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Towards a Complex Systems Meta-Theory of Learning as an Emergent Phenomenon: Beyond the Cognitive Versus Situative Debate

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Abstract. This paper proposes a meta-theory of learning based on conceptual perspectives and methodologies being employed in the study of complex physical and social systems to inform research in the learning sciences and education. The contexts in which learning occurs are in fact complex systems with elements or agents at different levels—from neuronal, cognitive, intrapersonal, interpersonal, cultural—in which there are feedback interactions within and across levels of the systems so that collective properties arise (i.e., emerge) from the behaviors of the parts, often with properties that are not exhibited by those parts. We analyze the long running cognitive versus situative learning debate and propose that a *complex systems meta-theory of learning* (CSMTL) provides a principled way to achieve a theoretical rapprochement. We close by considering other theoretical and methodological implications of the CSMTL for research in the learning sciences.

There are various perspectives from which to ground systematic inquiry into *learning*, which, of course, is the central enterprise of educational research. Discussions of these perspectives tend to argue for the primacy of a specific locus of theory and philosophy that in turn grounds various research agendas that generally intend to validate, enhance, or challenge particular perspectives. As a field that studies learning and education, there have important debates or "fault lines" (diSessa, 2006) about theory and methods. For example, there has been a vigorous debate of theoretical import about the primacy of cognitive (i.e., individual) versus situative (i.e., socio-cultural) perspectives about learning (Anderson, Reder, & Simon, 1996, 1997; Greeno, 1997; Norman, 1993). We are perhaps on the verge of a third distinct theoretical and empirical perspective about learning that is emerging the neurosciences, and there are already appeals to assigning primacy for theory and research about learning from this field over cognitive and socio-cultural perspectives (for a critical discussion, see Bruer (2006)). As another example, there have been the so called "methodology wars" between proponents of quantitative and qualitative methods, with mixed methods employing elements of both representing perhaps an uneasy truce between these camps (e.g., Firestone, 1987; House, 1991).

Unfortunately, these debates related to theory and methodologies in the study of learning and educational research have been persisting for decades. This inability of the field to reconcile or vindicate one camp or another is a serious issue. For researchers, this has meant a "community of practice" in educational research that has fractured into "cognitive," "socio-cultural," and neuro-science" silos that are theoretically and methodologically isolated from each other, or perhaps worse, that simply ignore each other.

Given such debates seem to involve a "clash of cultures" (Norman, 1993, p. 3), how might a rapprochement be made? We argue in this paper that conceptual perspectives and methodologies being employed in the study of complex physical and social systems may help reconcile certain existing debates in the field and to help provide an enhanced foundation to use in educational research more generally. The paper is organized into four main sections. First, we provide a brief overview of the cognitive versus situative theories debate. In the second section, we propose an initial set of components for a *complex systems meta-theory of learning* (CSMTL). In the third section we discuss ways in which the CSMTL provides a principled reconceptualization and rapprochement of the cognitive-situative debate and related issues in the field. We close the paper with suggestions for future research involving the CSMTL and implications for the field of educational research more generally.

Cognitive Versus Situative Theories: An Overview of the Debate

In the seminal paper advocating a situated perspective of learning, Brown, Collins, and Duguid (1989) argued that knowledge should be viewed as situated, as being a "product of the activity, context, and culture in which it is developed and used" (p. 32). Such a perspective had important implications for schooling, which they believe had been narrowly concerned with the transfer of abstract and decontextualized formal concepts. However, the cognitive science research upon which many of the key arguments for situated learning by Brown, Collins, and Duguid was itself generating considerable debate. In 1993, a special issue of *Cognitive Science* pulled together nine papers that debated two perspectives about the study of human cognition. In the introductory paper by Norman (1993), he framed these two perspectives—the traditional symbolic approach for studying human cognition that focused on the processing structures and symbolic representations of the brain and the "new

upstart, the study of situated cognition" (also referred to as "situated action" or "situativity" by other authors) that focuses on the structures of the world constraining and shaping human behavior. The primacy of a cognitive level of analysis was clearly championed by Vera and Simon (1993), who argued that symbolic models of individual cognitive processes and representations have been quite successful in providing principled accounts of humans and their interactions with the world. In contrast, in arguing for the primacy of the situative level of analysis, Greeno and Moore (1993) propose the term "situative" to describe cognitive processes as interactions between a person and other people and physical systems. Similarly, Suchman's (1993) notion of situated action emphasizes "constructing accounts of relations among people, and between people and the historically and culturally constituted worlds that they inhabit together" (p. 71).

