2 Ten 'Lessons' from Complex Dynamic Systems Theory: What is on Offer

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In some ways, the fact that 'theory' is in the name of Complex Dynamic Systems Theory (CDST) is unfortunate. While the use of 'theory' is not incorrect, it tends to underestimate what is on offer. The purpose of this chapter is two-fold: First, to introduce ten lessons from CDST as I see them; and second, to make a convincing case that CDST has far-reaching consequences, beyond what one might normally expect with a new theory. The fact is that CDST has fundamentally challenged our goal for research and our way of conducting it. No longer can we be content with Newtonian reductionism, a Laplacian clockwork universe with its deterministic predictability, and the use of statistics to generalize from the behaviour of population samples to individuals. Given its potential for encouraging entirely new regimes of thought, it has been called a paradigm by some, by others a metatheory, and by still others a theoretical framework. The point is that its influence and its promise extend beyond that of most theories.

This is because CDST is transdisciplinary in two senses of the term. It is transdisciplinary in that it has been used in many different disciplines to investigate issues ranging from the spread of disease, to the contribution of diversity in ecologies, to the formation of ant colonies and to an explanation for the demise of an ancient Pueblo people. More important, it is transdisciplinary in the Hallidayan sense (Halliday & Burns, 2006) of redefining the structure of knowledge. Indeed, like other powerful cross-cutting themes, such as structuralism and evolution, which have contributed the ideas of 'organization' and 'the arrow of time', respectively, CDST introduces the themes of *dynamism* and *emergence* to modern scholarship. As for dynamism, CDST makes the study of *change* central. CDST also contributes the notion of emergence, 'the spontaneous occurrence of something new' (van Geert, 2008: 182) that arises from the interaction of the components of the system, just as a bird flock emerges from the interaction of individual birds. In brief, change and emergence are central to any understanding of complex dynamic systems.[1]

For the remainder of this chapter, I briefly outline 10 lessons of CDST as I see them. I attempt from time to time to relate them to the theme of this chapter – motivation – although the study of motivation in second language development (SLD) is not one for which I claim expertise. I leave it up to the authors of the chapters in this volume to apply the lessons to motivational research in ways that I do not. I conclude by suggesting that CDST holds the potential for reuniting the major streams of research in the field of SLD, bringing together an understanding of learning and learner.

Change

CDST interjects dynamicity into our 'objects' of concern. 'Essentially, nothing in its [a complex dynamic system] environment is fixed' (Waldrop, 1992: 145).

Clearly, this lesson looms large in this volume on motivational dynamics because it was not so long ago that the prevailing assumption of individual difference research was one of stasis. Although characterizing individual differences as static was never stated explicitly, it is a fact that most researchers aimed to find correlations between certain learner characteristics theorized to be influential in SLD and language learning success *at one time*.

Although the types of motivation were postulated with increasing sophistication, the fact remained that change was not part of the picture. Thus, this first lesson of CDST has far-reaching consequences, heightening our awareness that motivation is dynamic. Periods of stability may be reached, but motivation undeniably changes, sometimes often and certainly over time. If we really want to understand motivation, and other aspects of SLD for that matter, we must conceive of them more as processes than states. CDST is a theory of process not state; becoming not being (Gleick, 1987). Hence this volume, *motivational dynamics,* is aptly named.

Space

Not only is time foremost on a CDST agenda, so also is space. CDST uses topographical images. It helps us see time in spatial terms. With this shift in perspective, we gain a host of concepts to stretch our thinking in new directions. System change is seen as movement in a trajectory across a 'state space' or 'phase space'. As the learner's motivational system moves across state space, it is attracted to certain regions of state space, repelled by others. The former constitute attractors in space, places where the system settles, usually temporarily.

Another interesting characteristic of its state space is its fractal geometry. A fractal is a geometric figure that is self-similar at different levels of scale. For instance, a visual image of motivation over time might look like Figure 2.1.

