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Growth in ecological concept development and conceptual understanding in teacher education: The discerning teacher

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In a previous study, Puk and Stibbards (2010) demonstrated that a cohort of teacher candidates entering into an ecological literacy, Bachelor of Education program had very immature understanding of complex ecological concepts. Specifically, written definitions were either absent entirely, very vague, or missing essential criterial attributes, as well as lacking consistency in terms of their meanings. The current study was conducted at the end of the program with the same cohort and concepts in order to determine the effect that the innovative, emergent learning approach taken in this program had on teacher candidates‟ ability to define these concepts and their growth in conceptual understanding of these concepts from pre-course to post-course. The preservice course in ecological literacy in which these teacher candidates were enrolled featured dynamic, embodied activities that seek to promote deep understanding of the complexity found in the intersections between natural systems and human systems. The current study found that there was significant growth in developing more mature definitions of key ecological concepts, which is attributed in part to the use of these emergent instructional activities. In addition, teacher candidates expressed a new, discerning approach to the general usage of some of the concepts as demonstrated by their critical assessment of their own definitions. The findings suggest that growth in ecological concept development and conceptual understanding for teacher candidates can be achieved through the use of nature-embedded, embodied experience.

Keywords: ecological concept development, conceptual understanding, discernment, teacher education, embodied learning, complexity

Introduction

Although concepts are not the sole manner through which we relate to the external world (one can sense the heat of the sun without knowing what heat is or that it is coming from the sun), in the modern world they play a crucial role. What appear to be small, insignificant "words" are in fact full of meaning. And each "word", or concept, cannot be seen as isolated from other concepts. Much of the research into concept „change‟ (we prefer concept „development‟ for reasons that will be explained shortly) examines how students improve individual concept definitions in isolation (e.g. Arnaudin & Mintzes, 1986; Chi, Slotta, & Leeuw, 1994; Thompson & Logue, 2006; Zhou, Nocente, & Brouwer, 2008). Though we do examine the development of

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individual concept definitions in this research, we see a process whereby the development of mature definitions occurs through increased awareness of a particular concept‟s connection to other, related and prerequisite concepts. The ability to see these interconnections between concepts reflects what we call „conceptual understanding‟, which is akin to Wieman‟s (2010) „expert‟ understanding; whereas simply being able to repeat sanctioned definitions for individual concepts is seen as „novice‟ understanding.

Sophisticated conceptual understanding is particularly important for teacher candidates in their area of expertise, as they will be expected to help their future students develop their understanding of concepts. Puk and Stibbards (2010), though, demonstrated that teacher candidates, before taking a course in teaching for ecological literacy, were unable to adequately define key ecological concepts (many of whom had undergraduate degrees with majors in disciplines such as sciences and geography that would be expected to have led to these students having a solid understanding of the terms). Puk and Stibbards (2010) concluded that teacher candidates need to be exposed to learning experiences that engender conceptual understanding, which Gregoire (2003) points out, often does not happen.

Thus, the purpose of the current study was to a/ examine the post-course definitions of key ecological concepts to determine the level of maturity of concept definitions, b/ determine whether or not growth occurred in teacher candidate definitions for these concepts based on their pre-course results and c/ suggest how instruction using ecological macro-models might contribute to the results. The key issue in developing courses for teacher candidates that do lead to sophisticated conceptual understanding is the underlying understanding a professor has about the manner in which these learners actually make meaning out of learning experiences. In terms of concept development and conceptual understanding, many programs continue to focus on the transmission of information through lecture and text reading (Christensen Hughes & Mighty, 2010). It appears that there are (erroneous) assumptions about what concepts are (and are not), and how they develop, that underlie such approaches. Meyer (2010) suggests that „threshold concepts‟ (concepts that open up a "new and previously inaccessible way of thinking about something new", p. 204) exist in every discipline, and cannot be directly taught, but rather emerge out of the piecing together of several related and less sophisticated concepts. To learn key disciplinary threshold concepts, the learner needs much more than the passing on of information, and instead must have the opportunity to construct meaning through appropriate experiences. What follows is a brief exploration of literature regarding concepts and their development in education, presented with the aim of demonstrating that approaches to helping teacher candidates develop deeper meaning need to include an understanding of the complex and embodied nature of learning.

There is a wide body of literature, especially in science education, regarding „concept change‟ and how to promote it in educational contexts. Posner, Strike, Hewson, and Gertzog‟s (1982) highly influential Conceptual Change Model (CCM) suggests that science teachers need to create situations in which 1) a student‟s original, naïve concept is seen as inadequate, i.e. the individual is dissatisfied by the original concept 2) a new conceptualization is understandable and plausible, and 3) the new conceptualization is more „powerful‟ than the original. Criticisms of this model (from within the „misconceptions‟ perspective) focus on the lack of explanation of the role of motivation and affect in concept change. Strike and Posner (1992) themselves have criticized their original model as „cold‟, i.e. too cognition-focused, and have argued, along with others, for the need of a „hot‟ model that includes a description of the role of motives and emotions in conceptual change.

Gregoire‟s (2003) Cognitive-Affective Model of Conceptual Change (CAMCC) is an attempt to integrate older cognitively based models (such as the CCM) with models that

incorporate the role of motivation and affect, such as dual-process models that examine both a cognitive („systematic") and affective („unsystematic") role in attitude change. The basic difference in the CAMCC model is that it may explain why students, when confronted with the „inadequacy" of their existing conceptions may not change them for a better concept, due to affective or motivational factors. In other words, emotions or motivation such as fear or apathy may lead to a lack of concept change. This is important in that most theories of concept development rely on the supposition that if learners are confronted with the inadequacy of their existing concepts, they will change to a new concept that is a better representation of the reality they are confronting. However, though viewing themselves as constructivist, Posner et al. (1982) and Gregoire (2003) still present models that fit into a „right/wrong perspective" in that old, „wrong", concepts are replaced by new, „right" ones.

