts to protect pre-existing meta-values. Thus, encouraging the adult-as-learner to critically reflect on their own meaning-making n order to achieve transformative learning (Moon, 1999; 2008) may compel internal representations to entertain new directions and allowing new possibilities to help us question established meta-values (Taylor, 2007). Teacher educators and more generally university instructors might benefit by being aware of false self-efficacy in their adult students and establishing strategies to deal with this phenomena.

Most importantly, Stage 3 would involve the development of individual growth routes (dependent on how well the learner has internalized the meta-frameworks and how plastic the brain remains) that utilize the ecological cognitive seeding laid down during the previous stage. Those ecological seeds (i.e. meta-frameworks for self-directed learning) will now be an integral component of the internal representations and the brain will naturally attempt to protect them and utilize them to alter the external world.

For current adults however who have not had the opportunity to have these representations laid down pre-puberty, it might first be advantageous to assess how open they are to ecological literacy and ecological change, determine the best starting points for teaching ecological literacy and develop individual growth routes for the current adult population. We would need to develop instruments that will provide feedback as to the ecological meta-values that the adult learner possesses. Questions such as: i/ how much effort do you believe society should expend to eliminate the threat of irregular climate? ii/ do you believe that we have a lot of time to resolve our ecological problems? iii/ how much effort are you willing to expend to eliminate the threat of irregular climate? iv/ do you support recycling? v/ how much are you willing to change your lifestyle in order to create a healthier world? , would help identify ecological meta-values and willingness to engage the topic. With these responses, program developers for lifelong ecological literacy would be better able to adapt instruction/discussion and develop a growth sequence that would begin with the readiness of the adult learner to engage ecological integrity.

The Primary Emphasis of Stage 3: a/determine ecological meta-values and degree of neurorigidity in the learner, b/ develop growth sequence for lifelong ecological literacy, c/ add complex issues through nature-embedded, embodied experience.

Conclusion

This paper has suggested that schooling and lifelong education might benefit by considering the implications of neurobiology as they effect lifelong ecological literacy and ecological consciousness by contributing a framework for stages of growth for acquiring ecological consciousness based on neurocognitive development. It is not enough for educators at different stages of education to only focus on the stage with which they are currently involved. Educators at all levels need to understand how neurobiology affects ecological literacy at each stage of neurocognitive development and how the whole continuum is greater and more complex than the individuals parts/stages.

Neuroconstructivism recognizes the reciprocal relationships between cognitive processes, neural networks and experience. The downside of neuroplasticity is that while there is a capacity for the brain to develop neural networks and for continued growth in cognitive processing throughout life, there is also a tendency on the part of the brain to protect the internal representations it has invested pre-puberty which can lead to a degree of neurorigidity during adulthood. This is happening at a unique time in human existence just when we need a more receptive adult brain/mind capable of laying down new ecological meta-values in a short period of time. As Rose (2005) points out, at an early age our brains learn to extract 'regularities' from our surroundings and that this was an advantage to early humans at a time when these regularities would not have varied significantly over a short life-time and would have been more nature-based. In today's 'modern', global world, *change is the regularity* and for the most part is anthropogenic. However, our brains have not had time to evolve to this new reality. Perhaps we can take advantage of the neurobiological characteristics of pre-puberty plasticity in order to accelerate adult brain evolution by a/ making sure early childhood internal representations are heavily influenced by nature through embodied experience, b/ putting more emphasis on teaching young learners discernment in regard to ecological literacy which the adult brain will then seek to protect, and c/ continuing to take advantage of the albeit diminished plasticity of the adult brain by identifying the meta-values of the adult learner prior to learning episodes and providing nature-embedded, embodied experience through lifelong instruction. Developing the ecologically literate and ecologically conscious person needs to be conducted in a systematic, wholistic manner through lifelong education.

References

Barsalou, L.W. (1999). Perceptual symbol systems. *Behavioral Brain Science*, 22, 577–660.

Barsalou, L.W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617-645.

Beder, S. (2002). *Global spin: The corporate assault on environmentalism*. White River Junction, Vermont: Chelsea Green.

Blakemore, S.J. & Frith, U. (2005). *The learning brain: Lessons for education*. Oxford, U.K.: Blackwell.

Calero, M.D. & Navarro, E. (2004). Relationship between plasticity, mild cognitive impairment and cognitive decline. *Archives of Clinical Neuropsychology, 19* (5), 653-660.

Calvo, P. & Gomila, A. (Eds). (2008). *Handbook of embodied cognition*. San Diego: Elsevier.

Case, R., Okamoto, Y., Griffin, S., McKeough, A., Bleiker, C., Henderson, B. & Mara, K.(1996). The role of central conceptual structures in the development of children's thought. *Monographs of the Society for Research in Child Development*.

