Learning from Nature:  
Natural Computing Meets Virtual Learning  

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Abstract

From an examination on where virtual learning stands in the overall learning spectrum, we point out the important impact of natural computing on virtual learning. We survey and analyze selected literature on important role of natural computing aspects, such as emergence (using swarm intelligence to achieve collective intelligence) and emotion, to virtual learning. We note that although scattered efforts have been made in incorporating various natural computing concepts into virtual learning, more systematic studies of promoting natural computing as a whole in virtual learning environment are needed. We address issues related to achieving natural computing-enriched virtual learning, including the need for investigating a virtual learning architecture (or framework).

Keywords: Emergence, emotion, natural computing, swarm intelligence, collective intelligence, virtual learning architecture

1. Introduction: The learning spectrum

As a software system, a virtual learning environment is intended to offer a virtual environment for learning where the learning process is based on information technology (IT). Virtual learning environment facilitates computerized learning or computer-enhanced learning (e-learning). Many projects in virtual learning have been designed to facilitate teachers in the management of educational courses for their students, especially by helping teachers and learners with course administration. The system can often track the learners' progress, which can be monitored by both teachers and learners. With advanced learning technology (ALT) it supports, virtual learning makes learning as a life-long journey easier to achieve than anytime else in history, and the entire world now becomes an open university.

Virtual learning is concerned with IT assisted human learning and much of research work in virtual learning addresses various technical issues to enhance human learning. However, when we talk about learning using contemporary IT techniques, we should also consider machine learning (http://robotics.stanford.edu/people/nilsson/mlbook.html), a subfield in AI mainly concerned with developing algorithms for enhanced performance of computers. Even virtual learning (for humans) and machine learning are two separate research areas, they are both concerned with learning with computers, and we would like to include them in the same big picture so we can have a better understanding about where virtual learning stands.

This broad perspective raises an important issue: Virtual learning should not be simply viewed as just a set of IT tools (or techniques) to assist learning or education. It reminds us the importance of examining fundamental issues related to learning, such as nature of intelligence, various forms of intelligence, consciousness and thinking, as well as recent research progress related to brain and mind, and even about various forms of life – not just humans, but animals as well, so long as they demonstrate a kind of learning ability. These studies could shed meaningful insight for better virtual learning. As noted in [15], in recent years educators have explored links between classroom teaching and emerging theories about how people learn. Recommended educational approaches, consist primarily of trying to maintain a relaxed, focused atmosphere that offers options for learning in individually satisfying ways. One thing we must be kept in mind is that the brain is complex and while research has revealed some significant
findings, there is no widespread agreement about their applicability to the general population or to education in particular. Nevertheless, brain research provides rich possibilities for education [15]. Articles in the new magazine *Scientific American Minds* (http://www.sciammind.com/) also shed interesting lights on brain/mind research and education.

This broad perspective also reminds us that in a virtual learning environment, many previously impossible things now may become possible because of new opportunities. In order to take full advantage of virtual learning environment, we would further ask the question: Is anything setting in between virtual learning and machine learning? Although this may be an open question subjecting to debate, here we offer a possible answer: learning from nature through *natural computing*, which is the computational version of the process of extracting ideas from nature to develop “artificial” (computational) systems (“artificial” means human-made). Since natural computing is aimed to model the nature or even compute with the nature, it looks for intellectual inspiration from all forms of life (not restricted to human beings) – such as ants. Since natural computing sets between the research of “full human” (i.e., virtual learning) and non-human (i.e., machine learning), it fits in the missing link in the learning spectrum. Amending the hierarchical diagram provided by [1], we have the learning hierarchy as shown below:

- Machine learning
- Learning from nature (Natural computing)
- Virtual learning (for humans)
- Resource-based learning
- Technology-based learning

But why should we bother natural computing at all in the context of virtual learning? The answer is simple: It would benefit virtual learning so that virtual learning can better achieve its goal. In fact, natural computing is not new to virtual learning community: As we are going to see soon, projects using various natural computing techniques have been conducted for virtual learning. Yet we feel there is a need to take a more systematic look on the rich impact of natural computing in virtual learning. Virtual learning provides an excellent environment for human learning never existed before, and natural computing can make significant contributions here. Such kind of investigation will eventually benefit the study of natural computing as well, because the diverse applications in virtual learning extend the horizons of natural computing.