Robinson, Ross, and White (1985) suggest that rather than the notion that students either "have concepts or don't have them", we should take the perspective that "concepts grow" (p.183). Similarly, Akerlind (2008) offers the phenomenographic idea of *incomplete*, as opposed to *wrong*, in terms of concept development, and *expansion* rather than *change*. Because concepts are seen as nested hierarchies, rather than on a scale of desirability (the „cognitive" perspective), concept growth is not about getting rid of „misconceptions", but is instead a process of expanding one's awareness of more mature criterial attributes of a concept. In terms of learning, expansion of concepts means being exposed to potentially new relationships that a particular concept has with other concepts. We prefer the term „concept development", as „development" reflects Robinson et al.'s (1985) notion of growth and Akerlind's (2008) emphasis on expansion rather than „change", implying an increasing sophistication. The „change" literature, conversely, implies that learning regarding concept definitions is a process of throwing out the old (i.e. misconception or preconception) and bringing in the new. The phenomenographic model also focuses on the interconnected nature of concepts, which we believe is key to understanding how conceptual understanding develops. Our main thesis, as suggested above, is that concepts must be developed through processes that allow individuals to make new meaning through connecting past understandings and experiences with new ones. Though we do not subscribe to absolute notions of „right" definitions or understandings of concepts, it is clear that some definitions are just plain wrong. In an ongoing study (Puk & Stibbards, in press) for example, one teacher candidate defined „photons" as "something to do with electricity". A purely constructivist (relativist) argument regarding the development of sophisticated concept definitions and understanding does not adequately explain this type of phenomenon. As constructivists, we believe that teacher candidates should be given the opportunity to develop shared meanings through engagement with learning materials, natural surroundings and each other. We also do not believe that concept definitions should be judged by some dictionary gold-standard. The specific words used to define a concept and the order in which they are arranged are less important than capturing the essence of meaning of a particular concept. And yet, in using the term „essence" we betray a less than „radical" constructivist bent. It is obvious to us that there are some definitions that students give for concepts that are wrong and some that are more mature than others. We are not aware of an adequate treatment of this issue in the literature, and therefore utilize an approach to analyzing participant definitions of key ecological concepts that allows us to straddle this tension. Our analytic approach is best supported by complexity views regarding concept development and conceptual understanding.

In terms of knowledge and concepts, complexity theory, like „coherence" (e.g. constructivist) theories, are interested in how useful, or adaptive, a particular concept is in a particular situation (Cilliers, 1998; Davis & Sumara, 2007). Concept development is a process in which old concepts are enhanced, made more sophisticated, through experience, either by adding

new criterial attributes to the concept, or by making connections to other existing concepts, to handle newly encountered situations. So, rather than „wrong" concepts being discarded in favor of „new/right" concepts, growth is the development of what already exists. However, unlike constructivist theory, complexity theory stresses more than just human social systems. Interrelationships in the natural world, including humanity, are what lead to the emergent phenomena of concept development (Gabora, Rosch, & Aerts, 2008). In other words, outer reality *matters* in determining how sophisticated a concept definition, or conceptual understanding is, and there is room in this theory for concept definitions that simply do not reflect the systems we are a part of. Complexity theory, then, provides a bridge between rigid „correspondence" (positivist) theories and radical relativist theories, which suggest the sociological or cultural influences exclusively determine the (variable) meaning of concepts. Though it certainly subscribes to the subjective and historical aspects of coherence theories, complexity theory is also focused on external reality. Gabora et al. (2008) state that:

> …it is when stimuli in the world come to be understood in conceptual terms that they acquire the weblike structure and self-organizing dynamics characteristic of *ecology*.… Concepts … do not represent the world in the mind, as is generally assumed, but are a participating part of the mind-world whole. Therefore, they only occur as part of a web of meaning provided both by other concepts and by interrelated life activities (p. 95).

Gabora et al. (2008) insist that the role of context must be explicit in any model that attempts to explain the ways humans employ concepts. They suggest that rather than identifiers, concepts are "bridges between mind and world that participate in the generation of meaning" (p. 84). This is because context can be demonstrated to change the way concepts are employed – they are not static, rigid structures, but rather are flexible enough to negotiate the interrelationships inherent to ecological reality. Complexity approaches to concept development, then, not only include „accuracy„ and „utility", but emphasize the interactive and inseparable (objective/subjective) nature of sophisticated concepts – they rely on acknowledgement of „conceptualizer" *and* context, and the inter-influential relationships between all „parts" of a system in the process of meaning-making (Davis & Sumara, 2005).

A related and burgeoning movement in psychological research can be loosely termed „embodied cognition". As Calvo and Gomilla (2008) suggest, though there are many branches of embodied cognition research, the evidence generally is clear that we cannot separate sensory and motor dynamics from the „executive" functions of the brain as the cognitive movement has done for so long. What we consciously experience, and how we learn, involves an intimate and ongoing dynamic interaction between our external world, our bodies and their sensory and motor abilities, emotion, and what we have traditionally seen as the „mind", the so called „executive" functions of our brains. Embodied experience begins with the senses interacting with one"s surroundings during bodily action from which the brain acquires conceptual understanding through a reciprocal relationship (Gallese, 2005; Thelan, Schoner, Scheier, & Smith, 2001). Rather than being thought of as algorithmic or computational, the "human mind is a meaning and doing organic system" (Kauffman, 2010, p.177). And rather than concept development and conceptual understanding being either entirely subjective construction or finely tuned representations of objective reality, they are instead reliant on an ongoing process of dynamic interaction between the whole of ourselves and our surroundings. Embodied cognition and complexity research have major implications for education, and for our understanding of concept development and conceptual understanding.

We have outlined complexity and embodied cognition perspectives here to highlight the importance of recognizing that learners at all levels are embodied individuals who interact in and with their surroundings. Therefore, the development of ecological concepts and deepening of conceptual understanding regarding the reciprocal relationship between human systems and natural systems, in our view, are dependent on the creation of educational contexts which allow the learner to have embodied experiences in natural surroundings. The current study is intended to address this perspective.

Current Study

The current study examines the conceptual development of a cohort of teacher candidates through a complexity lens, both in terms of the assessment of concept definitions and conceptual understanding and in terms of the learning approach utilized with the intention of helping students develop useful, interconnected, mature understanding of key ecological concepts.

The Course

Teacher candidates were enrolled in a course that was 72 hours (18 weeks) on campus (one four-hour class each week for 9 weeks in the fall and 9 weeks in the winter) and three immersion weekends off-campus from September to March. The concept of “discernment” was one of the meta-values of the course.