This debate broadens and deepens in many ways as reflected in a series of papers in *Educational Researcher* in the middle to late 1990s in which the focus shifts from considerations of how people think and act to implications of cognitive versus situative perspectives for teaching and learning. The paper of Anderson, Reder, and Simon (1996) characterized situated learning as a view that much of what students learn is specific ("situated") to the context in which it was learned, which implies knowledge does not transfer between tasks and that learning abstractions is of little value. They go on to provide a critique of the application of situated learning in mathematics education in particular, and propose that educational approaches based on cognitive research into learning processes may be more efficacious than those based on situated perspectives.

The following year, Greeno (1997) provided a response in which he argued that the main differences between situative and cognitive perspectives discussed by Anderson, Reder, and Simon were primarily due to underlying framing assumptions of these two perspectives. In particular, Greeno (1997) maintained:

> The cognitive perspective takes the theory of *individual cognition* [italics added] as its basis and builds toward a broader theory by incrementally developing analyses of additional components that are considered as contexts. The situative perspective takes the theory of *social and ecological interaction* [italics added] as its basis and builds towards a more comprehensive theory by developing increasingly detailed analyses of information structures in the contents of people's interactions. (p. 5)

In the same issue of *Educational Researcher*, Anderson, Reder, and Simon (1997) provide a rejoinder to Greeno in which they found a degree of agreement between the cognitive and situative positions on evidence for findings and a consensus on certain educational issues. They also agreed that Greeno raised a substantive issue as to "whether the more profitable research path is one that takes individual or social activity as the principal unit of theoretical focus" (p. 20). Not surprisingly, Anderson et al. end their rejoinder with a robust assertion of the superiority of the cognitive information processing approach over a situative theoretical approach.

This debate broadens in a paper by Cobb and Bowers (1999) in which they criticized the conflicts between cognitive and situative learning theories as being of primary interest to educational psychologists and not to educators involved with classroom-based learning design and research. Still, the detailed discussion of their research for studying the learning of mathematics in classrooms primarily employed a situative analysis approach as they found little theoretical utility in the cognitive perspective of Anderson, Reder, and Simon for understanding the "essence of individual and collective human activity" (Cobb & Bowers, 1999, p. 13).

In 2003, Derry and Steinkuehler provided a critical review of the literature related to cognitive and situative theories. They proposed that cognitive theory regards cognition as symbolic computation, and broadly includes perspectives of *socio-cognitive* theoreticians such as Piaget as well as others summarized by Anderson, Reder, and Simon (1996). The situative perspective according to Derry and Steinkuehler embraces a family of social science theories including *situated cognition*, *sociocultural theory*, *distributed cognition*, and *activity theory*. Derry and Steinkuehler propose what might be called a "pragmatist view" of the cognitive-situative debate, as they comment that many researchers and designers working in classroom environments were fusing points of view from the cognitive and situative perspectives. However, they also note that a well-defined theory between these two communities of educational practice had not been proposed, which we believe is still true today. They speculate that what may emerge is a:

> *complex systems theory* [italics added] of cognition understood in its broadest ecological sense, and that the resulting methodological approach will be superior to either theoretical viewpoint standing alone, capable of providing more complete understanding of learning and education. (Derry & Steinkuehler, 2003, p. 805)

We next describe our initial efforts in this area, which we regard as a meta-theory of learning based on complexity.

