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The Ecology of Teaching & Learning (Science)

A Ecologia do Ensino e da Aprendizagem da Ciência

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Abstract: The present position paper articulates insights of complexity science, a progressive approach to understanding living systems that is compatible with critical perspectives on teaching and learning. Drawing from examples of an outdoor activity in a teacher education science methods course, we argue that complexity science offers an ecological perspective on education itself. That is, learning and teaching are understood as nurturing students to adaptively reorganize their belief systems to adjust to larger biological, social and cultural practices that are themselves constantly evolving. The infusion of complexity theory into education – and the associated development of a wider appreciation for the intricate nature of teaching and learning processes – not only makes it more likely for teachers and students to be able to interact effectively with(in) the world in multileveled and relational ways, but it also empowers (provokes) them to act upon current global socio-ecological problems in more just and sustainable ways .

Keywords: ecology of teaching and learning, complexity science, food education, science education, teacher education

Resumo: O presente artigo articula uma perspectiva ecológica sobre os processos de ensino e aprendizagem (em ciências) baseada em elementos da ciência da complexidade. A partir de exemplos de uma atividade ao ar livre num curso de ciências para a formação inicial de professores (licenciatura), argumentamos que ensinar é uma forma de encorajar os estudantes a reorganizar os seus sistemas de crenças para se ajustarem a práticas biológicas, sociais e culturais, que estão em constante evolução. A infusão da teoria da complexidade na educação (científica), bem como o desenvolvimento de uma apreciação mais ampla da natureza dos processos de ensino e aprendizagem, não apenas torna possível que professores e alunos possam interagir efetivamente com/no mundo, mas também os capacita (provoca) a agir de maneira mais justa e sustentável em relação aos atuais problemas sócio-ecológicos globais.

Palavras-chave: ciência da complexidade, ecologia do ensino e aprendizagem, educação alimentar, educação científica, formação inicial de professores (licenciatura)

Introduction

Ecology is classically defined as the branch of biology that studies the relations of organisms to one another and to their physical surroundings (Allaby, 1998). In other words, ecology is one of the disciplines teachers and students need to learn well in order to deal effectively with current environmental problems (Reis & Scott, 2018). At the same time, we argue here, ecology also provides a generative framework for understanding teaching and learning processes as self-organized adaptations at multiple linked levels, from the cellular to persons to cultures and the ecosphere.

Although we draw upon diverse array of influences – ranging from neurology/physiology to constructivism and sociocultural theory – to support our argument, we rely mostly on complexity science to articulate the progressive (critical) notion that *learning is ecological* (analogously to living systems and their dynamics). Complexity science is a cross-disciplinary discourse developed in the past few decades to study complex, living systems such as cells, whole organisms, cities and ecosystems. Unlike traditional analytic science, which only analyses component parts and linear causation, complexity also looks at the dynamic, non-linear relations and interactions within and among parts. From a complexity science perspective, learning is understood ecologically: that is, as a multilevel and relational process. This, in turn, suggests that individuals adaptively reorganize their beliefs in order to interact effectively with our world. Similarly, they are embedded within larger social knowledge practices that are themselves evolving, or adaptively reorganizing. To say that a living, complex system "knows" something means that it has "coupled" with some aspect of its environment — although such knowing is always provisional and temporary, as environments are themselves constantly changing.

In sum, we argue for the infusion of complexity science into education – specifically science education – in order to help teachers and students everywhere not only to develop a wider appreciation of the sociocultural and ecological relationships around them and how to act effectively upon global problems, but also to understand how their learning and knowing are themselves ecological processes intertwined with these wider relationships. In order to practically illustrate these relatively abstract ideas about multilevel, ecological perspectives on teaching and learning, we draw upon examples from a recent visit to a community garden (socio-ecological activity) with science student teachers at a Canadian university.

Mechanical metaphors: Traditional approaches to learning

Young boy: I taught [my dog] how to whistle.
Friend: I don't hear him whistling.
Young boy: I said I taught him. I didn't say he learned it[1].