As Pugh, Linnenbrink-Garcia, Koskey, Stewart, and Manzey (2010) point out, though many innovative practices, based on deeper understanding of how students learn, are being developed, these practices are limited by the effectiveness of teacher implementation. Instruction in the course examined in the present study was centered on how to teach “ecological macro-models” (Puk, 2010) through nature-embedded, embodied experience. “Ecological macro-models are analogous representations of ecological and human systems or components of these systems in which the learner actively plays a role in order to better understand and internalize how these systems work” (p. 125). Examples of these macro-models include waste, entropy, fossil fuels, hydrogen fuel cell, photosynthesis, nuclear energy and organochlorines. These embodied and emergent macro-models provide the context for conceptual change that promotes the development of "mental organizational structure that facilitates the retrieval and effective application of [the learner's] knowledge" (Wieman, 2010, p.182).

Twenty-six macro-models were featured during the course, each featuring key ecological concepts. Each week at least one macro-model was conducted. Teacher candidates were first briefed on the rules and parameters for conducting the macro-model. Roles in each macro-model were assigned randomly, for example teacher candidates would choose a different colour of t-shirt, which in turn designated the role they would play in that macro-model. Macro-models were conducted outdoors in settings that helped exemplify the topic, e.g. river, pond, bush, etc.. Participants/teacher candidates were not given explicit instructions about what to do but rather performed their roles as they interpreted them from the parameters given.

Teacher candidates experienced first-hand how the macro-model works by being immersed in the activity. Thus, learning was emergent and depended upon the role, initiative, ingenuity and decision-making of the participants. Sometimes the instructor played a role and at other times helped to facilitate the activity. After some macro-models the class debriefed the activity, discussing what was observed, what meaning each person derived in regard to the key ecological concepts, the interrelatedness of concepts, what the macro-model emphasized in terms of instruction (e.g. motivation through mystery and ambiguity, imagination, embodied experience), and the implications for teaching in their own (eventual) classes. However for some macro-

models, no debriefing took place, in order to emphasize the need to reflect on and derive meaning from the experience for oneself. Teacher candidates were required to hand in a follow-up to each macro-model including a summary of what they learned from the activity and how they might change their own behaviors/lifestyles based on what they learned. The instructor then provided written comments on these follow-ups and often met with teacher candidates individually to facilitate further discussion.

Macro-models were also featured during the weekend immersion sessions, though these sessions also included traveling by either foot, large canoes or cross-country skis through natural settings in order to be immersed in natural systems. Finally, at some point in the course, pairs of teacher candidates taught a one hour lesson to the class on a topic of their choice featuring a macro-model they had developed.

However the concepts that each macro-model features are not isolated in the real-world. Thus discussion throughout the course as more and more macro models are conducted involves the connections between macro-models and more importantly between concepts. For example, an activity involving the electro-magnetic spectrum and the different kinds of photons assists the teacher candidate in understanding how photolysis and photosynthesis work. Understanding photolysis assists in understanding how it works in tandem with decomposition to break down matter, much of which ends up in the soil. After participating in more and more macro-model experiences, the teacher candidates begin to understand the comprehensive and gestalt-like nature of ecological literacy (e.g. understanding how entropy weaves its way through all these systems) and that to be ecologically conscious, one has to examine how ultimately everything interconnects, when focusing on solutions to complex problems.

Examples of the Ecological Macro-model Teaching/Learning Process

The following (Figure 1) is an example of a macro-model for the concept of „transpiration" in a tree (Puk, 2010). An outline of the layers of a tree is created from ropes lying on the ground on a hill with the top of the tree at the top of the hill, a core/pith area in the middle and layers of xylem and phloem on both sides and the "roots" at the bottom of the hill. As participants in the macro-model, some teacher candidates run from the bottom of the tree i.e. the roots to the top of the tree i.e. the leaves and back again in a continuous circuit through the "xylem layer" carrying pails of water which are then thrown into the air by other teacher candidates who are the leaves. Other teacher candidates carry "food" (colored balls) manufactured in the leaves down to the roots through the "phloem layer" and then run back to the leaves in a continuous circuit to obtain more "food". Teacher candidates change roles several times to facilitate the transfer of knowledge from one role to another in order to understand how the whole system/organism works. Thus teacher candidates learn how the tree conducts transpiration, through embodied experience and how to teach the macro-model when they become teachers.

Another example of a macro-model involves „soil" (Puk, 2010). This macro-model (see Figure 2) exemplifies the complexity involved in natural systems and our reciprocal relationship with natural systems as there are many roles/organisms in soil all working together in a non-linear, „chaotic" manner. Teacher candidates are assigned roles including: plants, bacteria, protozoa, nematodes, soil, litter, humus, earthworm, fungus, arthropod, vole, tractor, pesticide, and population. The playing area is underneath tarps tied waist-height off the ground (representing the limited space below ground that many of these organisms interact within) with a plant standing upright at either end of the tarps. Some „organisms" are given tokens which they must give to other organisms that catch/tag and kill/utilize them, thus representing the continuous transfer of energy (each token represents a new life so that no one is ever out of the activity). Each entity has a set of rules they must follow e.g. bacteria, nematodes and protozoa stay close to