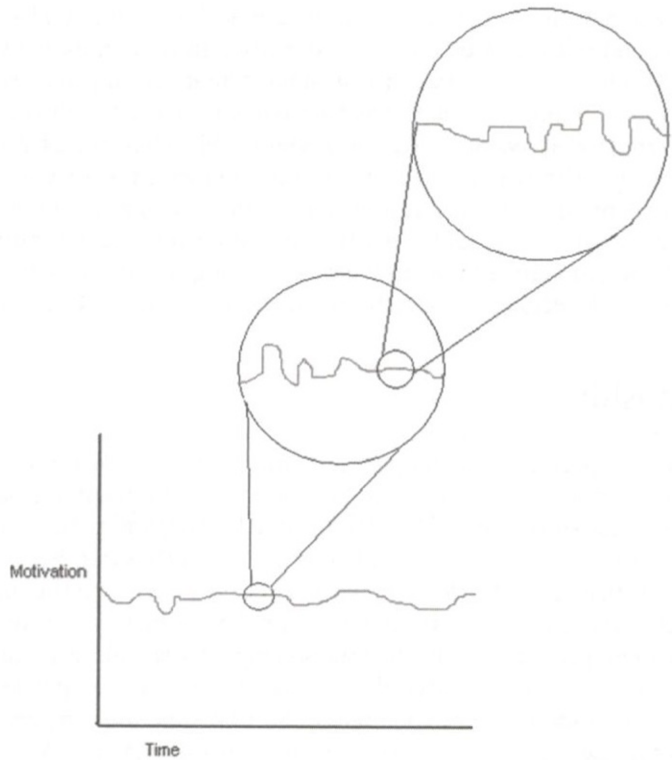

Figure 2.1 Example of a visual image of motivation over time at three different time-frames. (Figure courtesy of Frea Waninge)

If we compare the bottom line, say the time spent studying a modern language over a university semester, with the middle line, say a week in that semester, with the top line, say a lesson during the week, we see that each line displays periods of relative stability and periods of fluctuating motivation. We also see that what appear to be periods of stability at larger time-frames are made up of fluctuating motivation levels at shorter timeframes. Thus, another contribution of CDST is that it gives us a new set of images by which to describe motivation; ones that show scale independence, the structural dynamics of fractal geometry.

Complexity

As systems make their way through space/time, they display patterns – something novel – something that could not have been anticipated by probing their component parts one by one. An important concept in CDST, self-organization, 'refers to any set of processes in which order emerges from

the interaction of the components of a system without direction from external factors and without a plan of the order embedded in an individual component' (Mitchell, 2003: 6). In contrast to preformationism ('the assumption that in order to build a complex structure you need to begin with a detailed plan or template' (Deacon, 2012: 50)), the novel behaviour of a complex system emerges through the self-organizing interaction of its components, be they elements in a weather system, agents in a social group or neurons in a neural network. Thus, CDST shifts the search for understanding from reductionism to understanding how patterns emerge from components interacting within the ecology in which they operate (van Lier, 2000: 246).

Relationship

What is important in a complex dynamic system is the interdependent relationship among the factors that comprise it. Again, from a CDST point of view, it is not sufficient to view factors one by one, and then to conduct a univariate analysis, such as a simple correlation between a factor and the language proficiency of the learner. This is not only owing to the mutability of the factor. It is also important to recognize that learner factors overlap and interact interdependently, with factors playing a larger role at certain times and not at others. It is not difficult to imagine, for instance, parents' ambition for their children to learn a language for instrumental purposes being a strong component of the children's motivation initially. However, as language study proceeds, the children's own sense of self-efficacy might determine their perseverance, and the parents' influence wanes. There is thus a reciprocal interaction. We cannot get a true measure of the influence of a factor if we isolate it from the others and examine it at one time.