Deeply entrenched in Western cultures is the belief that learning occurs when teachers *teach* and students *are taught* information. This view of school education is well aligned with traditional (formal) forms of instruction, where "a monologic teacher is largely concerned with the transmission of knowledge to pupils" (Lyle, 2008, p. 225). From this perspective, knowledge acquired through systemic schooling is a valuable socio-cultural commodity available for sale (Norris, 2011; Reis, 2018a). Therefore, it is not uncommon for teaching and learning to be described by simplistic mechanical metaphors, such as acquisition of knowledge and skills or controlling inputs to achieve desired outputs (Osberg, Biesta, & Cilliers, 2008; Paavola, Lipponen, & Hakkarainen, 2004; Sfard, 1998). Worse yet, this type of approach to education implies that individual teachers are the only specialists (gatekeepers of knowledge) and that students are the only learners (*tabula rasas* awaiting to be filled with their teacher's wisdom). This understanding of how people teach and learn not only starkly contrasts with what is already well stablished in the field of education (Bransford, Brow, Cocking, & NRC, 1999), but also leaves indelible marks on the overall perceptions of people of the value of schooling, school curriculum, and the teaching profession (Reis, 2018b).

One way to characterize traditional views of education is *mentalism* (Davis, Sumara, & Luce-Kapler, 2015). From ancient Greek thought and later religious

[1] Dialogue extracted from a comic strip by Bud Blake ("Tiger," circa 1974).

philosophy, we have inherited the notion that our spirit, *psyché* or mind, is a sort of container that can — if properly instructed — take in (absorb) enlightenment or truths. In more recent centuries, the focus became more practical: acquiring information about the world and putting this information together in one's head so that it corresponds as closely as possible to the objective truth. While the metaphors employed have changed from blank canvases to computers, the underlying assumption of mind-as-container has endured. Indeed, its influence can still be seen in theories such as information-processing (Davis, 2004). Paulo Freire (1972) even coined the term "banking model of education," to critique the notion that knowledge is considered static (stable and constant) enough to be deposited (or directly transferred) into people's heads – much like we bank with our money.

Another approach that has left an impression on how teaching and learning is understood is *behaviourism* (Ormrod, Saklofske, Schwean, Andrews, & Shore, 2010). It is often contrasted with *mentalism*, but actually shares with it the assumption that learning is a property solely of individuals. Like the 19th century physicists and chemists that they sought to imitate, early behaviorists focused only on what was observable and measurable – environmental stimuli and people's responses to them – not unobservable internal mental processes. Behaviourism has been very influential in education and can be seen in attempts to exercise classroom management strategies, which seek to mold student behaviour through conditioned associations, rewards and punishments (e.g. grades, detentions, etc.) as well as through curricula that emphasize what teachers are expected to "deliver" and students to "demonstrate" as part of pre-determined packages of content scattered throughout the academic year. While behaviorism offered a refreshing focus on actions and relationships, it has been widely critiqued for its reductive assumption that humans can be trained like input-output machines or domesticable animals. A behaviourist approach to education may reinforce basic skills or force teachers and students to temporarily comply to rigid systems, but it is not a useful model for nurturing deep learning, innovative problem-solving or ethical decisions (Kohn, 1998).

Organic metaphors: Ecological approaches to learning

In the last hundred years, educational researchers have developed more ecological (biological) and organic metaphors for understanding teaching and learning (Timberlake, 1984). Theories include radical constructivism, socio-cultural theory, enactivism, complexity science, and even recent studies on neural plasticity and the immune system (McMurtry & McMurtry, 2016). Some are concerned with how parts of the human body learn, while others are concerned with learning in organisms, humans, social groups and ecosystems. What unites these new approaches is rejection of simplistic, mechanical metaphors like mentalism and behaviourism and embrace of more ecological (i.e. biological, organic, adaptive and evolutionary) frameworks for understanding education. That is, they emphasize the vibrancy and activeness of teachers and learners, who are not easily controlled or predictable as they construct their own knowledge and make sense of their environment to one another. In addition, it can be said that these theories collectively present a big ecological picture, where learning is seen as a complex, relational, adaptive, multi-level process that cannot simply be equated with contents of individuals' heads or behaviours.