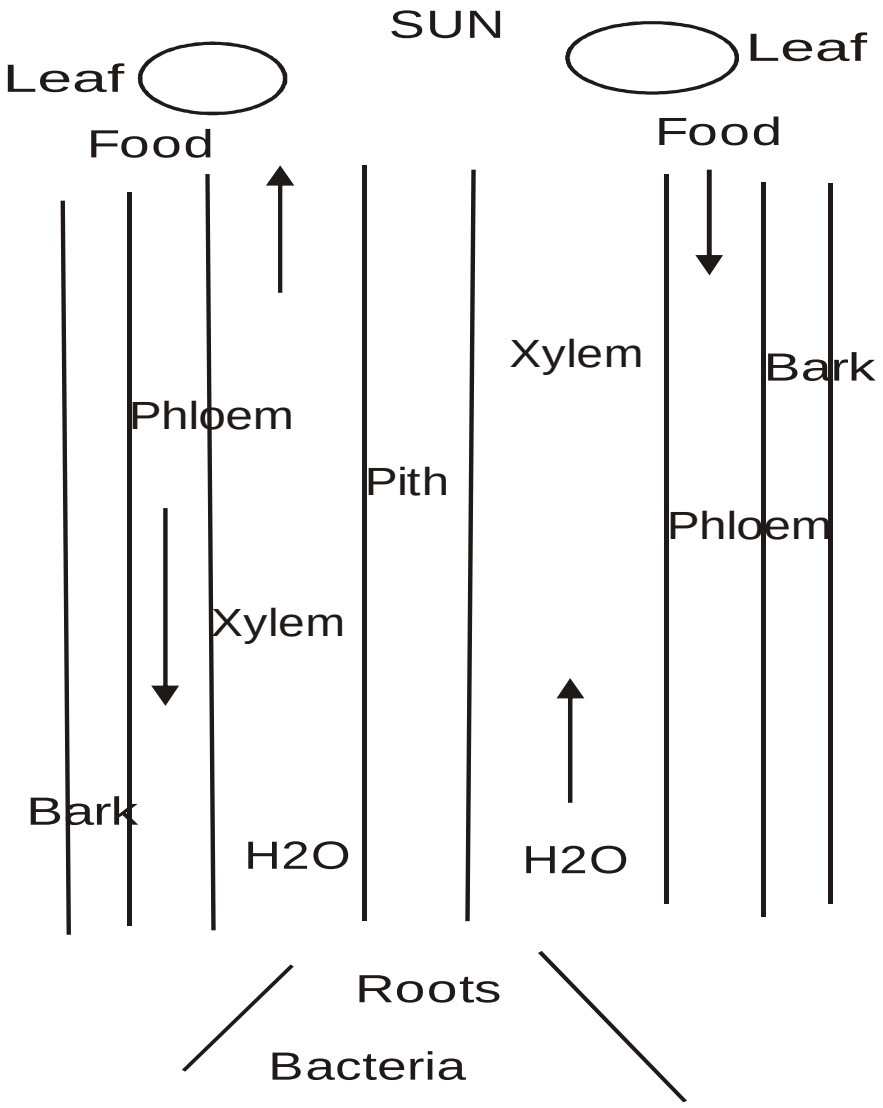

Figure 1. Ecological Macro-Model-Big Dentro Puk (2010)

the plants providing energy; the tractor, pesticide and population are roaming over the whole playing area taking energy chips from the other organisms. Each entity either has their feet tied together or can only crawl in the playing space. Thus there is constant interaction as all participants are bumping into/communicating with each other on a continuous but slow basis. There is no sequence to this macro-model as these interactions occur in a self-organizing and chaotic manner; rather the parameters that are inherent in each role create emergent interactions that no one (including the instructor) can predict. Once again, teacher candidates change roles

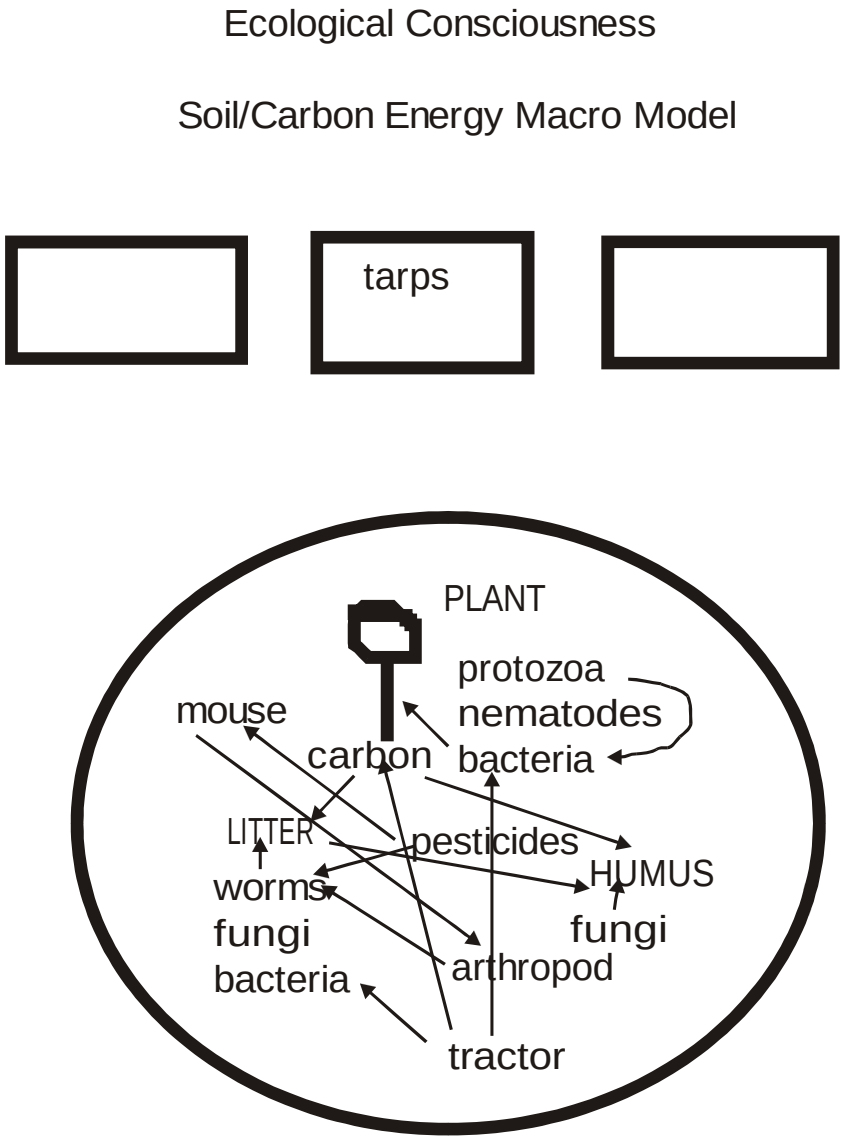

Figure 2. Ecological Macro-Model-Soil/Carbon Energy Puk (2010).

several times in order that a more comprehensive understanding of the complexity of soil is achieved.

In a recent study, teacher candidates in this same course rated ecological macro-model learning very highly (Stibbards & Puk, 2011). The main implication of the study was that the "ecological macro-model" emergent learning approach significantly increased teacher candidates‟ confidence regarding their own understanding of ecological concepts and their ability to utilize macro-models in their own teaching practice. Further, the emergent, embodied learning approach was viewed very positively by these teacher candidates (Stibbards & Puk, 2011), which increases the likelihood that they will use the approach in their future teaching practice.

Participants

Twenty teacher candidates enrolled in a pre-service teacher education course in ecological literacy in a faculty of education in Ontario were voluntary participants in this end-of-course study. There were thirteen (13) females and seven (7) males involved in the study, with ages ranging from 22-33. Six candidates had undergraduate degrees in science (e.g. Honours Bachelor of Science, Bachelor of General Science), eight had degrees in geography (e.g. Bachelor of Arts in Geography) and six had degrees in social sciences (e.g. Honours Bachelor in Social Work, Bachelor of Social Sciences in Religious Education, Bachelor of History). These teacher candidates were learning how to teach ecological literacy for grades 7-12. The pre-course study (Puk & Stibbards, 2010) involved fifteen teacher candidates and the post-course study involved twenty teacher candidates, as five additional students enrolled in the course subsequent to the pre-test. The pre-course and post-course comparison analysis (see Dimension 3 of analysis below), therefore, includes only the fifteen teacher candidates from the pre-course study.