Towards a Complex Systems Meta-theory of Learning

In this section we outline a complex systems meta-theory of learning that may provide a principled basis for a rapprochement between cognitive and situative perspectives, as well as to inform other issues in the field. However, what do we mean by a *meta-theory*? As the name suggests, a meta-theory is a theory about theories. While a theory is concerned with specifying concepts and relations that can provide accounts for aspects of the natural or social world, a meta-theory provides concepts for describing what form theories should take, and for identifying requirements of what they should achieve. We also note that at this time there is not a general "theory" of complex systems. Rather, the study of complex physical, biological, and social systems by multidisciplinary fields has been providing a framework of conceptual perspectives, principles, and methods (e.g., emergence, sensitivity to initial conditions, dynamical attractors, agent-based modeling, scale-free networks) that we believe can function to generate and evaluate specific theories of relevance to particular types of systems (Jacobson & Wilensky, 2006).

We conceive of learning not as something that *is*, but rather, as something that *emerges* in the context of formal and informal systems of education. We concur with Clancey (2008) that environments in which human cognitive processes—and therefore learning—occur are in fact *complex systems* that are "inherently social, interactive, personal, biological, and neurological, which is to say that a variety of systems develop and depend on one another in complex ways" (p. 11). As we discuss in more detail below, the construct of *emergence* is a central one in the study of complex systems, which encompasses several new theoretical perspectives (e.g., general systems theory, complexity theory, system dynamics, complex adaptive systems, chaos theory) as well as attendant approaches for modeling these systems (Bar-Yam, 2003; Gell-Mann, 1994; Gleick, 1987; Holland, 1995; Mitchell, 2009; Prigogine & Stengers, 1984) that represent important methodological innovations (also of relevance to learning sciences research). As background, we next provide an overview of perspectives about complex systems and complexity and then rejoin our consideration of the main components of a complex systems meta-theory of learning.

What is Complexity?

Scientific study of complex systems—sometimes referred to as *complexity*—over the past three decades has lead to insights about the world that classical approaches tended to over simplify or to ignore (Bar-Yam, 2003). Briefly, complex systems consist of elements or agents that interact with each other and their environment often based on simple rules. Feedback interactions within and across levels of the system result in self-organization, with emergent patterns forming at mezzo and macro levels of the system. There is also a dialectical co-existence of linearity and nonlinearity in the behavior of complex systems, such as the linear predictability of seasons that emerges out of the nonlinear and probabilistic nature of day-to-day weather. Another key characteristic of complex systems is that collective properties arise (i.e., emerge) from the behaviors of the parts, often with properties that are not exhibited by those parts. Examples of complex systems include adaptation of white blood cells to invading bacteria, emotional and cognitive brain behaviors out of the interaction of individual neurons, the flocking formation of individual birds, dynamic equilibrium in ecosystems out of individual predator-prey interactions, segregation patterns in cities out of individual choices in places to live, and so on.

However, before we can advance our argument for a complex systems meta-theory of learning, the question may be asked if the study of complex systems has yielded findings or insights that are different than those from theoretical, research, and disciplinary perspectives of more traditional scientific fields such as physics, biology, chemistry, and so on. This is an issue discussed in the recent book by Mitchel (2009). One significant contribution is the conceptualization of complex problems in ways that challenge long-term scientific assumptions. As examples, chaos has demonstrated that intrinsic randomness of a system may not be necessary for the overall behaviors of the system to look random; recent findings in genetics challenge the centrality of the role of genetic change in evolution; and chance and self-organization are being viewed as dynamics that challenge the primacy of natural selection in evolution. Mitchel also notes the importance in both scientific communities and the general population of ways of thinking that include nonlinearity, decentralized control, networks, hierarchical levels in systems, statistical representations of information, and so on. We next consider how selected complexity ideas such as these are now being incorporated into educational research.

Research on Learning and Complex Systems

There has been a shift in the learning sciences and related fields of educational research over the past decade from earlier work on students learning concepts about complex systems to the application of perspectives about complex physical and social systems to understanding learning processes and environments (for an overview, see Jacobson and Wilensky (2006)). One indication of this latter trend is reflected in the use of complexity concepts by researchers who are studying learning environments. For example, Bereiter and Scardamalia (2005) have argued that:

> As complex systems concepts such as self-organization and emergence make their way into

> mainstream educational psychology, it becomes increasingly apparent that there are no simple causal explanations for anything in this field. In general, what comes out of a sociocognitive process cannot be explained or fully predicted by what goes into it. Creative works, understanding, and cognitive development are all examples of complex structures *emerging* [italics added] from the interaction of simpler components (Sawyer, 1999, 2004). Learning itself, at both neural and knowledge levels, has emergent properties (p. 707) (Pribram & King, 1996).