Educational researchers employing complexity science as a theoretical framework have argued that these differing theories are quite compatible and transdisciplinary; they just apply to different levels of complex systems (Phelps & Davis, 2005). For example, radical constructivism is useful for studying individual learning, socio-cultural theory is fitting for studying group learning and behavior, and evolutionary discourses are employed for studying how species – humans included – adapt to (learn within) their environments (Davis & Sumara, 2006; McMurtry, Rohse, & Kilgour, 2016).

Furthermore, complexity researchers have suggested that education at each of these levels is characterized by similar processes of self-organization and adaptation. That is, teaching and learning are understood as adaptations to current environments, yet this adaptation is always a function of self-organizing dynamics of the interactions among teachers and learn-

er, rather than directly imposed by an external force (Heylighen, Cilliers, & Gershenson, 2007).

Capra (2002) offers a lucid illustration of this contrast between merely mechanical systems and complex, living, learning ones:

> [W]hen you kick a stone, it will react to the kick according to a linear chain of cause and effect. Its behavior can be calculated by applying the basic laws of Newtonian mechanics. When you kick a dog, the situation is quite different. The dog will respond with structural changes according to its own nature and (nonlinear) pattern of organization. (p. 35)

To restate: this ecological approach contrasts with traditional, mechanical theories described above, which characterize teaching and learning in terms of acquiring accurate representations or desirable behaviours. From an ecological perspective, education is defined in terms of self-organized adaptation in accordance with people's current contexts.

Finally, educational complexity researchers have argued that these levels are all ecologically linked (Normark, Pata, & Kaipainen, 2012). In the same way that species and ecosystems mutually influence each other, for instance, individual learning and social group learning mutually influence each other. Thus, complexity is an umbrella discourse to understanding education in ecological terms.

In what follows, we will describe how learning at various levels (i.e. individual, social and cultural) can be seen as self-organized adaptation to learners' environmental contexts, as well as how educators might supportively engage with these learning processes. Our examples come from a socio-ecological outdoor activity in a teacher education science methods course, where student teachers learned about and worked at a local community garden situated on the university campus.

Individual level

At the level or individual learning, perhaps the most prominent school of thought associated with ecological metaphors is *constructivism* (Piaget, 1950), although this term is sometimes inappropriately grafted onto traditional approaches as well. Constructivism is associated with the work of Jean Piaget (1896-1980), who argued that learning should be compared to the growth of living organisms, rather than mechanical training or mental information storage. To say individuals learn means that they reorganize their web of beliefs or *schema* to adapt to their environment or circumstances. Likewise, he proposes that learners' experiences prompt them to continuously update their beliefs and maintain coherence. In that sense, teachers must engage with students' existing knowledge in order for learning to be meaningful. On that note, it is not surprising that Piaget would use ecological concepts like self-organization and adaptation as key principles of his learning theory. He was originally a biologist who conducted his doctoral thesis work on how mollusks adapt to different environments (Proulx, 2006).

Individuals' knowing is therefore always a subjective construal, shaped by their biological and experiential histories. From a constructivist perspective, learning and knowing are about what *fits* (internal & external *coherence*) with a person's current physical and social experiences, not *correspondence* to an objective truth. As the constructivist thinker Ernst von Glasersfeld (1989) writes about individual learning, "[k]nowledge cannot and need not be 'true' in the sense that it *matches* ontological reality; it only has to be 'viable' in the sense that it *fits* within the experimental constraints that limit the cognizing organism's possibilities of acting and thinking" (p. 162, emphasis in original). Thus, our knowledge fits the world in the same way our lungs fit the atmosphere – not as a representation, but as a viable coherent construction.

Constructivism has important implications for teachers. Instead of assuming that students *receive* the information we present or can be trained at think the way we want them to, we need to engage with students' existing knowing and attempt to supportively challenge and elaborate on it. Otherwise, we run the risk of doing a disservice to the individual learners by suggesting that education is a simple collection of facts (information) disconnected from people's reality and useless in the exercise of their citizenship.

