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Theoretical and Methodological Implications of Complexity

Learning as an Emergent Phenomenon: Methodological Implications

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In this paper, we put forth a theoretical cum methodological proposal for a line of inquiry that seeks to understand learning as an emergent phenomenon. Our theoretical and methodological arguments detail how an emergent conception of learning places limits on experimental and descriptive approaches, whether used alone or in combination. These limits are not so much a function of causality or reduction, but the need to deal with the dialectical co-existence of linearity and non-linearity that often characterizes complex phenomenon. To overcome these limits, albeit only partially, we leverage complexity theory to advance computational agent-based models as part of an integrated, iteratively validated phenomenological-ABM inquiry cycle to understand learning as an emergent phenomenon from the "bottom up."

Although there is much excitement about the possibilities that computational methods bring to the table, there remains little theoretical and methodological exposition of why and how computational methods can be integrated with existing quantitative and qualitative methods to potentially expand the research toolkit of educational researchers. How do existing quantitative and qualitative methods fall short and how might computational methods be integrated to provide better understanding of the phenomenon of learning, and vice versa? Our argument is based on the premise that learning is a complex phenomenon, which under certain conditions exhibits emergent properties. Indeed, many contexts of learning—formal or informal, groups or individuals—are in fact complex systems (Jacobson & Wilensky, 2006; Kapur et al., 2007). It is this very complexity that sets up the stage for the emergence of knowledge structures, interactional patterns, values, norms, identity, culture, and so on. Invoking emergence, however, requires that we deal with a fundamental tenet of complexity: an emergent phenomenon is ontologically and methodologically irreducible, i.e., *an emergent phenomenon is its own shortest description* (Kauffman, 1995). This simple yet powerful tenet poses serious methodological challenges. Through a careful analysis of the assumptions underpinning quantitative and qualitative methods, we will build a case that existing methods fail to adequately address the issues of *non-linearity*, *temporality*, *spatiality*, and *phase-space* that are of central to understanding emergent phenomenon. We will discuss how and the extent to which these issues can be addressed by *integrating* computational agent-based methods with existing quantitative and qualitative methods (Abrahamson & Wilensky, 2005; Blikstein, Abrahamson, & Wilensky, 2006; Goldstone & Janssen, 2005). In the final analysis, we propose an iterative process of building from and validating with phenomenological theory and data to seek a better understanding of the complex phenomenon of learning noting very well that, any method, be it quantitative, qualitative, or computational, used alone or in combination, will necessarily remain reductive.

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Ontologies as Scale Free Networks: Implications for Theories of Conceptual Change

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This paper provides a “theoretical case study” of how perspectives from complexity research might provide insights into debates of theory in the learning sciences. The debate we examine concerns the “fault line” in the field related to the “knowledge-in-pieces” versus “coherent knowledge” about conceptual change (diSessa, 2006), which extends back to the seminal monograph in *Cognition and Instruction* in which diSessa (1993) articulated his theory of phenomenological primitives (p-prims) and of “knowledge-in-pieces.”

An Ontological Networks Theory (ONT) is proposed in this paper that combines complexity views about scale-free network topologies with learning sciences perspectives about knowledge representation, conceptual change, and learning. Briefly, scale-free networks (Barabasi, Albert, & Jeong, 1999; Barabasi & Bonabeau, 2003; Steyversa & Tenenbaum, 2005; Watts & Strogatz, 1998) resemble the airline system that consists of *hubs*, which are nodes with a very high number of links, in contrast to *random networks*—such as a national highway system—that consist of *nodes* with randomly placed connections. Barabasi et al. (1999) demonstrated that the basic mechanism that produces a scale free network involves: (a) *growth* (addition of new nodes), and (b) *preferential attachment* (the probability of a new node linking with an existing node is proportional to the number of links the existing node has).

The ONT is explicitly based on these core properties of scale-free networks. We propose that the representation of knowledge about a variety of scientific phenomena consists of network configurations of nodes and hubs involving preferential attachment and selection processes. *Ontological nodes* or O-Nodes are relatively “small” domain specific ideas about natural phenomena. O-Nodes are conceptualized as being similar to the construct of phenomenological primitives or p-prims (diSessa, 1993). In contrast, *ontological hubs* or O-Hubs are highly connected nodes (i.e., hubs in scale free network theory) that we regard as similar to the psychological construct of “ontological categories” (Chi, 1992, 2005; Lakoff, 1987). (The full paper discusses the ONT in more detail, including selection processes and deactivating of nodes.)

Recently it has been argued by diSessa (2006) that several theories about how people solve problems and learn often conceptualize knowledge as being relatively stable, consistent, and “coherent.” He maintains that these “coherent knowledge” theories have been more common than “knowledge-in-pieces” theories (such as diSessa’s) in which ideas are viewed as fragmented and highly influenced by contextual cues and factors. Chi and her associates have articulated one representative theoretical view of “coherent” knowledge and conceptual change. Chi (1992) proposed a theory (which has been iteratively revised for several years, see Chi (2005)) that difficulties learners have with changing their concepts about certain types of knowledge, particularly in the sciences, may be explained as a result of ascribing the concepts being learned to inappropriate ontological categories. Chi’s basic argument is that students will need to make an ontological shift if they are to achieve conceptual change about such scientific concepts.