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A COMPLEXITY THEORY APPROACH TO SECOND LANGUAGE DEVELOPMENT/ ACQUISITION

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As noted in the introduction to this volume, my original orientation to second language acquisition (SLA) was cognitive. This should not be surprising: I came of academic age in the early 1970s, when language acquisition was just starting to be studied scientifically. I was intrigued by Corder's (1967) hypothesis, itself inspired by Chomsky's universal grammar, of a "built-in" syllabus in learners. My interest mounted when Selinker (1972) added the interlanguage construct—a transitional linguistic system activated by a "psychological structure . . . latent in the brain" (p. 211). I saw in both ideas the potential to facilitate the SLA process. Instructional syllabi could be aligned with the built-in syllabus, and second language (L2) instruction could follow natural acquisition processes. This thinking was encouraged by Brown's (1973) discovery of a highly regular acquisition order of English grammatical morphemes for three first language (L1) acquirers. SLA researchers subsequently proposed an acquisition order common to all learners of English as a second language (Dulay & Burt, 1973). This was a revolutionary claim at the time because most L2 behavior was thought to be shaped by the L1.

I, too, undertook early L2 morpheme acquisition studies (Larsen-Freeman, 1976). Although many have since faulted such studies, they inspired researchers to move beyond contrastive analysis and consider the L2 learning process in its own right,[1] as well as to understand that SLA is psycholinguistic rather than purely linguistic (Larsen-Freeman & Long, 1991). These important shifts spawned research into learning strategies, interlanguage processes, and interaction effects, all seeking to account for how learners acquire mental grammars. This effort endured: Four decades later, many still regard SLA as centrally a cognitive process (Doughty & Long, 2003).

While I certainly endorse a role for cognition in SLA, over time I became disenchanted with the limitation of this focus. Although the factors thought to influence SLA kept multiplying, no greater understanding seemed to result. Experimental designs attempted to control for all factors except the one

hypothesized as causal. Not only was such research of suspect ecological validity, it also rested on the questionable assumption that a single factor caused some effect. To me this denied the commonsense understanding that SLA processes were complex, situated, and likely multivariate. Then, too, aggregating findings across studies seemed impossible, given differences in how and where data were collected.[2] Ubiquitous variability was also evident in SLA, both intra- and interindividually. Some of this variability was due to the social contexts in which learners lived and studied, but such contexts could not be treated as static backdrops. Moreover, language teaching clearly did not involve transferring mental systems from head to head. It was clear that SLA was no simple process of accretion and that stage views had to address the fact that development was neither unidirectional nor linear.

Thus, I was ready to think anew about SLA when I serendipitously encountered James Gleick's (1987) writing on chaos/complexity theory. Gleick wrote: "The act of playing the game has a way of changing the rules" (p. 24), and, though he was writing about naturally occurring dynamic systems rather than linguistic rules, I perceived deep parallelism with language and its acquisition. In contrast to my own (generative) training in linguistics, I came to understand language as a complex adaptive system, which emerges bottom-up from interactions of multiple agents in speech communities (Larsen-Freeman, 1997; Ellis with Larsen-Freeman, 2009), rather than a static system composed of top-down grammatical rules or principles. The system is adaptive because it changes to fit new circumstances, which are also themselves continually changing.

This view of language had implications for understanding SLA. There is no built-in syllabus and, while general, innate cognitive processes and social drives may exist, it is more accurate to say that interlanguage systems emerge from use. This was consistent with my earlier finding that morpheme accuracy order and the frequency of these same morphemes in the input correlated significantly (Larsen-Freeman, 1976). Learners interact locally, and in so doing tune to and imitate frequently occurring patterns, especially those that are salient and semantically transparent. However, the imitation is not exact. It might be better to think in terms of "adaptive imitation," wherein learners adapt patterns—sometimes amalgams of old and new—to suit their communicative needs (Macqueen, 2009). These patterns subsequently become part of learners' language resources, available for further use and modification.

In sum, I concluded that language, its use, and its acquisition are mutually constitutive, simply occurring at different levels of ecological scale—individual through speech community—and timescale. I turn next to introduce the theory that inspired me to think this way.

Overview

Organized Complexity

As indicated earlier, complexity theory originated in the natural sciences. It has a particular place, described by Weaver (1948) as occupied with problems of

organized complexity. In contrast, Weaver characterized 17th–19th-century science as dealing with problems of *simplicity*—situations having small numbers of measurable and controllable variables. Problems of simplicity abound in science. Thus, high school physics courses often feature the simple problem of predicting the motion of a billiard ball on a pool table. When two or more billiard balls are introduced, however, the problem becomes surprisingly difficult. With 10 billiard balls, it becomes unmanageable. Problems that involve many elements in this way are not simple; instead, they reflect the class of problems Weaver called *disorganized complexity*. Each of the many individual variables may exhibit erratic behavior; however, one can still talk about the average properties of the collective system. Indeed, this is the basis of actuarial science. How long any individual will live is not known, but life insurance companies remain in business because someone has calculated the average age of death. According to Weaver, problems of disorganized complexity are numerous, and the spectacular success of recent science has been largely in dealing with such problems, e.g., the fundamental laws of heredity and the motion of atoms.

