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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.

In this paper, we propose that the ONT may be used to reframe this debate in a principled manner. First, p-prims appear to be "node-like" in that they are described as "*Elements*: P-prims are rather small knowledge structures, typically involving configurations of only a few parts…" (diSessa, 1993, p. 111). In contrast, other major theories of conceptual change, such as by Chi, seem to describe cognitive structures such as "ontological categories" that are more "hub-like" than the "node-like" p-prims of diSessa. We believe the ONT has theoretical properties that are consistent with the major assertions and empirical findings associated with these two major conceptual change theoretical camps in the learning sciences (i.e., "coherent knowledge" versus "knowledge-in-pieces"). Further, the ONT as advantages over the learning sciences theory, such as the incorporation of a mechanism or process for how and why certain ideas link or do not link together, that is, the principle of preferential attachment, whereby more highly connected nodes (and hubs) have a higher probability of being linked to than less connected nodes. Thus new scientific ideas we might wish for students to learn would have a higher probability of linking to already formed ontological hubs (i.e., ontological categories), and thus there is a degree of "coherence" or consistency in how a conceptual network is activated, which research on conceptual change by researchers such as Chi has shown. Another potential advantage of the ONT is that as other researchers make progress on the properties and characteristics of scale-free networks mathematically and in terms of applications in other domains (e.g., neuroscience), these advances may in turn inform and enhance our understanding of processes of learning in our field. Finally, it is hoped this "theoretical case study" might be suggestive of how complexity perspectives more generally may be explored for their potential to inform other issues of theory and methodology in the learning sciences.

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