A different but related discourse that draws upon organic metaphors to explain how we make sense of our experiences is *embodied learning* (Evans, Davies, & Rich, 2009; Skulmowski & Rey, 2018). That is, the experiences from which we construct meaning could never exist for us without our bodies, emotional perspectives, and relationships with other bodies and things (Lakoff & Johnson, 1980; Damasio, 1994; Thompson, 2007; Reis, 2015; Reis & Roth, 2010). As Alexandra Howson (2013) puts it: "We do not simply have bodies that we do things with and to, but we are bodies, our sense of who we are inseparable from our own body" (p.13). Again, our bodies do not represent a world; rather they adapt in a self-organized manner in relation to our particular environments – for example, the way muscles and nervous system adaptively reorganize when we play sports or dance (Leder, 1990).

The picture below (figure 1), showing the hand of a science student teacher covered with soil, grass and a bug, can be used to illustrate these ideas. First, it emphasizes the embodied nature of teaching and learning. The student can only interact with these things as a body, with particular ways of seeing, feeling and smelling. His skin, nervous system and muscles are inevitably affected by this experience: "Embodied knowledge is the body, the organic entity modified by behaviour, training, and experience, deeply enculturated" (Downey, 2010, p. S36). Second, his schema or web of beliefs will likely adapt by building on prior knowing of soil, grasses and bugs, but also accommodating these new experiences.

Figure 1—What it is in your hands?

Through kinaesthetic (bodily) experiences like this, we expect that the student will develop a deeper understanding of soils, grasses, bugs and their relationships. Each one of those elements in his hand does not exist without the other at that very moment and – we hope – will be forever associated with one another whenever the experience is recollected or recounted to (shared with) others. It is not about transmitting true representations to him; rather, teaching and learning are about nurturing more sophisticated knowing that fits coherently with his other beliefs and with the world beyond him. In Deweyan terms, this is experience is also part of a *continuity of experiences* in which students engage throughout the science methods course, necessary to provide context and meaning to immediate experiences as well as shape subsequent individual and community growth (Molnar, 2002).

As we shall see next, just as the mind cannot be separated from body and the surrounding physical (biological) environments, neither can individual learning be separated from its social context. Indeed, one might argue that learning is embodied not only in us and our intricate biological makeup (genes, cognitive networks, blood, etc.), but also in the social environments we share with others.

The social level

We will now shift focus from individual learning and learners to larger scale social learning and learners: groups, teams, companies, cultures and classrooms. Numerous influential theories – like Vygotskian sociocultural theory, social constructivism, activity theory, communities of practice, etc. – all argue that to understand teaching and learning, one must first look to social dynamics, practices and interactions.

Many of the theories mentioned above go even farther, asserting that knowledge is embedded and enacted in social practices, such as farming, language, skilled trades and mathematics. Individuals teach and learn as they participate in and attune themselves to these practices, but much of the knowing remains at the social level. As Jean Lave and Etienne Wenger

(1991) write, "[k]nowing is… located in the relations among practitioners, their practice, the artifacts of that practice, and the social organization and political economy of communities of practice" (p. 122).

From a complexity science perspective, these social learning processes can be seen in ecological terms; we can shift our focus from the individual to social processes and even to their larger scale ecosystems. For example, companies emerge from the interactions of individuals who compose the company and are also shaped by the actions of other companies, suppliers and the wider economic market (Davis & Sumara, 2006). In the same way, a school is defined by the people who work there (teachers, administration and janitorial staff) as well as the larger community where it is situated (parents and other schools in the board).

Second, collective social learning can be seen, much like individual learning, in terms of self-organized adaptation. For example, sports teams must adapt to new rules and innovative play styles of other teams. However, such adaptation is typically self-organized, in that members of the company or team (including coaches) are the ones who drive such adaptation (McMurtry, 2008).

Recognizing the crucial role of social processes in both individual and collective learning empowers educators to broaden what we do in the classroom. It prompts us to work with social dynamics and cultural tools in our classrooms as well as to see interactions and group work as a resource for continuous individual and collective learning (Oliveira-Jayme, Reis, van Eijck, & Roth, 2012; Reis & Barwell, 2013). It asks us to consider collectives as evolving organisms working in synchrony (Davis, Sumara & Luce-Kapler, 2015).