Methodology

The Concepts

Pre-course

During the first week of class in September, fifteen (15) of the teacher candidates in this course were asked to define nine concepts as they related to ecological education: The Environment, sustainability, green, fossil fuel, entropy, waste, ecological literacy, ecological integrity and ecological consciousness. These concepts were chosen because a/ they were key concepts featured in the course, b/ some are found in various Ontario Ministry of Education curriculum guidelines, c/ many are embedded within the literature (Orr,1992; Cutter-Mackenzie & Smith, 2003; Biriukova, 2005; Puk & Makin, 2006) and/or d/ most are common in daily usage, either in media, books or daily conversation. The results of the pre-course study are found in Puk and Stibbards (2010).

Post-course

During the first week of March at the end of the course, all twenty (20) teacher candidates were asked to define the concepts. In both the pre-course and post-course studies, the teacher candidates were provided with unlimited time to complete their definitions. This current study will a/ provide the results of the post-course definitions, b/ compare the results of the pre-course and post-course definitions for the fifteen (15) teacher candidates who gave pre-course definitions, and c/ examine the growth that occurred in ecological concept development.

Concept Analysis

A variation of concept analysis (Puk & Stibbards, 2010) was utilized to interpret and code these definitions. The essence of this form of “discourse analysis” is to reveal the mental representations (i.e. the concept meanings) that people have stored in their neural pathways that we cannot otherwise observe. Because these written definitions are forms of discourse, there is always a degree of interpretation. “Reality can be interpreted in various ways and the understanding is dependent on subjective interpretation" (Graneheim & Lundman, 2004, p. 106).

Dimension 1: Analysis of Meaning.

A similar methodological sequence was followed in the post-course study as was utilized in the pre-course study (Puk & Stibbards, 2010):

> **a/** the teacher candidates were asked "what is it ? (provide a definition)" for each concept. These written responses became the "units of analysis". Concepts that were not defined at all (i.e. the responses were blank) were coded as "non-definition" at this stage.
>
> **b/** Within these units of analysis, criterial attributes were identified, each of which contain a "chunk" of meaning.
>
> **c/** Content areas were then collapsed into "categories" and coded primarily on the basis of the number of similar and dissimilar criterial attributes in each definition.
>
> **d/** Finally, "dominant themes" were formulated to signify the "thread of underlying meaning" found in each category.

A second level of concept analysis (Robinson et al., 1985) was also applied to determine a/ if the attributes were vague (meaning is either absent or cannot be interpreted), b/ if the attributes were propositions (that said something about the concept without defining it), c/ if the attributes were limited in their meaning, d/ if there were missing attributes, e/ if the attributes were themselves so complex as to require further definition, f/ if attributes were redundant due to repetition, and g/ if the attributes were incorrect. Responses that fell into this broad category (a-g) were coded as "non-definition".

A sample of how the concepts were analyzed can be found in the following sequence for the concept of "Ecological Consciousness":

> a/ *Identify Units of Analysis:* units of analysis are the whole definitions. The following are examples of units of analysis: #1."Feeling of kinship with ecological systems, as well as the internalization and intentional application of ecological literacy to make positive change in everyday life"; #2. "To be aware of the natural systems that go on around us that help the earth".
>
> b/ *Identify Criterial Attributes*: criterial attributes are the individual "chunks" that in combination provide the meaning inside the unit of analysis/definition; e.g. i. three criterial attributes were identified in example #1: "feeling of kinship with ecological systems", "internalization and intentional application of ecological literacy" and " to make positive change in everyday life"; ii. two criterial attributes were identified in example #2: "To be aware of the natural systems that go on around us" and "that help the earth".
>
> c/ *Determine Categories*: individual definitions are assigned to the same category when they contain similar criterial attributes; i. definition #1 was centered around the need to make positive changes based on one"s knowledge about and feelings for the natural world, whereas ii. definition #2 was based on awareness of natural systems but did not include the criterial attribute that involved action.
>
> d/ *Provide Themes*: themes provide the overarching meaning implicit in multiple definitions in the same category even though different words and different syntax may be

found in the individual definitions; i. definition #1 (and any others in the same category) was given the theme of "applied affective action" whereas ii. definition #2 was given the theme of "awareness".

Dimension 2: Discernment

The central dimension of interest in the pre-course study involved the criterial attributes (i.e. the meaning) of the concepts found in the teacher candidates‟ responses. However during the post-course analysis, a new dimension was evident in the responses. For four of the concepts, teacher candidates provided extensive critical comments on the perceived common usage of the term as expressed in media, books and daily conversations. This dimension was not evident in the pre-course data. Thus, a second emergent dimension of "discernment" was added and an additional step, i.e. "determine level of discernment", in the post-course analysis.

Dimension 3: Growth in Conceptual Understanding

A third dimension in concept analysis involves growth in conceptual understanding. With both pre-course and post-course data, we were able to analyze the degree of "increased maturity" (Robinson et al., 1985, p. 169) that the fifteen (15) teacher candidates who gave pre-course definitions achieved in their understanding of key ecological concepts ostensibly as a consequence of the course curriculum and instruction. Increased intellectual maturity is used here in the sense of increased sophistication in conceptual understanding. For this dimension, we placed the responses along an emergent maturity scale according to:

Level 1: Unacceptable: immature: these are responses found in the non-definition category as described previously.

Level 2: Minimally Acceptable: limited maturity: this level is characterized by definitions that contain one viable criterial attribute.

Level 3: Enriched: enriched maturity: this level is characterized by definitions of increased maturity, enriched by a partial set of viable criterial attributes.

Level 4: Exemplary: robust: this level is characterized by definitions that contain a mature, coherent set of viable, interconnected criterial attributes. Mature is used here in the sense of what might be expected at this level of education.

At each level, meaning emerges by passing through a threshold of increase maturity in conceptual understanding. The complete "methodology for determining growth in ecological concept development" is found in Figure 3.