Nonlinearity

As complex dynamic systems make their way through space/time, they can enter into periods of criticality or chaos, where predictions are not likely to be borne out. This is most often illustrated in terms of a sand pile (Bak, 1996). Bak explained that as grains of sand are added to a sand pile, the height of the pile increases until a certain critical level is reached. At that point, even the addition of one more grain will cause a different result – an avalanche of sand. In other words, the sand pile demonstrates nonlinearity: the effect, an avalanche, is not proportionate to the proximate cause, a single grain of sand. Complex dynamic systems that reach this critical state are unstable and unpredictable, in other words, chaotic. That an effect will follow a cause is certain, but predicting exactly when or to what extent the cause will have an effect is not. Thus, making predictions is appropriate for

periods of linearity; I can predict that the sand pile will grow commensurately with each additional grain of sand, but when a system enters into nonlinearity, predicting an outcome is hopeless.

What this means for researchers is that commonly employed regression models are inadequate for the study of complex systems (Byrne & Callaghan, 2014: 6–7). We need all the tools in a complexity toolbox; therefore, the trick is to recognize indicators of criticality when systems become nonlinear, hence unpredictable. At this point, research in SLD is best carried out from a retrospective or retrodictive perspective (Dörnyei, 2014; Larsen-Freeman & Cameron, 2008). Retrodiction is predicting that one will find evidence of past events of which one at the time of retrodiction has no knowledge (Herdina, personal communication, 2013). One can explain behaviour after the fact, and one can anticipate behaviour based on general trends, but the reliability of a prediction is always subject to one of myriad factors unaccounted for.

CDSs Exhibit Sensitive Dependence on Initial Conditions

A slight change in initial conditions can have vast implications for future behaviour. It is, unfortunately, all too frequently the case that language learners terminate their study prematurely, convinced that they have no aptitude for study, based on an initial unsatisfactory experience. Moreover, there may be any one of a number of contributing factors that make the experience unsatisfactory: the time of day of the class, the teacher, the method, the grading, interaction with other students, etc. A change in any of these may restore the learner's motivation and lead to more salutary results.

In chaos theory, this concept has been popularized as 'the butterfly effect', the idea that a small influence in a nonlinear system can have a large effect at a later point in time, i.e. a butterfly flapping its wings in one part of the world will influence the weather in another. Perhaps an example that is easier to relate to is that of a rock at the top of a hill. Depending on its orientation when it is pushed, it will end up at the bottom of the hill in very different places. The point is that the systems with different initial conditions follow different trajectories, leading to divergent outcomes.

It is worthwhile pointing out that the term used, 'sensitive dependence on initial conditions', may give the impression that it is only the point at which a system commences where it is sensitive to minor disturbances. This is not the case. At any point in the evolving trajectory of a system, even a minor influence can lead the system in a different direction. This phenomenon has sometimes been referred to as 'the tipping point'. The point is, though, that a prior state influences a subsequent one, not always in a way that is anticipated, sometimes characterized as 'the law of unintended consequences'.

Openness and Nonfinality

As long as a complex system remains open, interacting with its environment, it will continue to evolve. It has no final state. Just as evolution is a process without a goal, a complex dynamic system has no foresight; it is not defined by its endpoint. Instead, a complex dynamic system is said to be autopoietic, self-modifying. Provided it is open to outside influences, it will continue to move and change. A complex dynamic system iterates in that it returns to the same state space repeatedly although its orbits never intersect. As it returns time and again, the system is built up, resulting in a hierarchical structure of nested levels.

Feedback Sensitivity/Adaptation

The order that complex dynamic systems exhibit is shaped by the fact that they are feedback sensitive. Feedback in SLD usually refers to the dynamic whereby the teacher gives, and the student receives, corrections. Positive feedback is seen as good, negative as bad. However, in CDST terms, feedback is seen more broadly in terms of cybernetics, where change in one instance results in either amplification (positive feedback) or dampening (negative feedback) of that change. A complex system adapts by changing in response to either type of feedback. In other words, an adaptive system changes in response to feedback from its changing environment. Therefore, adaptation is not a one-time process. 'A system is never optimally adapted to an environment since the process of evolution of the system will itself change the environment so that a new adaptation is needed, and so on' (Heylighen, 1989: 24). Thus, complex dynamic systems do not remain passive in light of changing events; they 'learn' or adapt to an ever-changing environment.