However, even these scientific developments have ignored a third set of problems—those of *organized complexity*. These problems arise in systems where the number of variables is not the defining factor. Although complex systems usually have many components, either inert elements such as gas molecules or living agents such as schooling fish, what is different from problems of disorganized complexity, to which statistical methods hold the key, is that problems of organized complexity deal simultaneously with sizeable numbers of factors interrelated into an organic whole. Weaver (1948, p. 539) offered the following examples: "What is a gene and how does the original genetic constitution of a living organism express itself in the developed characteristics of the adult?" On what does the price of wheat depend? How to explain the collective behavior of organized groups like labor unions? And especially relevant today: "To what extent must systems of economic control be employed to prevent the wide swings from prosperity to depression?" These and many other problems involve a substantial number of relevant and interdependent variables coming together in organic wholes. Organized complexity, I believe, challenges us to understand language and SLA anew.

Relational Systems, Dynamism, and Self-organization

Von Bertalanffy (1950) proposed General Systems Theory to account for how complex order arises. He opposed reductionism in explaining entities as the sum of their parts, advocating instead a systems approach—understanding the relationships among parts that connect them to the whole. It is important to note that these relationships keep changing, with some parts playing more central roles at times, and at other times playing minor or no obvious roles at all. Complexity theory has benefited from this core perspective because it advocates a systems view of complex phenomena, one that centers on the relations among a system's elements or agents. Just as a bird flock emerges out of the interaction of individual birds, complex systems

self-organize via the interaction of their parts. Self-organization is the creation of more complex order spontaneously, without outside influence or internal plan (Mitchell, 2003). That is, stabilities in a dynamic system *emerge*. This dynamic process is responsible for the patterns and orderly arrangement of both the natural world and the realms of mind, society, and culture (Heylighen, 2008).

The stabilities of complex systems are based in their autopoietic (Maturana & Varela, 1972) nature, which means that they continually change and build new structures while maintaining their identity. This can easily be seen by the fact that the body's cells are constantly being transformed, as some die and are replaced by new cells, all the while preserving the organism's identity. The same quality also applies to language, which is perpetually changing, while staying sufficiently robust to keep its name, e.g., Swahili.

Complex Systems are Open and Adaptive

In the 1970s chemist Ilya Prigogine studied systems open to energy from outside themselves. Open systems continue to change and adapt as their dynamics are "fed" by energy coming into the system, whereas closed systems reach a static state or equilibrium. Energy taken into an open system leads to self-organization. The resulting more complex structure is planned or managed by no outside source or central authority. Instead, each developmental step sets the conditions for the next step, just as with epigenesis, where "the form of the [human] body is literally constructed by the construction process itself—and is not specified in some pre-existing full instruction set, design or building plan" (van Geert, 2003, pp. 648–649).

Because the system is open, self-organization is not a once-and-for-all process. According to Heylighen:

> 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 . . .
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> Another difference between . . . [a] simple model and more complex evolution is that evolution is in general *parallel* or *distributed*: there is not just one system and its environment, there is a multitude of systems evolving simultaneously, partially autonomously, partially in interaction. This "network" structure of evolutionary processes entails that no absolute distinction can be made between internal and external, i.e. between system and environment. What is "system" for one process is "environment" for another one.
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> (1989, p. 26)

This perspective is also central to cybernetics, where action by an environmentally situated system causes change in the environment, and that change then manifests itself to the system as information, or feedback, that causes the system to adapt to new conditions: The system changes its behavior.

Change in Complex Systems

Complexity theory is fundamentally about change. Behavioral change in complex systems takes two forms. The first is gradual and linear. The second is sudden and dramatic, in which the system undergoes a *phase transition* or *phase shift in state space* in which a new order self-organizes, generating new, emergent behaviors. The sudden rise of new orders is characteristic of nonlinear systems—changes that are not proportionate to their causes. Unpredictable behavior in a nonlinear system is known as *chaos* and is the primary focus of chaos theory.[3] Even in chaotic systems, however, there are patterns.

Nonlinearity in chaotic systems is due to their sensitivity to initial conditions. Working on the problem of weather prediction, meteorologist Edward Lorenz (1972) discovered that small differences in initial conditions of weather systems could have big effects later on, a phenomenon he named "the butterfly effect." A small difference, such as a butterfly flapping its wings in one part of the world, can affect weather patterns elsewhere, making it impossible to predict weather beyond short-term forecasts. The point here is that even the smallest detail in a complex system can have profound effects.

In sum, complexity theory seeks to explain complex, dynamic, open, adaptive, self-organizing, nonlinear systems. It focuses on the close interplay between the emergence of structure on one hand and process or change on the other. Language, its use, its evolution, its development,[4] its learning, and its teaching are arguably complex systems. Thus, complexity theory offers a way to unite all these phenomena. Complexity theory can therefore be tapped for its useful perspective on dynamic phenomena such as L2 development. No longer must we decontextualize, segregate, idealize, and atemporalize language (Larsen-Freeman, 2008). One of complexity theory's innovations is that in acknowledging the complexity of natural systems, it avoids reductionist solutions. It sees complex behavior as arising from interactions among many components—a bottom-up process based on the contributions of each, which are subject to change over time.