By assigning a numerical rating of '1' for Level 1 definitions, '2' for Level 2 definitions, '3' for Level 3 definitions, and '4' for Level 4 definitions, we were also able to apply paired sample t-tests to examine the significance of teacher candidates' increases in maturity in concept definition. Our hypothesis was that with each of the concepts, the sample group of teacher candidates would demonstrate significantly increased maturity in defining concepts, as demonstrated by significant increases in their ratings for concept definitions between pre and post-course.

Results

Dimension 1: Analysis of Meaning

In the post-course study, twenty teacher candidates provided personal definitions for five of the concepts (they only provided critical reflection for the other four concepts rather than personal definitions). Of these five concepts (ecological integrity, ecological consciousness, ecological literacy, entropy and fossil fuels), all but fossil fuels acted as "threshold" concepts. In the pre-course study (Puk & Stibbards, 2010), the vast majority of teacher candidates had "non-definitions", i.e. either no definitions or "immature" definitions for all concepts. In the post-course study, the vast majority of teacher candidates had either enriched or robust definitions for all five concepts.

Ecological Integrity

Nineteen teacher candidates (95%) said that ecological integrity meant that the primary goal of society should be the taking care of natural systems. Of these nineteen, five teacher candidates (20%) felt that ecological integrity involved the actions required to maintain a "balance" and to protect the "resiliency of natural systems" in order to allow them to "rejuvenate and assimilate", eleven (55%) stated that ecological integrity involved the actions required to "protect" natural systems and three single responses (15%) included: "a belief system", "connection with the land" and "commitment to communities". In addition, one response was a vague, non-definition.

Ecological Consciousness

This concept had the highest degree of uniformity of the main theme in comparison to all the other concept definitions. Nineteen out of twenty (95%) stated that ecological consciousness involved a/ "positive" "action" towards b/ "natural systems" c/ based on one's "ecological literacy" in order to d/ create "change" in behaviors. Examples of this include: ecological consciousness is "a feeling of kinship with ecological systems, as well as the internalization and intentional application of ecological literacy to make positive ecological change in everyday life"; "being able to act upon information of ecological systems to reduce impact on the systems and properly inform others of their implications and how to reduce impact". In addition, eleven teacher candidates (55%) also said that ecological consciousness involved developing a "kinship" or feeling of "ecophily" "with nature". One response (5%) defined ecological consciousness as "awareness about natural systems".

Ecological Literacy

Fourteen teacher candidates (70%) stated that ecological literacy was "an understanding of the interconnections between natural systems and human systems". Five teacher candidates (25%) added a second theme by saying that ecological literacy was the "capacity to act on" or "modify ones actions", based on an understanding of the interconnections between natural and human systems. One response was a vague, non-definition- "the state of knowing on how to become ecologically conscious".

Entropy

Eleven responses (55%) stated that entropy was the "loss of energy" "when energy moves from one state to another". Three responses (20%) said that it was "a change in state of energy which leads to equilibrium in a closed system". One teacher candidate said that it was "a force that

Dimension A: Analysis of Meaning
1. Identify Units of Analysis (i.e. definitional responses)
2. Identify Criterial Attributes
3. Identify Non-Definitions in Units of Analysis and Criterial Attributes:
    a/ if vague
    b/ if propositions
    c/ if limited
    d/ if missing
    e/ if complex
    f/ if redundant
    g/ if incorrect
4. Determine Categories
5. Provide Themes

Dimension B: Level of Critical Reflection
6. Determine Level of Critical Reflection

Dimension C: Analysis of Growth
7. Place pre-test and post-test definitions on emergent maturity scale

Figure 3. Methodology for determining meaning, critical reflection, and growth in ecological concept development

degrades energy, moving it in one direction (available to unavailable) in order to create equilibrium". Three (20%) had vague, non-definitions e.g. "a universal force which is degradable through transfer but cannot be destroyed". Two teacher candidates (10%) had one criterial attribute which was incorrect when they said it was a transfer of energy from "equilibrium to disequilibrium". This concept produced the highest number of non-definitions with five.

Fossil Fuel

Sixteen teacher candidates (80%) stated that a fossil fuel was "a substance made from plant or animal matter" (40%) or carbon/organic matter (40%), "compressed over time" "underground" and "used by humans as a source of energy". Three teacher candidates (15%) had 1-2 of these criterial attributes missing e.g. "a resource made up of compressed organic matter used to produce energy". One teacher candidate had an incorrect attribute when s/he said it is a "gas".

Dimension 2: Discernment

In the post-course study, four of the concepts (the environment, waste, sustainability and green) received extensive critical reflection, so much so that the authors added this dimension to their analysis. For the concept green, 100% of teacher candidates provided critical comments about its common usage, the environment received 90% critical reflection, the concept of waste received 95% critical reflection and sustainability received 80% critical reflection.

The Environment

Eighteen out of 20 teacher candidates (90%) took a critically reflective or "discerning" approach to this concept, i.e. they did not actually provide a personal definition but rather commented on

what they felt was problematic with the common usage of this term. One response stated that "there is no precise definition for it". Sixteen out of 18 in this category said that the term was usually "misused" by others to describe the natural world. Two of sixteen in this category said that it was usually used to refer to ones "surroundings". One hundred percent of those in this category felt that the way this term was normally used was harmful as it "separated" or "disconnected" humans from the natural world. Several went as far as saying that the use of the term was "destructive" because of this defined separation. Two (10%) of the teacher candidates took a "non-critical" approach. One defined the environment as everything, including the natural world and human world. The other respondent defined the environment as involving "the natural world" only. The results for this concept were significantly different than the pre-course results. At that time, none (0%) of the teacher candidates took a discerning approach in defining this concept after four to five years of university study. They had simply defined ecological concepts in the same manner they had come to understand them as found often in the media and everyday conversation (e.g. "nuclear energy is green") without really questioning the rigor of the common usage.

Waste

Seventeen teacher candidates (85%) stated that the concept of waste was commonly used in the sense that waste either had "no use" or "no value" to humans while two candidates (10.5%) stated that waste was used to signify "objects that have served their original purpose". However after defining waste as they felt it was commonly used, all but one teacher candidate (95%) took a critically reflective approach towards the societal use of this term with comments such as "it is important to understand that waste does not exist in the natural world", "by calling it "waste", we have absolved ourselves of responsibility for it", "it is important to show people that nothing is "waste", and "it is important to know that waste is a human-constructed term because people take the term and use it as an excuse to throw away items they do not want". In other words, they found the common usage of the term to be problematic. One teacher candidate took a non-critical approach, making no additional critical comments about the general use of this concept. However this same teacher candidate provided a non-definition and instead provided a proposition that "waste is created by humans to be thrown out into the dump".