This paper is intended to endorse systematical studies of incorporating natural computing to virtual learning. The rest of the paper is organized as follows. In Section 2 we provide a very brief background on natural computing. Since natural computing is a big umbrella for many subfields, we have chosen two particular aspects to focus on, namely, emergence and emotion: In Sections 3 and 4 we review related work for virtual learning, and offer suggestions for needed research work in these areas. We conclude our paper in Section 5, where we propose an investigation of an architecture (or framework) for natural computing-enriched virtual learning. Even due to space limitation we are not able to present specifics of our ongoing work here, we believe this paper makes contribution to virtual learning by calling attention to this important issue.

2. Natural computing: A very brief review

There are numerous resources available for natural computing. For beginners, [4] provides a comprehensive coverage on the major fields with natural computing. The brief review in this section is much based on that book.

The philosophy of natural computing lies in that most of computational approaches natural computing deals with are based on highly simplified versions of the mechanisms and processes present in the corresponding natural phenomena. Research work in natural computing can be grouped into three major categories, namely, computing inspired by nature, simulation and emulation of natural phenomena in computers, and computing with natural materials. Since the last one does not have direct impact on virtual learning (at least for now), we will not address it here.
The first category, computing inspired by nature, refers to making use of nature as inspiration for the development of problem solving techniques. The main idea is to develop computational tools (algorithms) by taking inspiration from nature for the solution of complex problems. The diverse areas (or approaches) under this category include evolutionary computing, neurocomputing, swarm intelligence, etc. Swarm intelligence refers to a property of systems of unintelligent agents of limited individual capabilities exhibiting collectively intelligent behavior, and has drawn attention from researchers to find useful applications in virtual learning (as to be briefly described later).

The second category, simulation and emulation of natural phenomena in computers, refers to a synthetic process aimed at creating patterns, forms, behaviors, and organisms that (do not necessarily) resemble “life-as-we-know-it.” Its products can be used to mimic various natural phenomena, thus increasing our understanding of nature and insights about computer models. An interesting area under this line of research is artificial life, which is the study of man-made systems that exhibit behaviors characteristic of natural living systems. It has been hoped that by extending the empirical foundation upon which biology is based beyond the carbon-chain life that has evolved on Earth, artificial life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could be.

Regardless of computing inspired by nature or simulation and emulation of natural phenomena in computers, there are several general concepts underlying various approaches in natural computing, such as agent, parallelism and distribution, interactivity, adaptation, feedback, self-organization, emergence, etc. In addition, emotion is demonstrated not just in human beings, but many species of animals as well. Emotion has also been studied in artificial life.

Various natural computing concepts have already been used by authors working in virtual learning. Much effort has been put on researchers’ “traditional” favorite such as adaptation. Yet successful employment of natural computing in virtual learning goes far beyond adaptation. Below we examine selected literature involving two crucial elements of natural computing and provide comments on their relevance to virtual learning: Emergence and emotion.

3. Exploring emergence for virtual learning
As a typical demonstration of computational approach for emergence, swarm intelligence is a property of systems of unintelligent agents of limited individual capabilities exhibiting collectively intelligent behavior. Swarm intelligence includes any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insects and other animal societies. Swarm intelligence is an emergent property of the swarm system as a result of principles of the five principles: proximity, quality, diversity, stability and adaptability. Two main lines of research in swarm intelligence are either based on social insects, or based on the ability of human societies to process knowledge [4].