The critique of simple causal explanations made by Bereiter and Scardamalia centers on the construct of *emergence*, that is, properties emerging from the interaction of simpler components. We believe that the construct of emergence is centrally important for the study of learning that has important theoretical and methodological implications. Before considering these implications, we next "unpack" emergence as well as related perspectives of linearity and nonlinearity, more fully.

Emergence and the Dialectics of Linearity and Nonlinearity (1)

Interest in emergence is a recent area for learning and cognitive scientists (Clancey, 2008; Goldstone, 2006; McClelland, 2010). For example, inter-subjective processes at the local (individual) level yield cognitions—such as opinions (Isenberg, 1986), generation of abstract representations (Schwartz, 1995), representation and schema learning (Rumelhart, Smolensky, McClelland, & Hinton, 1986), group dynamics (Kapur, Voiklis, & Kinzer, 2008), knowledge building (Bereiter & Scardamalia, 2005), among others—that differ both in complexity and kind from those produced by any collaborating agent or those expected from the central tendency among collaborators (Vallabha & McClelland, 2007). Moreover, these cognitions emerge spontaneously, without forethought or awareness among collaborating agents (Goldstone, 2006). Apparently, both the individual and the group learn. Complexity theory posits that learning is at once distinct and emergent—which is consistent with the critique of simple causal mechanisms by Bereiter and Scardamalia above.

However, the concept of emergent behavior is paradoxical. On the one hand, it arises from the interactions between agents in a system (e.g., individuals in a collective). On the other hand, once such a behavior emerges in a system, it influences and/or constrains subsequent interactions between the micro level actions of agents. Thus an emergent pattern or behavior can seem to have a life of its own independent of the local interactions (Kauffman, 1995) and therefore, cannot be reduced to the individual agents (or parts) of the system (Lemke, 2000). For example, a traffic jam emerges from the local interactions between individual drivers; at the same time, it constrains the subsequent local interactions between these individuals. Once underway, traffic jams do seem to have a life of their own—such as the backwards propagation of a traffic jam (i.e., a clump of cars)—and this emergent pattern cannot be reduced to the behavior of the individual cars that generally move forward. Similarly, structures (norms, values, beliefs, lexicons, and so on) within social networks emerge from the local interactions between individual actors, and then, once emerged, these structures constrain the subsequent local interactions between these actors (Lemke, 2000; Watts & Strogatz, 1998).

Understanding *how* properties such as opinions, representations, group dynamics, indeed, learning actually emerge requires, in our view, a careful consideration of how macro-level behaviors emerge from and constrain micro-level interactions. This critical dynamic relates to another important complexity perspective—*the co-existence of linearity and nonlinearity in complex systems,* which we illustrate with an example. Consider the brain as a collection of neurons (agents). These neurons are complex chemical systems themselves, but they exhibit simple binary behavior in their synaptic interactions that are often modeled as *linear*, probabilistic functions (or rules). This type of emergent behavior, which demonstrates the complexity at the individual micro level resulting in simplicity at the collective mezzo level, is called *emergent simplicity* (Bar-Yam, 2003). Put another way, *nonlinear* chemical reactions can result in a *linear*, global behavior.

Linearity may be broadly conceived both as a *mathematical operator* as well as a *functional relationship*. A linear operator is essentially an additive operator (Bertuglia & Vaio, 2005). For example, traditional analytical methodologies such as linear differential equations and statistical modeling, regardless of their mathematical sophistication, are essentially linear operators. They work well for closed, linear systems (or approximations thereof) where the whole is equal to the sum of its parts, thus allowing one to break a system into its components or parts, study the parts individually, and then add the parts together to form the whole. However, applying the linear operator and its associated quantitative methodologies to the study of emergent behavior in open systems is *fundamentally problematic* because, by definition, *emergent properties have properties that are different than the parts, not additively composed of the parts*.