Theoretical Principles

Language is a Dynamic Set of Graded Patterns Emerging from Use

Complexity theory sees language as a dynamic set of patterns emerging from use. Over time, those that frequently, saliently, and reliably occur become emergent stabilities in a complex system: "Sequences of elements come to be automatized as neuromotor routines" in individuals (Beckner et al., 2009, p. 11), sedimented out of discourse, with grammar seen not as the source of understanding and communication, but rather a by-product of communication (Hopper, 1998). The patterns or routines themselves are variegated in form—not necessarily linguists'

units, which may not have psychological reality for speakers. Usage-based linguists (e.g., Tomasello, 2003) call these patterns "constructions"—form–meaning–use composites ranging from single morphemes to idioms to partially filled lexical patterns to complex clauses. The borders of constructions are graded, not discrete.

Invoking the closely related dynamic systems theory, Spivey (2007) spoke exactly like this about cognition itself. Rejecting a symbolic-computational approach to cognition inspired by the serial-processing computer, Spivey argued that the "external discreteness of actions and utterances is commonly misinterpreted as evidence for the internal discreteness of the mental representations that led to them" (p. 3). Instead, Spivey proposed "a perspective on mental life in which the human mind/brain typically construes the world via partially overlapping fuzzy areas that are drawn out over time," a thesis he referred to as "continuity of mind." This view entails a synchronic account of a language involving "graded probabilistic contingencies (not logical rules) governing the relationships between syntactic categories" (p. 171).

The gradedness applies to pronunciation, too: The same word is pronounced differently by the same speaker with every use (Milroy & Milroy, 1999). The variation may not be perceptible, although over time it results in grammaticization processes such as phonological reduction in high-frequency words, semantic shift, faster processing, fusion ("I am going to" shortening to /aimənə/), and the promotion of a stochastic grammar (Bybee & Hopper, 2001, p. 10). The language system is in constant flux. Stability is possible only through constant change—just as we remain erect only by making constant microadjustments in distributing our weight to our two feet. Even when not undergoing obvious qualitative change, the system changes every time a form is used, if only to increase the probability of the form's use in the future.

Language-using Patterns are Heterochronic and Adapted to their Context of Use

Because of its link to the environment, "complexity theory challenges the nomothetic programme of universally applicable knowledge at its very heart—it asserts that knowledge must be contextual" (Byrne, 2005, in Haggis, 2008, p. 169). Language is adapted to its contexts of use. In complexity theory "reciprocal causality" (Thompson & Varela, 2001) is invoked: "Upwards" emergence of patterns from individuals interacting is nonetheless "downwardly" entrained due to both the historic trajectory of the system and by its present-day sociocultural norms. Indeed, as Semetsky (2008, p. 91) stated, "The dynamical process comprises the 'past that is carried into the present.'" Thus, dynamical systems theorists give special attention to the historicity of a system as well. As with other complex systems, language-using patterns are heterochronous: Language events on some local timescale may simultaneously be part of language change on longer timescales (Lemke, 2002, p. 80).

Language Development Proceeds through Soft-assembly and Co-adaptation

This same dynamic view applies to language development, a term I prefer these days to acquisition because open systems are never fully acquired (Larsen-Freeman, 2010). As with speech communities, interlanguage emerges bottom-up through use. As such, no innate language faculty is posited, though, as indicated earlier, innate domain-general cognitive abilities and social drives may exist. Instead, learners' language resources are thought to develop from interactions they experience. This takes place through processes of *co-adaptation* (Larsen-Freeman & Cameron, 2008a) and *soft-assembly* (Thelen & Smith, 1994).

Language development itself occurs in social context. From a complexity theory perspective, such context contributes significantly to language development by affording possibilities for co-adaptation between interlocutors. As a learner interacts with another individual, their language resources are dynamically altered, as each adapts to the other—a mimetic process. Dynamic systems theorists term this the "coupling" of complex systems, which concerns neither rule acquisition nor "conformity to uniformity" (Larsen-Freeman, 2003). Nor does it concern the acquisition of a priori grammatical structures, which cannot be known separately from our perception of their emergence in the ongoing flow of experience (Kramsch, 2002). Co-adaptation is an iterative process; indeed, language development itself can be described as an iterative process, with learners visiting the same or similar territory repeatedly.

With each visit, learners soft-assemble their language resources. Thelen and Smith (1994) coined the term "soft-assembly" to refer to processes involving articulation of multiple components of a system, where "each action is a response to the variable features of the particular task" (p. 64). In other words, the assembly is said to be "soft" because the elements being assembled, as well as the specific ways they are assembled, can change at any point during the task or from one task to another.

Larsen-Freeman and Cameron (2008a) appropriated the term "soft-assembly" to signify how learners use their language resources to respond intentionally to the communicative pressures presented by their interlocutors, including classmates and teachers. For L2 learners, these language resources include not only what they know and can do in the L2, but their L1 patterns (e.g., manifest in relexification), patterns from other languages/language varieties they control, and nonverbal behavior. They cobble these together—a real-time response—considering options and constraints, their intrinsic embodied dynamics, their language-using identities and history, who their interlocutors are, the ongoing activities they are engaged in, and the affordances of the context.

Stable Patterns Emerge Bottom-up from Frequent Soft-assemblies in Co-adapted Interactions

From repeated soft-assemblies in co-adapted interactions, stable language-using patterns emerge. "Stable" does not mean "static"—the learner's system is best

considered a "statistical ensemble" of interacting elements (Cooper, 1999). It has a historicity because it is a cumulative, though selective,[5] record of one's linguistic experience (Bakhtin, 1981). Using the patterns leads them to become entrenched in the user's mind and, at another scale-level, to be taken up collectively, although not usually intentionally, by the speech community. Thus, usage-based views of L1 acquisition (e.g.,Tomasello, 2003) and emergentist views of SLA (Ellis & Larsen-Freeman, 2006) align well with complexity theory.