The picture below (figure 2) is an educational example of activity that can be seen as harnessing the benefits of social activities (group interaction) for teaching and learning. Here, students are being instructed by the garden keeper on the various tasks they need to perform in order to prepare it for the Winter. Collectively, students can help each other in many different ways by sharing tasks, imitating one another's actions and even by repeating (even if not literally) the instructions to other students who were late or could not clearly hear what the garden keeper said. The shared participation of all members of the group illustrates how human knowledge is collectively produced and individuals learn by attuning themselves to these processes. Indeed, teaching and learning should be understood in terms of participation in agreed-upon social practices (language, work, etc.), which both *enable* and *constrain* our thinking. Otherwise, without a communal understanding and acceptance of how to behave and what is to be accomplished in certain situations, an entire well-planned educational activity can fail to sustain itself for more than a short time (Reis & Guimaraes-Iosif, 2012).

The collective knowing is entwined with – but distinct from – individual knowing. Collective knowing is not so much about sharing individual knowledge. It is more about how the collective is working together, sharing tasks, modelling best practices, etc. – all of which are well represented in the garden activity.

Figure 2—Group learning

Another way to explain the significance of our social engagement is to consider the amount and quality of work that 20+ students were able to complete compared to what would've been done by one person or even all of the individuals acting in isolation. It is a form of collective knowing, where individuals teach and learn by participating in the tasks assigned to them by the garden keeper; that is, students internalize practices that are intentionally designed for social circumstances where the division of tasks (labour) is viable.

But the increasing expertise of the group is a form of learning and teaching too. Just like our webs of belief and bodies learn and evolve with repetition provided by continuous enactment (Lee & Roth, 2005), so too do our collective webs of interaction and practice.

The cultural level

Even wider scale cultural developments and norms play a role in teaching, learning and knowing. Our Western cultures, for example, can be seen as developing and learning new technologies, social structures and ethical norms over the course of history (Hobsbawn, 2014). Both we (as individuals) and our social organizations participate in – and are shaped by – these cultural developments. Also, cultural teaching and learning processes are self-organized and adaptive. After all, we help to create our cultures and so we can transform them. We, as educators, should recognize how these processes shape us as well as become more conscious of our participation in them (Davis & Sumara, 2006). Only then we will be able to promote the changes we need in order to continue living on this planet.

Such culturally – but also politically, economically and ecologically — conscious approaches to social learning emphasize the need to critically evaluate the knowledge, identities, norms and tools we employ in class and society at large. It invites – better yet, it *provokes* – us to consider teaching, learning and knowledge through the lenses of ethics, power and privilege. Are they fair and democratic to all (humans or not)? Or do they perpetuate unjust, stereotypical or oppressive ways of thinking and acting? If the world is indeed a site of domination – which is not just limited to social spheres, but also includes environmental oppression (Martusewicz, Edmundson, & Lupinacci, 2011) – then why aren't we engaging our students in actively seeking ways to free the planet from humanity's destructive patterns? Some of our readers might see such a call as a shift in our argument – from ecology as a theory to understand teaching and learning, to ecology being a subject matter. To us, however, these two arguments – ecology as subject matter and ecology as a framework for understanding learning and teaching – are connected. They are both part of a wider recognition that we are not separate from the 'natural' world but rather inextricably linked and part of the evolving story of life on Earth. The more deeply we comprehend this, the more effective and inclusive out actions can become.

The picture below (figure 3) contains a word that was written on the blackboard of a classroom. It represents the concept that motivated the visit to the community garden. Why take a science class to a community garden? What could students learn from getting their hands dirty while turning the garden in preparation for the winter?

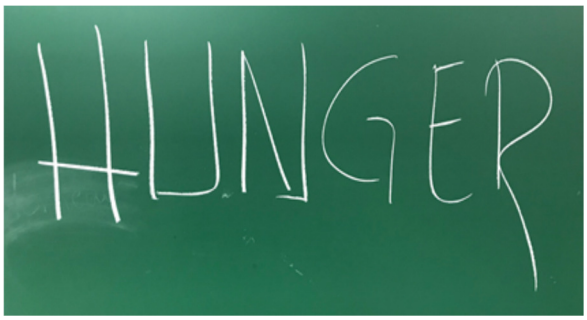

Figure 3—What does hunger have to do with science?