Sustainability

Sixteen teacher candidates (80%) made additional discerning comments about the use of the term and 12 candidates in this category (60% of all teacher candidates) centered their critical comments around the observation that they believed that the concept of sustainability was used in an "anthropocentric manner", i.e. that preserving/conserving/maintaining natural resources was being advocated for humans primarily, not for the other kingdoms of life. Several commented that this meant that other kingdoms could be abused under this common usage of the concept. Other critical comments stated that the concept was "flawed", "doesn't exist", "very arbitrary" and "does not coincide with ecological integrity". Eighteen teacher candidates (90%) said that this term was used in the sense of "preserving"/ "conserving"/ "maintaining" natural resources or natural systems " for future generations". One teacher candidate said that it was about maintaining a [human] "lifestyle for future generations" and one provided a vague non-response.

Green

This concept received the most critically reflective comments as 100% of the teacher candidates made discerning comments about the use of this word. Sixteen (80%) said it was a either a "mar-

keting ploy" or "marketing tactic" instigated by business, industry or government. Other comments included that this was a "propaganda term", used in "brainwashing" and "green-washing" to convince consumers that the product was "environmentally-friendly". Five of the teacher candidates (25%) said that there was "no" definition or "no precise" definition for this concept. All the rest of the class (75%) gave definitions of how they felt the term was generally used but also making it clear they did not use the term in this manner. Eight teacher candidates (40%) said that green products were perceived as either "environmentally" or "ecologically friendly". Three teacher candidates (15%) said it implied products were "less harmful" and one felt it was used to imply that green products were "not harmful". Three (15%) said that green was commonly used to mean "better" and "healthier for the environment".

Dimension 3: Growth in Conceptual Understanding

Table 1 indicates the differences in percentages between Level 1 - 4 definitions given by the teacher candidates before and after the course. Note that these differences include only the 15 students who were in both the pre-course and post-course studies. As the table makes clear, the majority of pre-course definitions supplied by teacher candidates were unacceptable/immature or minimally acceptable/limited maturity. It is worth pointing out again that many of these students entered the course with undergraduate degrees in sciences or geography, and therefore should have been expected to have had some exposure to at least some of these key concepts. After the course, the majority of definitions given by teacher candidates were either enriched/enriched maturity or robust/exemplary, leaving us, as researchers and instructors, with a much more positive outlook regarding the influence these teacher candidates will have on their future elementary and secondary students regarding ecological conceptual understanding.

For entropy, 13% of definitions were rated at level 4 as they referred to the attributes of "a force that degrades energy, reduces disorder and increases equilibrium in a closed system". Sixty percent of definitions were rated at level 3 as they each contained several of these attributes but did not contain the complete set. For fossil fuels, 66.6% of definitions rated level 4 as they

Table 1. Levels of Growth in Ecological Concept Development, Percentages Pre and Post-course

Percentage (%) of sample group	Level 1 Unacceptable (immature)	Level 2 Minimally Acceptable (limited maturity)	Level 3 Enriched (enriched maturity)	Level 4 Exemplary (robust)
entropy	pre-100 post-27	pre-0 post-0	pre-0 post-60	pre-0 post-13
fossil fuels	pre-66.6 post-6.6	pre-26.6 post-0	pre-6.6 post-26.6	pre-0 post-66.6
ecological literacy	pre-46.6 post-6.6	pre-33.3 post-0	pre-20 post-26.6	pre-0 post-66.6
ecological consciousness	pre-40 post-0	pre-40 post-0	pre-20 post-0	pre-0 post-100
ecological integrity	pre-66.6 post-6.6	pre-26.6 post-0	pre-6.6 post-46.6	pre-0 post-46.6

referred to "natural substances found in the earth‟s crust composed of carbon and hydrocarbons as a result of heat and pressure applied to animals and plants millions of years ago and used by humans as sources of energy". Ecological consciousness was scored the highest as all definitions referred to "taking continuous positive action towards natural systems based on one‟s ecological literacy in order to create change in behaviors" and were rated level 4. In regard to ecological literacy, 66.6% of definitions were rated level 4 as they referred to "a capacity to make decisions based on one‟s understanding of the interactions between natural systems and human systems" while 26.6% definitions rated level 3 as they contained an incomplete set of attributes. For the concept of ecological integrity, 46.6% of definitions rated level 4 as they referred to the goal of "preserving the resilience of natural systems to rejuvenate and assimilate as they change" and 46.6% rated level 3 as they did not contain the complete set of attributes. It is important to point out that the wording of each definition did not need to be exactly the same as the wording expressed above in order to score at a certain level but rather that the meaning of each criterial attribute had to be present.

a) *Increased maturity in definitions.* As indicated in the methodology section, we also translated Level 1 - 4 ratings on concept definitions into numerical values, so that further analysis on growth in conceptual development could be conducted. Table 2 illustrates this analysis, showing the means for pre and post-course ratings of definitions, differences between means, standard error, degrees of freedom and t-score for each difference. Each of the definition ratings demonstrated significant increases from pre to post-course: entropy, $t(14) = 5.870$, $p < .001$; fossil fuels, $t(14) = 10.212$, $p < .001$; ecological literacy, $t(14) = 12.911$, $p < .001$; ecological consciousness, $t(14) = 15.922$, $p < .001$; and ecological integrity, $t(14) = 11.225$, $p < .001$. These changes are remarkable, not only due to the size of the mean rating differences for each concept, but because the t-scores are extremely high for a sample group of 15, which is considered quite small for quantitative research. That significance levels are below .001 for increases in ratings for each concept, pre to post-course, means that these increases are not due to chance, but rather reflect real increases in definition maturity, which strongly supports the concept analysis results reported in Table 1.

b) *Ability to provide a definition for key ecological concepts.* In the pre-course study, 17% (23 of 135) of the total possible definitions were blank i.e. there were no definitions provided. Entropy had the highest number of blank definitions with 66% of the teacher candidates not able to provide one (Puk & Stibbards, 2010). In the post-course study, there were zero blank responses for any of the concepts i.e. all concepts were defined.

c) *Vague definitions.* In the pre-course study, there were overall 25 definitions that were categorized as being "vague", thus non-definitions. Vague definitions are characterized by criterial attributes that don‟t address the meaning of the concept. The concept of "fossil fuel" had nine vague responses just for itself . In the post-course study even with the addition of five more students, there were overall only seven vague responses. As well, there were zero vague definitions for the concept of fossil fuel.

d) *Variability of definition themes.* The primary characteristic in the pre-course study was the variability between teacher candidates in the themes found in their definitions. For example, there were seven different themes (seven different meanings) identified for the concepts of green and waste and six for sustainability. In other words, there was little agreement on the meaning for the same concepts (Puk & Stibbards, 2010). In the post-course study, ecological consciousness had the highest level of congruency (and lowest level of variability) with 100% expressing the same theme while entropy had the most variation in meaning with three themes.