Linearity may also be conceived as a functional relationship, such as constant proportionality or a straight line. When applied to model a causal relationship, linearity restricts one to phenomena in which the effects are proportional to their causes. This is because linearity tends to treat small changes or perturbations as temporally transient without any long-term effects. However, emergent behavior often exhibits *nonlinear* global

effects *even if the local action is linear*. As we demonstrated above, linearity and nonlinearity can co-exist in a system, and thus one cannot assume that global effects are proportional to their local causes. In fact, small linear changes or perturbations such as El Nino can and often do have large, nonlinear effects. Nonlinearity in climate systems has been metaphorically referred to as the so called "butterfly effect" in the seminal research of Lorenz (1963) a half a century ago. Unfortunately, important nonlinear relationships among variables across scales and hierarchies may be missed entirely, or worse, be inappropriately and inaccurately modeled linearly since that is only what the linear method can handle (Holland, 1995).

However, it is *not* the case that understanding emergent behavior requires that we make a "conceptual shift" from linearity to nonlinearity. Rather than characterizing the distinction between simple and complex systems in terms of dichotomies such as linear versus nonlinear, we propose a more productive characterization of complexity, and of emergent behavior, lies not in emphasizing these dichotomies, *but in collapsing them*. We argue that complexity is better characterized as a *dialectical co-existence of linearity and nonlinearity*. The complexity of emergent behavior comes from the co-existence of linearity and nonlinearity across and within multiple levels or scales of an open system. Indeed, because of this, complex systems exhibit seemingly opposing properties and behaviors: randomness and order, predictability (e.g., attractors, highly connected nodes or hubs) and unpredictability, coherence and incoherence, stability and instability, centralization and decentralization, and so on. Complexity is not one or the other, it is *both* (Kauffman, 1995).

There are important general implications of emergence, linearity, and nonlinearity for understanding the dynamics of learning and cognition in complex social systems. Perhaps the most important implication has been well summarized by Gureckis and Goldstone (2006): "Rules that govern behavior at one level of analysis (the individual) can cause qualitatively different behavior at higher levels (the group)" (p. 1). We revisit this critical point in our discussions of debates such as cognitive versus situative perspectives and quantitative versus qualitative methodologies for educational research.

The CSMTL and Re-conceptualizing the Cognitive Versus Situative Debate

Recall that the central argument of this paper is that there are key long standing educational research debates that we believe may be re-conceptualized through the use of a complex systems meta-theory of learning (CSMTL) that is based conceptual perspectives and methodologies employed in the study of complex physical, biological, and social systems. To illustrate this thesis, we focus on the debate about the theoretical primacy of cognitive versus situative perspectives on human cognition and learning. In our review of the cognitive-situative debate, there are two main aspects of contention in the literature: (a) *level of theoretical primacy and theoretical mechanisms*, and (b) *methodologies for research*. We also believe there is third issue implicit in this debate: (c) *epistemic challenge of simple explanations for complexities of learning*. Given space limitations, we next consider (a) and (c) here; please see Jacobson and Kapur (2012) for a discussion of (b).

Level of Theoretical Primacy and Theoretical Mechanisms

In the cognitive-situative debate in the 1990s, there was a clear advocacy of theoretical primacy for one perspective or the other that then relegated the other perspective to secondary importance. For cognitive advocates, individual cognition was the fundamental level and the social context was viewed as a secondary additional component (Vera & Simon, 1993), whereas situative advocates regarded the level of social and ecological interactions as being theoretically primary and individual cognition as secondary (Greeno, 1997).

A metaphor for this facet of the debate is that advocates of cognitive and symbolic representations view a system of learning as "trees" whereas advocates of situative perspectives view such a system as a "forest." Regarding a learning system in terms of its micro-level "trees"—i.e., individuals as cognitive symbolic processing agents or neurons as agents—provides essential details but will miss patterns that arise when trees are contextualized at a macro-level "forest"—i.e., classroom community or socio-cultural milieu. Conversely, focus on "forests" of situated social and cultural contexts will fail to see the details of the micro-levels of a learning system. Thus for this critical facet of cognitive-situative debate it follows, in our view, that there is not a sufficient argument for the theoretical primacy of *either* perspective.