Davis, B. & Sumara, D.J. (2005). Challenging images of knowing: Complexity science and educational research. *International Journal of Qualitative Studies in Education, 18(3),* 305–

321.
Davis, B. & Sumara, D. (2007). Complexity science and education: Reconceptualizing the teacher's role in learning. *Interchange, 39(1)*, 53-67.
Dennis, M. (2000). Developmental plasticity in children: The role of biological risk, development, time and reserve. *Journal of Communication Disorder, 33* (4), 321-332.
Dewey, J. (1963). *Experience and education*. N.Y.: Collier Books.
Doidge, N. (2008). *The brain that changes itself. London*, England: Penguin Books.
Environment Canada. (20010). *Canada's greenhouse gas inventory 1990-2007* www.ec.gc.ca/pdb/ghg/inventory_report
Flannery, T. (2006). *The weather makers*. Toronto: HarperCollins.
Hansen, J. (2009). *Storms of my grandchildren*. Bloomsbury Press.
Hansen, J., Sato, M., Kharecha1, P., Beerling, D., Berner, R., Masson-Delmotte, V., Pagani, M., Raymo, M., Royer, D. L. and Zachos, J. C. (2008). Target atmospheric CO: Where should humanity aim? *The Open Atmospheric Science Journal*, 2, 217-231.
Goswami, U. (2008). *Cognitive development: The learning brain*. New York: Psychology Press.
Holldobler, B., & Wilson, E.O. (2010). *The superorganism*. New York: W.W. Norton.
Hutchins, E. (2010). Cognitive ecology. *Topics in Cognitive Science, 2*, 705-715.
Intergovernmental Panel on Climate Change. (2007). *Climate change 2007: The physical science basis*. Paris: IPCC.
Jacobsen, R. (2008). *Fruitless fall: The collapse of the honeybee and the coming agricultural crisis*. New York: Bloomsbury.
Kauffman, S. A. (2010). *Reinventing the sacred: A new view of science, reason and religion*. Basic Books.
Knapp, D. (2000). The Thessaloniki declaration: A wake-up call for environmental education? *The Journal of Environmental Education, 31* (3), 32-39.
Louv, R. (2006). *Last child in the woods*. Chapel Hill, CA: Algonquin Books.
Mareschal, D., Johnson, M.H., Sirois, S., Spratling, M.W., Thomas, M.S.C. & Westermann, G. (2007). *Neuroconstructivism: How the brain constructs cognition*. Oxford: Oxford University Press.
Merzenich, M.M. (2001). Cortical plasticity contributing to childhood development. In J.L. McClelland & R.S. Siegler, (Eds.). *Mechanisms of cognitive development: Behavioral and neural perspectives*. pp. 67-92. Mahwah, N.J.: Lawrence Erlbaum.
Michaels, D. (2008). *Doubt is their product.* New York: Oxford University Press.
Monbiot, G. (2006). *Heat: How to stop the planet from burning*. Canada: Doubleday.
Moon, J.A. (2008). *A handbook of reflective and experiential learning: Theory and practice.* New York: Routledge.
Moon, J.A. (1999). *Reflection in learning and professional development.* London: Kogan Page.
Niedenthal, P.M., Barsalou, L.W., Winkleman, P., Krauth-Gruber, S. & Ric, F. (2005). Embodiment in attitudes, social perception and emotion. *Personality and Social Psychology Review, 9* (3), 184-211.
Pass, S. (2004). *Parallel paths to constructivism: Jean Piaget and Lev Vygotsky*. Greenwich, CT: IAP.
Pellegrini, A., Dupuis, D. & Smith, P.K. (2007). Play in evolution and development. *Developmental Review, 27*, 261-276.
Pittenger, C. & Duman, R.S. (2008). Stress, depression and neuroplasticity: A convergence of mechanisms. *Neuropsychopharmacology, 33*, 88-109.
Puk, T.G. (1994), Espoused and *de facto* levels of aspiration: Implications of an analysis of Ontario ministry of education curriculum policy guidelines. *Brock Education, 4* (3), 11-19.

Puk, T. G. & Behm, D. (2003), The diluted curriculum: The role of government in developing ecological literacy as the first imperative in Ontario secondary schools. *Canadian Journal of Environmental Education, 8* (Spring), 217-232.

Puk, T.G. (2010), *Transforming the ecological self: stop peeing into the drinking water* (Thunder Bay: Lakehead University).

Puk, T. G. & Stibbards, A. (2010). Ecological concept development of preservice teacher candidates: opaque empty shells. *International Journal of Environmental and Science Education. 5 (4), 461-476.*

Puk, T.G. & Stibbards, A. (2011a). Growth in ecological concept development and conceptual understanding in teacher education: The discerning teacher. *International Journal of Environmental and Science Education, 6 (3), 191-211.*

Puk, T.G. & Stibbards, A. (2011b). Systemic ecological illiteracy? Shedding light on meaning as an act of thought in higher learning. *Environmental Education Research,* November, iFirst, 1-21. DOI:10.1080/13504622.2011.622840

Rose, S. (2005). *The 21st century brain: Explaining, mending and manipulating the mind*. London: Jonathan Cape.