Table 2. Means, Differences, and Paired-sample t-tests for Concept Development, Pre to Post-course

Concept		*M*	Difference (post-pre)	*SE*	*df*	*t*
entropy	pre	1.00	1.60	.136	14	5.870***
	post	2.60				
fossil fuels	pre	1.13	2.40	.153	14	10.212***
	post	3.53				
ecological literacy	pre	1.33	2.14	.160	14	12.911***
	post	3.47				
ecological consciousness	pre	1.40	2.60	.082	14	15.922***
	post	4.00				
ecological integrity	pre	1.13	2.40	.153	14	11.225***
	post	3.53				

Discussion

The teacher candidates in this study were products, pre-course, of four to five years of university education. As Gregoire (2003) has suggested, "teacher education programs are failing to do their job if perspective teachers enter into teaching with their initial beliefs intact. Unfortunately, the evidence is clear that this is exactly what happens" (p. 149). Liu and Thompson (2007) demonstrate that practicing high-school teachers are unable to consistently and accurately define the fundamental concept of „probability". Wieman (2010) reports that in traditional university science lecture courses, "students master no more than 30 percent of the key concepts that they didn't already know at the beginning of the course" (p.180). The current study demonstrated very different outcomes. Significant growth was demonstrated in the ability of teacher candidates to define key terms used in ecological education and in their disposition to critically examine concepts that they felt were problematic in their common usage. We attribute this growth directly to the embodied, emergent nature of the macro-model approach to learning. However, in Ontario where there are no discrete courses in Ecological Literacy in the K-12 provincial curriculum, all teachers are expected to "integrate" environmental education into the existing curriculum. Without a course such as the one investigated in this study, it is probable that these teacher candidates may have become teachers with their pre-course, "immature" definitions for ecological concepts intact. Meyer (2010) asserts that 'threshold concepts' exist in every discipline, and cannot be taught using didactic information transmission methods. Instead, comprehension of complex concepts requires syntheses between many less complex concepts, and experiences which facilitate encountering these interconnections. That is, complex concepts cannot be directly taught to students - they must have experiences that allow them to make and to construct, much more sophisticated cognitive connections. For more information, see Stibbards and Puk

(2011), where it was demonstrated that the macro-model, embodied approach provides the learner with the opportunity to encounter these interconnections. The present study has provided further evidence that teacher candidates can develop mature understanding of ecological concepts through the macro-model approach.

Recommendations

1. Educators at all levels should explicitly assess the understanding that learners have in regard to key ecological concepts that are featured in their courses and not take for granted that just because learners use the words articulately, there is mature meaning-making beyond the surface level use of the words.

2. Educators should encourage learners at all levels to be discerning in regard to the everyday usage of ecological concepts that they hear in the media and not assume that everyone using the same words (e.g. green and sustainability) shares the same meaning. Learners should be encouraged to question the use of simple words such as "green" when used to describe complex processes.

3. Educators should consider utilizing the nature-embedded, embodied experience found in the macro-model approach to teach ecological concepts. Embodied experience creates a lasting mental image of the system being studied from which the learner can derive meaning.

4. Teacher educators should consider utilizing the macro-model approach as an alternative to transmission instruction to teach teacher candidates and classroom teachers how to teach about complex ecological concepts. Embodied experience allows the teacher-as-participant to make observations about the learning process from within their own learning experience and to understand what preparations and adaptations they need to address during their own classroom teaching.

5. More research is required to shed further light on how exactly teacher candidates conceptualize the relationships between the various macro-models and their embedded concepts as well as what more can be done to facilitate these connections during the macro-model experiences. This is a very challenging and complex task.

In today‟s frenetic world, where simple words are used to sell products and messages, the sound-byte predominates. However it takes time and effort to understand the meaning that someone else has for the words they use. It also takes time and effort to figure out the meaning we have for our own use of concepts. In regard to moving towards ecological consciousness, we believe the effort for both would be time well spent in higher learning, especially for teacher candidates, as their understanding of ecological concepts and learning approaches will ripple down to future students. Embodied, emergent design provides rich possibilities towards the development of conceptual understanding and ultimately discerning teachers.

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Ekolojik kavram gelişimi ve öğretmen eğitiminde kavramsal anlama: anlayan öğretmen

Puk ve Stibbards (2010) tarafından yapılan bir önceki çalışmada ekoloji literatürüne giren bir grup eğitim programı öğretmen adaylarının karmaşık ekolojik kavramların yeterli olmayan anlamalarına sahip olduğu gösterilmişti. Özellikle yazılı tanımların ya tümüyle olmadığı, anlaşılmaz olduğu ya da esansiyel özelliklerin eksik, anlama ilişkin bir tutarlılıktan yoksunluk olduğu bulunmuştu. Hâlihazırdaki çalışma, yenilikçi öğrenme yaklaşımını esas alan program sonunda, aynı grup ve kavramlarla öğretmen adaylarının ön ve son kurs sürecindeki kavramsal anlamasındaki gelişme, bu kavramları tanımlayabilme becerisini tespit amacıyla yapılmıştır. Bu öğretmen adaylarının katıldığı servis öncesi kurs, dinamik, şekillendirilen etkinlikleri kapsamaktadır ve doğal sistemler ve insan sistemleri arasındaki kesişmede bulunan derin anlam karmaşıklığını araştırmaya yardımcı olmaktadır. Bu çalışmada yeni öğretme etkinliklerinin bir parçası olan anahtar ekolojik kavramaların gelişiminde anlamlı bir büyüme bulunmuştur. İlaveten, öğretmen adayları kendi tanımlarının kritik değerlendirmesinde gösterdikleri bazı genel kavramların kullanımında yeni bir yaklaşım ifade etmişlerdir. Bu bulgular, öğretmen adayları için kavramsal anlam ve ekolojik kavram gelişimin doğayla iç içe ve gömülü tecrübelerle gerçekleşebileceğini önermektedir.