Context-Dependent

In CDST terms, it would be said that a person is coupled with his or her environment. Van Geert and Fischer (2009: 327) write that development applies to person–context assemblies across time. One theory in biology makes this a central point, i.e. that an organism and the environment are coupled, co-constructed and always in transition (Oyama, 2011). With the coupling of the learner and the learning environment, neither the learner nor the environment is seen as independent, and the environment is not seen as background to the main developmental drama.

It is not difficult to imagine how a person's being in one place at one time as opposed to others might affect motivational dynamics (Dörnyei, 2009). The important point is that context is not simply another 'variable'. A related

point is that the observer/researcher does not occupy a position outside of the system that he or she is studying.

Complex Systems Also Have Non-Gaussian Distributions

A Gaussian distribution is one that is depicted by a bell curve, with the midpoint representing the average behaviour. It can be used with linear systems. Complex systems also have non-Gaussian distributions, often called 'heavy-tailed', which means that infrequent behaviour at the edge of a bell curve is much more common than it would be in a Gaussian distribution. It also means that computing the average behaviour does not tell us much about the behaviour of the components or agents that comprise the system (Larsen-Freeman, 2006).

A model based on samples of individuals does not automatically generalize to a model of individual processes. As van Geert puts it:

> Work on individual trajectory models has shown that such trajectories cannot be reduced to generic trajectory model trajectories based on sample information, plus or minus some random deviations. (van Geert, 2011: 274)

He adds '[Molenaar] and his collaborators have shown that the implicit step, so common in the behavioural sciences, from sample-based research to individual process statements is often demonstrably incorrect' (van Geert, 2011: 275). Indeed, one of Rogosa's (1995) myths is that 'The average growth curve informs about individual growth'. It clearly does not.

Of course, most researchers seek to generalize beyond the particulars of a given study. Foregoing the usual statistical means to generalize does not make this impossible in CDST. However, how this is to be achieved would be pursued in different ways. One way is to probe intraindividual variation of person-specific factors rather than interindividual variation at the level of population (Molenaar & Campbell, 2009). Individual case studies may not reveal much about the population of language learners, but they do have a direct bearing on theory (van Geert, 2011: 276).

A second way might be to discover particular configurations in state space. The possible configurations, at an abstract level, may be abundant, but not infinite. For instance, certain motivational archetypes might be identified, which would allow us to specify the signature dynamics of each archetype (Chan *et al.*, this volume).

A third possibility is to search for new ways of understanding. 'The development of regression models is ... completely predicated on straightforward linear modelling ... The blunt point is that nonlinearity is the product of emergence. We need to start from emergence and develop a science that

fits that crucial aspect of complex reality' (Byrne & Callaghan, 2014: 6–7). Methods that do just that are beginning to be developed. For instance, MacIntyre's idiodynamic method (2012) and others presented at the 2013 American Association of Applied Linguistics Colloquium on Motivational Dynamics, convened by Dörnyei and MacIntyre, and included in this volume, hold great promise to broaden our repertoire of research approaches in keeping with CDST.

Conclusion

I conclude by suggesting, as I wrote at the outset, that it is time to end the bifurcated research agenda in the second language acquisition field (Hatch, 1974), which has existed for almost 40 years. On the one side has stood the question of the nature of the process of second language (L2) acquisition. Is it similar to, or even identical to, L1 acquisition, albeit it with the important difference of knowledge of an L1 having already been established? The second side has focused on language learners, centred essentially on the differential success question, one in which 'individual differences' is the major topic of investigation. For almost 40 years, the two prongs of the research agenda have been pursued mostly independently.

While this is no indictment of either side, I have been concerned for many years (Larsen-Freeman, 1985) about efforts to characterize the learning process removed from context, under the assumption that the process is universal, and that once understood, learner factors can simply be added, making some allowances for slight deviations from the general process for individual differences. This way of thinking is misguided (Kramsch, 2002). I think that hope for the unification of the field rests in a situated view of learner and learning, using research methods that honour the ten lessons compiled for this chapter – in short, the broader view of research and understanding that is on offer from CDST.

Note

(1) 'Systems' is not being used in any special way. It means a set of interrelated components.

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