But how might the CSMTL resolve this issue? As Bar-Yam (2002) has pointed out, scientists who study complex systems do not conceptualize such systems as either "trees" or "forest" but rather as "trees-forest." In terms of the CSMTL, this dynamic relationship between micro- and macro-levels of a learning system is the study of learning as an emergent phenomenon. The *agents* in a learning system, whether neurons or symbolic cognitive constructs, interact with each other and their environments based on *rules* and typically *self-organize* through *within-level feedback* processes. These micro-level agent interactions yield *emergent patterns* such as thoughts and feelings or social norms and practices at hierarchically higher levels of the learning system. Critically, once higher system level patterns emerge, these may influence, shape, or constrain agent behaviors at lower levels through *across-level feedback* processes. For example, a student who cognitively makes sense (i.e., constructs a mental model with components similar to a scientific expert) of a predator-prey ecosystem and a chemical reaction as being at equilibrium will likely be better able to engage in science inquiry

activities with other students and in turn come to gain greater insights into other scientific knowledge and to come to enjoy engaging in other authentic types of scientific practices. The "trees-forest" metaphor also applies to the dialectical co-existence of linearity and non-linearity as one leads to the other and vice versa, just as micro-level actions lead to macro-level actions that in turn may constrain micro-level dynamics.

We argue that the CSMTL provides a way to resolve which theoretical level of a system to employ—neither cognitive nor situative—but rather *both*. Related, the CSMTL provides *theoretically principled mechanisms* (e.g., self organization, feedback, emergence) from which to understand how patterns in learning that situative perspectives are interested in *emerge* from the micro-level cognitive processes, as well as how situated and cultural contexts can influence the cognitive and symbolic aspects of learning. Although our discussion here is of necessity brief, we believe the CSMTL is superior to either theoretical perspectives alone and thus should be explored further in future learning research as well as to analyze existing learning research from its meta-theoretical perspective.

Epistemic Challenge: Simple Explanations for Complexities of Learning?

We have thus far considered conceptual implications of CSMTL for educational research, primarily using the cognitive versus situative debate as a crucible for these considerations. In this section we consider another issue, which is the epistemic implications of complex systems meta-theory and methods. A key, and perhaps counterintuitive, epistemic aspect of complex systems views is that the apparent complexity in the behavior of many complex systems may be described in terms of the interaction of system elements based on relatively simple rules (see also our discussion of *emergent complexity* and *emergent simplicity* above). This issue seems implicit in views of Simon (1996): "The central task of a natural science is to make the wonderful commonplace: to show that complexity, correctly viewed, is only a mask for simplicity; to find pattern hidden in apparent chaos (p. 1)." We call this the *simplicity-complexity* epistemic view.

The CSMTL represents an epistemic challenge to what we believe is a reasonably common epistemic view of *complexity-complexity*, which is that complex systems such as the ones educational researchers study must have "complex" explanations whereas simple systems would, of course, have simple explanations. Indeed, a *complexity-complexity* epistemic bias—and its corollary, a *simplicity-simplicity* epistemic bias—would seem to be obvious characteristics of "common sense." For example, a simple machine such as a pulley may be explained as a rope wrapped around a wheel to raise or lower something, whereas the behavior and operation of a complex machine such as a modern jet airliner could only be explained with complex concepts from physics (i.e., Bernoulli effect), engineering and materials science, business models to finance and maintain, and so on.

In our reading of the cognitive-situative debate literature, there have been two main ways in which what we characterize as an epistemic commitment to complex theories for human learning may be found reflected in perspectives of both cognitive and situative educational researchers (see especially Anderson et al. (1996), Cobb (1999), and Greeno (1997)). First, whether viewed from cognitive or social perspectives, human action and learning are complex, and second, sophisticated (i.e., complex) theory—whether cognitive or situative—is required to explain the complexity of human actions. We regard these views as being influenced by the *complexity-complexity* epistemic bias.