As it turns out, the word "food" appears 11 times in the Ontario science curriculum for grades 9-10 and 144 times (!) in the same document for grades 11-12. In contrast, the word "hunger" is utterly absent in both curricula, even though food insecurity is on the rise in the country, with around 4 million Canadians being food insecure – of which 1.5 million are children (Valeri, 2016). Thus, the community garden, which is located on a university campus and about 500 meters from the building where classes are held for the teacher education program, creates yet another concrete and powerful space (opportunity) for novice teachers to learn about the less socio-economically fortunate in the city (Santos, Singh, Cruz, Piassi, & Reis, 2019). Moreover, it teaches us all that growing food is more than just looking after edible plants. It is also a reminder that caring for the garden also means caring for the people who depend upon it — proof that they too matter as human beings and members of society.

In this scenario, students have a chance to reflect on the how their individual and collective acts of teaching science can impact – and are impacted by – the re-

ality of poverty in the community, their community. In this sense, poverty (along with food insecurity, hunger, etc.) is not only a socio-ecological phenomenon, but also a cultural one (Lewis, 2017). Here, it goes without saying that these novice teachers are expected to orient (self-organize and adapt) their teaching to those socio-cultural conditions to which their students are exposed, even though they might not directly participate in them. (For instance, teachers might decide to approach hunger and poverty in the classroom even thought their students have not experienced hunger or poverty themselves). Otherwise, there is little hope for change.

> Any analysis of the ways in which unequal power is reproduced and contested in society must deal with education. Educational institutions provide one of the major mechanisms through which power is maintained and challenged. These institutions and the manner in which they are organized and controlled are integrally related to the ways in which specific people get access to economic and cultural resources and power. (Apple, 2004, p. vii)

In other words, education (teaching and learning) is embedded within larger cultural currents that (explicitly and implicitly) frame what is legitimate, illegitimate, normal, and so on. As such, we (educators) should expose these conditions and work with others for socio-ecological change (Whalen, 2018).

Our cultural norms and actions surrounding hunger and poverty can be seen as a type of knowing – even if that knowing has some blindspots, inefficiencies, prejudices and injustices. But we do at least know how to grow food and distribute it, and to help others, fairly well. The question becomes what more can we learn and know, as a culture, about poverty, hunger, etc., and how they are linked to biology, ecology, economics, politics, pollution, sustainability and so on. Can (science) education assist us in collectively getting smarter and more just in what we know and how we act? Can education prompt us to become better adapted to all our relationships, both social and ecological (biological)? Those are the questions we should ask of cultural knowing.

Other levels: micro and macro

As described above, researchers associated with complexity science argue that similar ecological processes of self-organization and adaptation — that is, teaching and learning — can be seen at many other levels, from cells to the biosphere (not just among humans). In other words, wider physical systems — literally ecologies — also play a role in teaching, learning and knowing.

First and most obviously, we as a species nest ecologically within these systems. Structures such as our lungs, opposable thumbs and social sensitivities only makes sense when they are understood as linked to and co-evolving with the atmosphere, organisms like trees, tool use, and hunter-gatherer social groups. That is, learning is understood as the on-going co-evolution of species and habitats. From that perspective, human learning is but one part of a grander evolving cognitive process, which renders futile any attempt to anthropomorphize our existence as hierarchically superior to other animals (Monteiro & Reis, 2018).

Second, the historical development of species and even ecosystems can be understood as a form of self-organized adaptation. For example, giraffes' extraordinarily long necks make little sense unless seen as adaptation that allows the species to reach higher tree branches and compete more efficiently for scarce food sources. At the same time, this adaptive evolutionary change is governed by the giraffes' genetic repertoire (variations, mutations) and how they respond to environmental pressures. The giraffes are not externally redesigned like a machine. Just as any living systems, they adapt themselves in a self-organized way. Thus, through natural selection (evolutionary pressures), living species themselves can be said to learn from (or adjust to) the world around them. (Here, one must be careful not to mistake our argument with the erroneous – but common – association of evolution with the notion of progress [Reis, Brown, Pedreira, & Silva, 2019]). Basically, evolution is learning on a long-term, species level.