The ability of ants to find short routes between nests and food sources suggests an approach to cost-effective, flexible and implementable wayfinding support. Paths identified by ants are not pre-planned, but emerge, spontaneously, as a result of indirect communication between members of an ant colony – a form of indirect social navigation. Ants deposit a chemical substance called pheromone which can be sensed by other ants, thus achieving a kind of stigmergy, which refers to the process of indirect communication. This property can be very useful for virtual learning. In a virtual learning environment considered by [2], learners’ interactions with learning resources and activities are recorded automatically as they progress through a body of knowledge. The time stamping of these interactions allows learning sequences to be identified which can be processed and aggregated to derive a given “pheromone strength” favoring paths along which more learners have been successful. This information can be fed back to other learners, providing a new source of navigational guidance indicating “good” ways through the body of knowledge – a self-organizing, stigmergic approach to wayfinding support.

In another experiment by [13], ant colony optimization (ACO) heuristics was applied to an e-learning problem: the pedagogic material of an online teaching Web site for high school students is modeled as a navigation graph where nodes are exercises or lessons and arcs are hypertext links. The arcs' valuation, representing the pedagogic structure and conditioning the Web site's presentation, is gradually
modified through the release and evaporation of virtual pheromones that reflect the successes and failures of students roaming around the graph. A compromise is expected to emerge between the pedagogic structure as originally dictated by professors, the collective experience of the whole pool of students and the particularities of each individual.

Collective behavior as demonstrated from ant colonies and simulated in computer programs exemplifies collective intelligence (or symbiotic intelligence), an intelligence that emerges from the collaboration and competition of many individuals -- an intelligence that seemingly has a mind of its own. Yet emergence is not restricted in collective intelligence. In general, emergence refers to the way complex systems and patterns arise from a multiplicity of relatively simple interactions.

Two influential monographs on emergence should find profound impact on virtual learning: through a series of narratives to show complex adaptive systems that display emergent behavior governed by small sets of local rules, the discussion in [7] may shed useful intuitive thoughts on infrastructural support to achieve emergence in virtual learning, while [5] provides more technical insights on modeling issues of emergence in a more general, abstract setting, where emergence is explained through a reductionist perspective.

Summarizing discussion given above, we have the following observations and suggestions. Exploring emergent properties using swarm intelligence and other techniques should be continued and strengthened for research virtual learning. Yet, current research related to emergence in virtual learning is largely confined in specific tasks. More systematic studies of the role of emergence in virtual learning are needed, particularly those related to the overall infrastructure of virtual learning. In addition, in the context of learning/education (including virtual learning), there is a need to distinguish emergence as a process (such as emerging ideas) from emergence as a product (such as an emerging pattern) – a feature which has not attracted enough attention it deserves. Here is a partial list of issues to be studied about emergence related to virtual learning:

- Nature of emergence (relevant to learning), such as: differences between emergence and discovery
- What can be achieved through emergence? – emerging ideas
  - Specific creative task (such as construction of analogs through emergence for analogical problem solving)
- What can be achieved through emergence? – emerging “products”
  - Global solution (such as optimization of student pedagogical path)
  - Solution for individuals (learning by taking advantage of emergence), such as how to come up with creativity thoughts in general

In addition, there is a more general question: Is there a need to have a dedicated software component at system level to support emergence in a virtual learning environment? If yes, how to achieve this?