It is an important epistemic challenge of the CSMTL that we do not necessarily have to seek complex explanations for complex behavior; such behavior may very well be explained from the "bottom up" via simple, minimal information, such as utility function, decision rule, or heuristics contained in local interactions (Nowak, 2004). Of course, we recognize that future learning theory development may or may not align with a simplicity-complexity epistemic view, indeed, the authors of this paper debate this point amongst ourselves. Still, being aware of epistemic assumptions such as these has value to learning researchers, rather than an implicit acceptance of a position that might bias theory development or interpretation of data.

Still, we stress that the CSMTL does not hold that the rules of agents in complex systems are deterministic, depriving humans of any form of agency or deliberate, goal-directed activity. In fact, it is quite the opposite; these rules are context-sensitive, probabilistic, and sensitive to initial conditions (chaotic), and should be seen as explanatory constructs and relations developed by researchers to explain complex phenomenon. Once cognitive structures emerge through across level feedback mechanisms, these structures constrain the very linear, synaptic interactions between neurons that they emerged from (Epstein & Axtell, 1996; Kauffman, 1995). Further, a host of other co-evolving factors—social, cultural, and environmental—are also critical for behaviors such as cognition to emerge. Indeed, McClelland (2010, p. 753) argues:

> I don't think that anyone who emphasizes the importance of emergent processes would deny that planful, explicitly goal-directed thought plays a role in the greatest human intellectual achievements. However, such modes of thought themselves might be viewed as emergent consequences of a lifetime of thought-structuring practice supported by culture and education.

Conclusion

Before concluding our advocacy for a complex systems meta-theory of learning, we reflect on the oft referred to story of an individual who stops to ask a drunk at night prowling around on his hands and knees underneath a street light "What are you doing?" The drunk replies: "I'm hunting for my glasses." "But sir, they are not here; where did you lose them?" the stranger asks. "Over in the dark alley," says the drunk," but I can only see here."

In educational and learning sciences research, our "street lights" are our theories and methodologies, so that the cognitive versus situative debate might be metaphorically regarded as two different streetlights. We argue in this paper that viewing learning as emergence locates this phenomenon, at least partly, in the dark alley, hence our interests in new complexity-grounded theoretical constructs and methodologies that are being used to study complex physical and social systems (Jacobson & Wilensky, 2006; Goldstone, 2006). It is to be expected, of course, that new theoretical and methodological perspectives will invariably tend to generate more questions than answers. We both encourage and welcome this process, with hope that perspectives we suggest from the CSMTL might answer at least some claims for right questions

In the history of the physical sciences, new theories, such as Einstein's general theory of relativity that accounted for the precession of the perihelion of the orbit of Mercury, helped direct empirical research in physics to make an important new discovery that was inconsistent with earlier Newtonian theory. Likewise, new instrumentation and enabled research methods, such as the telescope for Galileo or particle accelerators for modern high-energy physics, invariably led to new theoretical breakthroughs. We hope our nascent CSMTL might provide conceptual perspectives that re-conceptualize issues such as the long-standing cognitive-situative debate in educational research, and that methodologies such as computational modeling techniques (e.g., agent-based modeling) might provide new instrumentation for researchers in the learning sciences.

Overall, we hope that principled considerations of learning as an emergent phenomenon in complex neural, cognitive, situative, social, and cultural systems will yield critically important insights of central relevance to our field that might not otherwise be possible with current perspectives and approaches. In addition, we believe viewing the environments in which learning occurs as complex systems provides researchers with powerful conceptual and methodological tools that are also being used by scientists in other areas of research. That there may be synergies of theory and methods between researchers in our field with scientists in other fields has the potential to enable more cross-disciplinary research as well as opportunities to more directly link findings from other fields to issues being explored by educational researchers and vise versa. We conclude humble and mindful of Einstein's famous admonition—"everything must be made as simple as possible, but not simpler"—as we articulate these first steps of a complex systems meta-theory of learning.

Endnotes

(1) For a fuller discussion of these and related issues, please see Jacobson and Kapur (2012).

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