Such views hold that humans are sensitive to frequency of perceptually salient and semantically transparent linguistic features in the language to which they are exposed. Thus, language development is a probabilistic process, with learners extracting probabilities of particular forms occurring in particular contexts with particular frequencies. Because language is a fractal[6] (Larsen-Freeman, 1997), the distribution of its forms obeys a scale-free power law. A language's most frequently occurring words are therefore used a geometrically greater number of times (Zipf, 1935) than the rest. The data learners are exposed to are thus *skewed* (perhaps intentionally in co-adaptation), making language easier to learn.

Goldberg, Casenhiser, and Sethuraman (2004) demonstrated the effect of Zipf's Law in L1 acquisition. For each English verb-argument construction in children's speech they examined, there was a strong tendency for a single verb to occur very frequently, a profile that notably mirrored mothers' speech to these children. It was argued that this promotes acquisition: Tokens of one particular verb account for the greatest share of instances of each particular argument frame, and this pathbreaking verb provides the prototypical meaning for the construction (Ellis, 2002). In learning categories from exemplars, acquisition is thus optimized by introducing an initial, low-variance sample centered upon prototypical exemplars (Elio & Anderson, 1981, 1984), allowing learners to get a "fix" on what will account for most category members. The category's boundaries can then later be defined by experience of the full breadth of tokens and a semantic/pragmatic bootstrapping process. Importantly, the categories do not exist a priori, but are "temporal, emergent, and disputed" (Hopper, 1998, p. 156).

Learners Play an Active Role in Language Development

Not only is "positive evidence" available and involved in the process, so is negative evidence. As Spivey (2007, p. 202) observed, learners can learn from the conspicuous absence of positive evidence. That is, learners may note when a particular form occurs less frequently than they expected. Or, as Spivey puts it, "Negative evidence from the environment is not needed in such a situation because the predictive learner generates his or her own negative evidence" (p. 202).

Thus, it is not necessary to posit a central, rule-governed, mental grammar functioning in a top-down manner. The knowledge underlying fluent, systematic, apparently rule-governed language use is the learner's entire collection of memories of previously experienced utterances, both the learner's own and those attended to in co-adapting to interlocutors. This socially situated perspective includes an

active view of the learner—someone learning from positive evidence while generating his or her own negative evidence by actively noticing and exploring the boundaries of the system. However, before continuing, three caveats to this account need to be acknowledged. The first concerns frequency, the second the critical role of individual variability, and the third L1 influence. I will discuss these in order.

Frequency is Important, but not Sufficient

Although I have made much of frequency effects in L2 development, I do not wish to exaggerate their role unduly. The failings of operant conditioning as an explanation for language acquisition are well known. Therefore, it is not only frequency—development of particular language patterns also depends on the degree to which their salience captures learners' attention, and their *cue contingency*, the reliability with which learners can ascribe meaning or function to the language patterns flowing around them. Having ascribed meaning/function to frequently occurring forms, learners can begin to categorize them, often doing so around prototypes. The social associations, social value, and role of particular forms in organizing discourse are also important (Celce-Murcia & Larsen-Freeman, 1999; Larsen-Freeman, 2002a, 2003). Indeed, L2 learners assume a high degree of agency in what they take from communicative exchanges for further use. All these factors conspire in the development and use of any pattern and suggest why learners' developmental trajectories can be similar, but not identical.

Neither does saying that frequency is important mean that learners merely reproduce what they hear, or else, as Chomsky (1959) argued, linguistic creativity would not exist. However, unlike Chomsky's claim that rule-governed processes are required for novel forms to arise, a complexity theory perspective highlights morphogenesis, or new pattern development, through analogy (Larsen-Freeman, 2003). Indeed, connectionists subscribing to emergentist accounts show that generalizations form from increasing experience of usage and develop longitudinally (Christiansen & Chater, 2001; Elman et al., 1996). Furthermore, connectionist simulations demonstrate that novel forms (i.e., forms not present in the input data) can arise through overgeneralization (Rumelhart & McClelland, 1986), just as they presumably do from social interaction in contexts of natural language acquisition.

Variability is Pervasive

The second caveat concerns the uniqueness of the paths trod by individual learners. Because people's experience with the language and identities they adopt with different co-adaptors is not static, along with commonalities in the learning process, there will also be variation. Indeed, a basic tenet of dynamic systems theory is that, for change to occur, stable patterns must become unstable in the endogenous environment—or what I have referred to as the intrinsic dynamics of the learner—in order for the learner's system to self-organize in new ways. Variability pervades

language production, its presence too profound to be relegated to noise and random performance factors (de Bot, Lowie, & Verspoor, 2007). This is due partly to the fact that humans bring with them unique starting points. Even our brains are different. Humans then shape their own contexts in a unique manner. The dynamism of different factors—the fact that their contribution to the learning process waxes and wanes in interaction with others—also explains why correlations between individual difference factors vary across studies.