Rosenzweig, M.R., Krech, D., Bennet, E.L. & Diamond, M.C. (1962). Effects of environmental complexity and training on brain chemistry and anatomy: A replication and extension. *Journal of Comparative and Physiological Psychology, 55*, 429-437.

Schwartz, J.M. & Begley, S. (2003). *The mind and the brain.* New York: Harper Perennial.

Sobel, D. (1995). Beyond ecophobia: Reclaiming the heart of nature education. *Clearing, 91* (Nov/Dec), 16-20.

Stephen, D.G., Dixon, J.A. & Isenhower, R.W. (2009). Dynamics of representational change: Entropy, action and cognition. *Journal of Experimental Psychology: Human Perception and Performance, 35* (6), 1811-1832.

Stibbards, A. & Puk, T.G. (2011). The efficacy of ecological macro models in developing ecological consciousness in preservice teacher candidates: transforming states of mind. *International Journal of Applied Environmental Education and Communications, 10 (1), 20-30.*

Taylor, R.S. (2007). The process of asking questions. *Journal of the American Society for Information Science and Technology, 13* (4), 391-396.

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge, Mass.: Harvard University Press.

Vance, D. E. & Crowe, M.(2006). A proposed model of neuroplasticity and cognitive reserve in older adults. *Activities, Adaptation & Aging, 30* (3), 61-79.

Vygotsky, L.S. (1987). *The collected works of L. S. Vygotsky, Volume 1*. (R.W. Rieber & A.S. Carton, Trans.). New York: Plenum Press. (Original work published 1982).

Walker, G. & King, D. (2008). *The hot topic.* Vancouver, Canada: Douglas and McIntyre.

Westermann, G., Mareschal, D., Johnson, M.H., Sirois, S., Spratling, M.W., & Thomas, M.S.C. (2007). Neuroconstructivism. *Developmental Science, 10* (1), 75-83.

Wexler, B.E. (2008). *Brain and culture*. Cambridge, Massachusetts: MIT Press.

Author

Tom Puk is a Professor at the Faculty of Education, Lakehead University and teaches and conducts research in the area of ecological consciousness and ecological literacy. **Correspondence:** Faculty of Education, Lakehead University, 955 Oliver Rd. Thunder Bay, ON P7B 5E1, 807 343-8710, Canada. E-mail: tpuk@lakeheadu.ca

Nörolojinin yaşam boyu ekolojik okuryazarlık ve farkındalık üzerindeki etkisi

İkinci dünya Savaşı'ndan bu yana küresel doğal sistemlerini küçük görme eğilimi artış göstermiştir Bu bakış açısının büyük bir bölümü ana akım medya aracılığı ile genel kitleye aktarılmıştır. Bunun bir sonucu olarak insan davranışları henüz anlamlı bir şekilde değişmiş gibi gözükmemektedir. Bu makalede beynimizin ve zihnimizin, özellikle beynin nöro-esneklik iz-yollarının çalışma biçiminin değişmeyen bu davranışa katkısı tartışılacaktır. Mevcut çalışma nöro-esneklik ve daha genel olarak nöro-yapılandırmacılık üzerine yapılmıştır. Nöro-biyolojinin bir sınırlaması olarak gözüken durumun, "nöral sistemlere yönelik pozitif tutumlara sahip olma" gibi gelişen zihnin meta-değerler yaratmasına yardımcı olarak bir avantaja dönüştürülebileceği iddia edilmiştir. Böylece bu tutum, yetişkin beyniyle ve öğretim sırasında ete kemiğe büründürme /somutlaştırma kavramını uygulamayla savunulabilir. Bu makale yaşam boyu ekolojik farkındalık için gereken nöro-biyolojik manifestolar kadar doğa-gömülü, somutlaştırılmış deneyimle ilgili mevcut araştırmanın dikkate alındığı gelişim dizisini ortaya koymaktadır. Bu gelişim dizisi eğitimcilere, yaşamın farklı evrelerindeki öğrenenlere ekolojik olarak daha bilinçli küresel vatandaş olmalarında yardımcı olabilecek zenginleştirilmiş bir bakış açısıyla tüm düzeylerde (örneğin yaşam boyu) destek sağlamaktadır. Eğitimciler için çıkarılabilecek bir sonuç, yaşamın her evresinin (örneğin erken dönem çocukluktan yetişkinliğe kadar) önceki evreden nasıl bağımsız olduğu ve sadece bireyin bilişsel gelişim evrelerine bakmanın aksine diğer evrelerle nasıl ilişkili olduğunu anlamamızın gerekliliğidir.

Anahtar kavramlar: nöro-biyoloji, nöro-yapılandırmacılık, doğa gömülü, somutlaştırılmış deneyim, ekolojik farkındalık kazandıracak bilişsel gelişim dizisi, yaşam boyu ekolojik okur yazarlık.