4. Exploring emotion in virtual learning

Recently the importance of emotion in education has drawn attention from researchers. For example, according to [16], educators may find the most useful information in research that focuses less on the physical and biochemical structure of the brain and more on the mind-a complex mix of thoughts, perceptions, feelings, and reasoning. Studies that explore the effects of attitudes and emotions on learning indicate that stress and constant fear, at any age, can circumvent the brain's normal circuits. A person's physical and emotional well-being is closely linked to the ability to think and to learn effectively. Emotionally stressful home or school environments are counterproductive to students' attempts to learn. While schools cannot control all the influences that impinge on a young person's sense of safety and well-being, classrooms and schools that build an atmosphere of trust and intellectual safety will enhance learning. Letting students talk about their feelings can help them build skills in listening to their classmates' comments. Finding ways to vent emotions productively can help students deal with inevitable instances of anger, fear, hurt, and tension in daily life. In an experimental study, [11] interviewed eleven students studying online. These students identified emotions which were critical to their online learning.
In order to better understand where emotion stands in learning and education, it would be beneficial to take a look at the two books on general aspects of emotions with quite different emphases. From a psychological perspective, the experimental research of [8] showed that emotion can occur without cognitive processing in the cortex. In particular, we can learn some general principles of emotions by studying fear. In evolutionary terms, “fearless” animals would have been less likely to survive. The author further demonstrates that fear can be related to learning and fear learning is implicit. Although by no means we should endorse any kind of “learning through fear,” this example does indicate emotion can have impact on education in a controlled manner, and with more secrets of emotion to be revealed in the future, some of the previously unknown principles involving emotions can be incorporated into virtual learning environment. Published one decade later, from a computational perspective, [9] aimed to establish a theory of how emotions get created. According to this theory, each emotional state is a different style of thinking. So there is no general theory of emotions, because the main idea is that each of the major emotions is quite different. For an adult person, the management is able to use these different ways of thinking very quickly as part of ordinary, common-sense thinking. What is the indication of this discussion to learning/education? The notion of emotion as a theory of thinking implies a potential opportunity to “mint” emotion into “mainstream” education theories, including those related to virtual learning.

In a recent comprehensive volume directly address the issue of emotion in education [14], various theoretical perspectives on emotions in education have been examined, include the discussions on control-value theory of achievement emotions, self-regulation and social-constructivist learning, emotions as a main component of attributional theory, implications of goal-theory for achievement-related emotions, macro-cultural psychology, etc. The theoretical work is complemented with sets of studies on students’ emotions in educational context, as well as teachers’ emotions in educational contexts. Such kind of research sheds light for future work of dealing with the emotion factor in a virtual learning environment.

As the literature surveyed above shows, so far the important issue of emotion for education is still largely discussed at the traditional classroom setting. Nevertheless researchers have started addressing this issue in the context related to virtual learning. For example, [3] presents an analysis of the issues pertaining to computational emergence and emotion in (cognitive) agent systems and describes how a developing computational theory of cognition can be used to monitor and manage interactions with and within complex systems; this would harness unwanted and emergent states and behaviors before the computational system becomes dysfunctional. In another work, [12] describes a modular hybrid neural network architecture, called SHAME, for emotion learning. In addition, computational experiments on emotion also exist. For example, [6] proposes the architecture of learning companion agent with facial expression of emotion. Based on ABC and ToK architecture, the emotion agent architecture contains five modules to realize the interaction in the world. A particular part of this research is the transition between emotion space in emotion module and facial expression space in facial expression module.

Summarizing the above discussion, we note that current research status shows that emotion for virtual learning is a vast area yet to be systematically explored. Some basic issues include: From a learning perspective, how many types of emotions can be distinguished? Under which conditions certain type of emotions should be controlled and under which conditions educators can take advantage of it? What are basic operations of emotions (such as filter out, enlargement, etc.) and how to develop computational mechanisms to support them? Finally, just like the case of the discussion related to emergence, we may wonder whether there is a need to implement any forms of emotion at the system level in virtual learning.

5. Conclusion: Investigation of a virtual learning architecture with natural computing aspects

The main theme of this paper is to call attention to the important role of natural computing in virtual learning, which should be supported at multiple levels in the infrastructure of virtual learning. In order to achieve natural computing-enriched virtual learning, in addition to the observations and suggestions we
have already made, we would endorse the idea of investigating a virtual learning architecture (or at least, a framework) which incorporates natural computing aspects. At a high level, a kind of network architecture inspired by biology as proposed in [10] may be implemented. Criteria for development such an architecture or framework, as well as related research agenda should be developed.

The “to do” list as provided in this paper is, of course, far from complete. Due to space limitation, no details of our ongoing work are described in this paper.

References
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