Dörnyei (2009a) has recently suggested that the seemingly straightforward picture of individual differences based on stable and monolithic learner traits is part of an idealized narrative. He noted that a situated and process-oriented perspective on SLA reveals that learner attributes vary considerably from time to time and situation to situation. As a result, seeking explanations of individual differences in cause-and-effect and generalizable findings does not fit a complexity theory perspective. Thus, it "is no longer sufficient to talk about individual differences in SLA against a backdrop of a universal learner . . . variation becomes the primary given; categorization becomes an artificial construct of institutionalization and scientific inquiry" (Kramsch, 2002, p. 4) such that it may not be possible to "tell the dancer from the dance" (p. 1, paraphrasing William Butler Yeats). In Ushioda's (2009, p. 218) terms, "The unique local particularities of the person as self-reflective [embodied] intentional agent, inherently part of and shaping his or her own context, seem to have no place in this [earlier] kind of [individual differences] research."

As learners shape their contexts, development can be radically affected. While development can often seem to be gradual and incremental, it also evidences sudden changes in performance, suggesting a fundamental *restructuring* of learners' language resources (McLaughlin, 1990). In short, language learning is not just about adding knowledge to an unchanging system. It is about changing the system (Feldman, 2006).

Cross-linguistic Influence Manifests Itself in Numerous Ways

The third caveat relates to the major influence on L2 development of the learners' knowledge of other languages. L2 learners come to L2 development with a lifetime of L1 experience and, given the world norm of multilingualism, likely of other languages too (Herdina & Jessner, 2002). Neural commitment to these patterns (MacWhinney, 2006), and to those of other languages, results in cross-linguistic influence, which manifests itself in numerous ways from a target-centered perspective: relexification, overgeneralization, avoidance, overproduction, and hypercorrection. The other languages also tune learners' perceptual mechanisms advantageously, but can sometimes also block them from perceiving L2 differences (Ellis, 2006). But it is not only in producing and perceiving L2 forms that cross-linguistic influence is evident. Cross-linguistic research shows that different languages shape how constructions are put together, leading to nonnative categorization and "thinking for speaking" (Slobin, 1996), with patterns of even very advanced learners reflecting underlying construals of the L1.

These various factors interact dynamically (de Bot et al., 2007; Ellis & Larsen-Freeman, 2006), such that even the most diligent older L2 learner does not develop the linguistic facility of L1 users. To assist L2 learners who wish to achieve target proficiency, their consciousness must be recruited and their attention directed through explicit instruction, which needs to be complemented by opportunities for these learners to use their language resources in psychologically authentic activities (Larsen-Freeman, 2003). Without explicit instruction, language use by most adult language learners results in developing limited language resources. By the same token, development is never complete: "There is no end and there is no state"—a title I gave to a book chapter (Larsen-Freeman, 2006a). Learners' language resources are always dynamic ensembles, expanding and contracting with time, place, and circumstance. Yet, rather than promoting a deficit view of second language development, adult learners are seen as multicompetent (Cook, 1991), attaining different levels of mastery, accomplishing what they intend, and using different languages, each appropriate to its particular time and place.

Intentionality and Agency are Important

Some have criticized the extension of complexity theory—a theory originating in the natural sciences—to human endeavors such as language acquisition. They have pointed out that self-organization may not be inevitable in human processes due to agency and volition, which can override any inevitability characteristic of naturally occurring complex systems. However, the fact that complexity theory originated in the natural sciences does not detract from its usefulness to applied linguists. Indeed, complexity theory gives applied linguists a new transdisciplinary theme, highlighting dynamism and complexity, thereby offering an alternative to the earlier transdisciplinary theme of structuralism (Larsen-Freeman, Lowie & Schmid, in press). I do think, however, that the charge of neglect of human agency deserves to be addressed.

To address the charge, I should first note that complexity theory has been widely applied to human activities, and agency or intentionality are not ignored in these applications. That humans make choices in the moment is certain, and it would be at a researcher's peril to ignore their agency. In language interactions, for instance, speakers make decisions to deploy language resources to realize transactional, interpersonal, educative, self-expressive, etc. goals and the multiple dimensions of self and identity, affective states, and social face. However, it is not contradictory that, at the same time as individuals are operating in intentional ways in the moment, their personal language resources and those of their speech communities are being transformed beyond their conscious intentions. It is not that we plan to change language; language changes. As Keller (1985, p. 211) observed: "Language is thus a consequence of human actions, albeit actions which are only unintentionally transformative." Similarly, due to the ways humans register and process information (e.g., construction frequencies), the self-organization of individuals' language resources is inevitable, provided the learner's system remains open.

Nothing is Foreclosed in Open, Dynamic Systems

Having claimed that self-organization in complex systems is inevitable, I must hasten to add that a system is not simply fated to go on reproducing itself. In an open system—the type studied by complexity researchers—anything can change. The openness of complex systems speaks to critical applied linguists' mission to challenge power imbalances in the world. From a complexity theory perspective, such imbalances are always potentially rectifiable. Complexity theory may not tell us how to do so, but understanding how systems operate is crucial to transforming them.