Once again, framing learning in terms of fitting or interacting effectively with contexts – whether among people, cultures of ecosystems – has ethical implications. Indeed, our continued survival as humans depends on how intelligently we can redefine our rela-

tionships with ourselves and other living systems in the biosphere (Reis, Ng-A-Fook, & Glithero, 2015). For example, the way that our insensibility to the ecological and economic value of plants and insects is obliterating our perception of – and conservation efforts towards – pollination, which is an essential "service" for the survival of our species (Reis, 2014). Or even how certain human hormones interact with the enjoyment of public urban green spaces (USDA, 2018). In sum, we all must gain an ecological understanding of education (teaching, learning and knowing) in order to see how even the smallest level systems interact with larger scale ones.

Finally... the classroom (concluding thoughts)

Schools play a vital role in nurturing (cultivating) knowledge, increasing awareness and cultivating action towards many aspects of life, including food-related issues of sustainability (e.g. poverty, food in/security and hunger). In this context, community gardens are a medium for learning about some of the larger social, cultural, political and environmental aspects of our society as well as providing the space for teachers and students to build relationships with others (Williams & Brown, 2012). More importantly for our argument here, community gardens serve as a sound example of how different complex system levels interact to concretely realize teaching and learning in schools generally, and (science) classrooms more specifically.

From the above, it should be clear by now that we understand classrooms much like any ecological system: they are self-organizing, adaptive social learner spaces composed of individual teachers and learners and nesting dynamically within larger cultural and environmental (biological) structures. This view is in accordance with recent educational research informed by complexity science (Davis & Sumara, 2006). It is also a very ecological perspective: it asserts not only that we are connected to larger ecosystems, but also that learning at all levels can and should be thought of in a more connected manner (figure 4).

Complexity offers useful models for understanding the dynamic relationships among learners. In combination with science education, it supports a socio-ecological framework for thinking and acting within our interconnected world (Ehrlich, 2009; Miller, 2003; Zeyer et al., in press). In order to build bridges between these two discourses (complexity and [science] education), we drew upon the work of a number of influential educational thinkers. In addition, we explored the following topics in relation to ecological education: socio-cultural and constructivist perspectives on learning; an ethics of knowing based on the complex relationships between people and other living systems; and learning as self-organized adaptation (or coupling) at multiple levels (i.e. individual, social, and ecological). In the words of Marilyn Doerr (2004): "[The traditional approach to learning] produces students who have memorized a body of knowledge, spat it back for the test, and moved on. An ecologist has to take ecological principles into [their] life; studying ecology has to be life altering" (p. 160). For example, an ecological educator might nurture both individual and collective learning by presenting student groups with a problem to solve and processes to support the interaction of diverse individuals' ideas – with the goal of constructing collective solutions that may exceed anything the teacher expected.

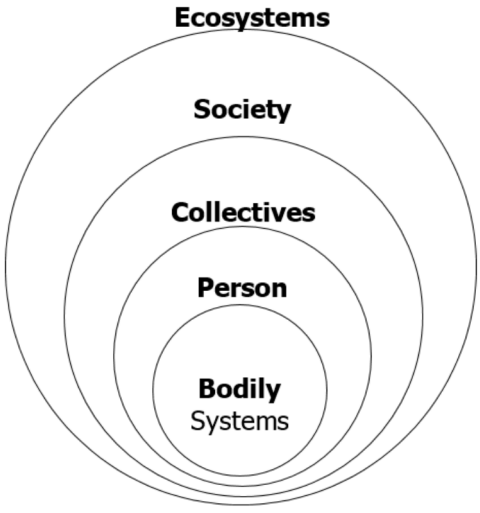

Figure 4— (Source: Complexity and Education Website, University of Alberta, Retrieved July 21, 2005 from http://www.complexityandeducation.ualberta.ca/)

As educators, the challenge becomes to view our job as teachers differently and to work with our classes' living processes of self-organization and adaptation, rather than trying to inflexibly control what students think or how they behave.

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