Speaking to this point, Osberg (2007) claimed that enlightenment understandings of causality are guided by "a logic of determinism." This logic is based on a linear and individual conception of cause and effect, in which self-determined causes yield predictable consequences; causality is based on processes that are fully determined. As such, there is no freedom within the process for anything else to occur. However, complexity theory provides a nondeterministic logic, suggesting that complex dynamic systems are free to develop along alternative trajectories—what Osberg called "a logic of freedom":

> This is a logic in which choice is an *operator* in the process itself—part of its internal "mechanics"—not something that happens *to* a process, something applied from the outside. Since emergent processes are not fully determined—they contain within themselves the possibility of freedom—the logic of emergence could therefore also be characterized as a *logic of freedom* (rather than a logic of determination).
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> (2007, p. 10)

Thus, while a complex system's potential might be constrained by its history, it is never fully determined by it: "Knowing how to negotiate our way through a world that is not fixed and pre-given but . . . continually shaped by the types of actions in which we engage" (Varela, Thompson, & Rosch, 1991, p. 144) is one challenge of being human.

Research Methods

Complexity Theory Requires Several Departures from Typical Research Procedures

The challenge presented by researching dynamic, nonlinear, open complex systems, together with their tendency toward self-organization and interaction across levels and timescales, compels us to rethink traditional research designs (Larsen-Freeman & Cameron, 2008b). Having made this point, I should immediately add that many extant research methods, both quantitative and qualitative, can be used to study complex systems.

However, several departures from normal procedures and assumptions must be acknowledged up front. For instance, in the context of quantitative research, Byrne (2002, p. 9) explained that conventional statistical reasoning in the social sciences is incapable of dealing with relationships among levels—or relating individuals to social collectivities—other than by regarding social collectivities as mere aggregates of individuals with no emergent properties. Moreover, although many extant research methods can be used with complexity theory, an exception may be that of the classical pre-test/post-test experimental design. Conventional experiments are problematic from a complexity theory perspective because of their lack of ecological validity. Further, they can only, at best, lead to claims about proximate, linear causes, while not allowing for multiple or reciprocally interacting factors that change over time. In addition, they ignore nonlinearity (Larsen-Freeman, 1997). Who can say, for example, based on a pre-test/post-test design that a particular experimental treatment did not work? If the results are non-significant, the effects of the treatment may simply not yet be manifest. While having control groups avoids some unwarranted inferences, there can be no expectation that the experimental group and the control group are equivalent, even if pre-test scores are not different at a statistically significant level. A further limitation of conventional experiments occurs when researchers attempt to control context and situation, rather than investigating adaptation to the unique particularities of context: "They try to ensure that an intervention is implemented uniformly despite different circumstances; and they focus on post intervention outcomes instead of what happens while the intervention is implemented" (Reinking & Watkins, 2000, p. 384). Indeed, it is processes—not outcomes per se—that are of most interest to complexity researchers.

A major challenge in studying complex systems is how to limit the focal point of interest. Because everything is interconnected, it is problematic to sever one component from the whole and single it out for examination. By doing so, one is likely to get findings that do not hold up when the whole is considered. Since the system is open to the environment, the challenge is even greater because clearly specifying the boundaries of a complex system is by no means intuitive (Cilliers, 2001) and, even if done with deliberation, "an overemphasis on closure will . . . lead to an understanding of the system that may underplay the role of the environment" (p. 141). This may not be a unique burden of complexity theory, however—perhaps we have been deluding ourselves in thinking that we can segregate *any* subsystem/component and still get meaningful results from its study. Because everything is always interacting and interfacing in human and nonhuman environments organically, notions of what are "inside" and "outside" a system are never simple or uncontested (p. 142).

Of course, it is humanly impossible to study everything at once: "Boundaries are still required if we want to talk about complex systems in a meaningful way—they are in fact necessary" (Cilliers, 2005, p. 612); however, strategic considerations are at stake when drawing them. Therefore, we must at least recognize the challenge in defining a focal point for our investigations. As Atkinson, Churchill,

Nishino, and Okada (2007) stated, we must "seek to view mind, body, and world relationally and integratively, as constituting a continuous ecological circuit" (p. 170). Gregory Bateson (1972, p. 465) put it this way: "The way to delineate the system is to draw the limiting line in such a way that you do not cut any of these pathways in ways which leave things inexplicable."

The biologist Richard Lewontin offered a functional solution to the boundary-drawing problem:

> [We] cannot escape from the dialectical relation between parts and wholes. Before we can recognise meaningful parts we must define the functional whole of which they are the constituents. We will then recognize quite different ways of breaking up the organism depending on what we are trying to explain. The hand is the appropriate unit for investigation if we are concerned with the physical act of holding, but the hand and eye together are an irreducible unit for understanding how we come to seize the object that is held.
>
> (1998, pp. 81–82)

Componential Explanations are not Appropriate when Studying Functional Wholes

Settling upon what the functional whole is, then, is key. Since the focus of complexity theory is relationships, a "componential" explanation (Clark, 1997, p. 104), which centrally assumes that one can best understand an object of inquiry by taking it apart and examining its pieces, will not do. Moreover, even if it were possible to understand the behavior of the individual parts and their interactions, the individual parts do not make the same contributions to interactions over time: One factor will be more influential at one time, but less so at another. This leads to the conclusion that researchers have to find new, functional ways of viewing our "objects of concern," reconceptualizing them in terms of processes, change, and continuities.

Complexity Theory Calls for Retrodiction instead of Prediction

Recall the butterfly effect, mentioned earlier, and the sensitivity of complex systems to initial conditions. Initial conditions are often unknowable at a particular point in time. This means that the usual scientific method, which calls for making predictions and then testing them, is fraught with problems from a complexity theory perspective. Systems and behavior can of course be described retrospectively—once change has happened; in fact, this is the central work of complexity theory. What we can observe in language development is what has already changed—the trajectory of the system. This is a "trace" of the real system, from which we try to reconstruct the elements, interactions, and developmental processes of the system (Byrne, 2002). Such an approach calls for *retrodiction* (or retrocasting) rather than prediction (or forecasting), i.e., explaining the next state by the preceding one.

This may not be as radical as it sounds at first blush. After all, many scientists have viable theories regarding phenomena but are unable to predict their behavior—think of meteorologists, seismologists, or evolutionary biologists. For instance, evolutionary biologists have an explanation for speciation, but they cannot even predict which flu strain will arise next year, or how virulent it will be. Of course, we may have expectations of how a process will unfold, or even its outcomes, based on prior experience, but essentially a complex systems perspective separates explanation and prediction.

Three Methods for Studying Complex, Dynamic Systems

Van Gelder and Port (1995) proposed three methods for studying dynamic systems: quantitative modeling, qualitative modeling, and dynamical description. *Quantitative modeling* is not possible when studying human beings because it involves assigning numerical values to everything in a system. Due to this intrinsic difficulty with mathematical models, complexity researchers typically prefer computer simulations, which, while of course being approximations, are easier to manipulate so that more different factors and variations influencing the phenomenon can be explored. *Qualitative modeling*, or computer simulation, has been employed in applied linguistics from a complexity theory perspective (e.g., Meara, 2006). It has several strengths. First, it forces the researcher to make explicit the assumptions about the complex system under investigation—computers can only be programmed on the basis of explicit assumptions. Second, models can be taken through multiple iterations, replicating temporal change in short order. Agent-based computer models have been used successfully in social science to model the emergence of large-scale regularities from individual agents interacting locally, such as epidemic dynamics, wealth distributions, and even the reconstruction of ancient civilizations. Of course, the computer model is an analogy vis-à-vis the real-world system, inevitably involving complexity reduction and approximation.

However, qualitative modeling need not involve computers. Larsen-Freeman and Cameron (2008a) have suggested procedures for "complexity thought modeling." Indeed, as Epstein (2008) pointed out, the choice is not really whether or not to model, because anytime you imagine a dynamic system unfolding, you are modeling. However, Cilliers (2001) warned that, "Our models have to 'frame' the problem in a certain way, and this framing will inevitably introduce distortions." He added:

> This is not an argument against the construction of models. We have no choice but to make models if we want to understand the world. It is just an argument that models of complex systems will always be flawed in principle, and that we have to acknowledge these limitations.
>
> (p. 138)

The third way to study complex systems—*dynamical description*—"provides a general conceptual apparatus for understanding the way systems, including, in

particular, nonlinear systems, change over time" (van Gelder & Port, 1995, p. 17). *Ethnography* offers a viable method for dynamical descriptions, which "attempt to honor the profound wholeness and situatedness of social scenes and individuals-in-the-world" (Atkinson, 2002, p. 539). Dynamical descriptions can also be generated by *formative experiments*, which focus on the dynamics of pedagogy. In a formative experiment, "the researcher sets a pedagogical goal and finds out what it takes in terms of materials, organization, or changes in the intervention in order to reach the goal" (Newman, 1990, in Reinking & Watkins, 2000, p. 388). Formative experiments attempt to investigate the potential of a system rather than its state. The researcher accepts the fact that change in one system can produce change in other connected systems, attempts to describe the interconnected web of factors influencing change, and investigates processes of co-adaptation in response to changed pedagogic goals.

Design experiments, too, work with a complexity approach. Barab (2006) explained that, in complex learning environments, it is difficult to test the causal impact of particular variables with experimental designs. Design-based research "deals with complexity by iteratively changing the learning environment over time—collecting evidence of the effect of these variations and feeding it recursively into future design" (p. 155). Then, too, *microdevelopment*, which permits the study of "motors of change" (Thelen & Corbetta, 2002, p. 59) using dense longitudinal corpora, as well as other longitudinal designs that yield rich descriptions, are compatible with a complexity theory approach.

Complexity theory increases our understanding of complex systems, but it does not present us with tools to predict or control behavior accurately. We may thus learn a lot about the dynamics involved in the functioning of such systems, but we will not be able to use these general principles to make accurate predictions in individual cases. Complexity theory underscores the importance of contingent factors, of considering the specific conditions in a specific context at a specific time. No general model can capture such singularities.

Supporting Findings

Although complexity theory is in its infancy vis-à-vis L2 development, input and interaction have long been central to accounts of SLA, and therefore some earlier findings support a complex systems perspective. For instance, as mentioned earlier, restructuring (McLaughlin, 1990) of learners' grammatical systems is compatible with complexity theory. In complexity theory terms, restructuring is a phase shift in language development that comes about through self-organization. Whereas development is often gradual and incremental, sudden shifts in performance can also occur. Such appears to be the case when English learners go from using regular and irregular verbs correctly in the past tense to overgeneralizing the regular to irregular forms, saying such things as "eated." The irregulars eventually reappear, their acquisition thus following a "U-shaped" pattern overall. The stage at which irregulars disappear and are replaced by regularized forms is sudden, suggesting a fundamental restructuring or self-organization of the underlying grammar.

More recent support for complexity theory in L2 development comes from research inspired by usage-based theories of child language acquisition (Tomasello, 2003). These theories have turned upside down generative assumptions of innate language acquisition devices and top-down, rule-governed processing, replacing them with data-driven, emergent accounts of linguistic systematicities (Beckner et al., 2009). This perspective, which complexity theory encourages, has just begun to be applied to L2 development. For instance, Ellis and Ferreira-Junior (2009) investigated the L2 emergence of verb-argument structure in English. Their corpus linguistic analysis of naturalistic and elicited NS and NNS speech showed that the language NNSs are exposed to and subsequently use adheres to a Zipfian profile—that is, several verbs occur far more frequently than others in particular verb-argument constructions, facilitating the acquisition of such constructions. This Zipfian profile is scale-free, which means that it occurs despite the size of the corpus. In this way it could be said that language is a fractal—a pattern of self-similarity characterizing dynamic systems (Larsen-Freeman, 1997).

Larsen-Freeman (2006b) offered a dynamical description of the interlanguage of five Chinese learners of English over time. Traditional measures of complexity, accuracy, and fluency demonstrated the nonlinearity of the development process at the individual level and trade-offs individuals made among them. Data analysis also revealed the existence of dynamic language-using patterns, some stable and some shaped by learners for each context of use.

For instance, one of the learners was explaining in writing how she ran into an ex-teacher at a social function in another city: "When I was taking my food, a lady past by me, and I had a feeling that I knew her, but her name just was on my tongue I could say it." Here, a Chinese expression is relexified into English—"taking my food"; "passed" is spelled like its more frequent homophone (and as many proficient L1 English speakers might spell it); the likely formula "I had a feeling that" is used; a Chinese idiom, "her name was on my tongue," which is slightly different from English "on the tip of my tongue," is adopted; the two final clauses are not linked; and the final clause is missing a negative.

Now, here is the same idea unit, written by the student six weeks later: "When I was picking up my food, a lady past by me, and I had a strong felling I knew her. I could not mention who she was." "Taking my food" is now replaced by "picking up," no longer relexified from Chinese; "passed" is still misspelled; "strong" is added to the formula; "feeling" is now misspelled as "felling"; the complementizer "that" is dropped; the final two clauses are connected; and the negative appears in the final clause. While this idea unit is still not accurate from a target-language perspective, it is closer. These two brief examples suggest that the learner was adapting her language resources in the moment. She was making use of L1 patterns, formulaic utterances, and competing forms, some target-like and some not, in order to communicate her intended meaning. How the variability and specific adaptation of "make-do" solutions at one time lead to instability and stability in cross-time development is of course a central question, and is not answerable from this study, which would have benefited from a denser corpus

collected over a longer time period. However, it is plausible that the repeated application of the procedure led to changes in the system (Verspoor, Lowie, & de Bot, 2008). As Hopper (1998) put it, forms are constantly being adapted to the needs of the hearer or audience—speech is performed in a context of adjustment to others. Thus, learners are not engaged in learning sentences, but rather in learning to adapt their behavior to increasingly complex surroundings.

Macqueen (2009) added to this finding by tracing the development of language-using patterns in the writing of four L2 learners. One learner, Catalina, appeared to be working on the pattern "have a/an . . . impact on. . . ." On May 5, 2005, she wrote, "it can *have a* negative psychological *impact above* some people," where the preposition was non-target-like.

From the beginning, Catalina used the verb *have* primed to collocate with *a* (adjective) *impact* and followed by a preposition. She also appeared to understand that it needed to be preceded by a negative adjective. However, Catalina needed to work out which preposition to use, especially since, as she told Macqueen, *on* and *above* are the same word in Spanish and so she was confused as to which one to use. Between May and October, Catalina noticed the combination of *impact* and *on*. Catalina could even remember the occasion when she first heard these words used together.

Later, she produced the general pattern as follows:

- "by *having a* negative emotional *impact on* their workers" (October 28, 2005);
- "Violence on TV and video games can *have a* negative psychological *impact on* teenagers" (February 23, 2006);
- "tax policy *has an* unsure *impact on* private saving incentives" (May 5, 2006).

Discussing all four participants in her study, Macqueen wrote:

> Tracing the geneses of these patterns revealed that their university patterning was an amalgam of old (pre-university) patterns and new imitations that had been freshly adapted from the disciplinary discourse. These pattern histories demonstrate firstly that the imitation of expert texts is a very significant feature of the participants' L2 use at university, and secondly that changes in imitated patterns are the result of a dynamic and interrelated combination of factors including new language experiences and subsequent encounters with patterns, perception, memory, attention, intention, experimentation, message, co-text constraints, task requirements, and identity forging.
>
> (2009, pp. 234–235)

Macqueen went on to endorse a complexity theory perspective in which both stability and variability in co-textual patterning emerged through an iterative process she referred to as adaptive imitation. In the two studies mentioned so far and Verspoor, Lowie, and van Dijk (2008), variability is clearly a central element, an intrinsic property of a self-organizing developing system.

Finally, Caspi (2010), in a recently completed doctoral thesis, has used the mathematical tools provided by dynamic systems theory, particularly those connected with Paul van Geert's (2003) precursor model. From her modeling, Caspi concluded that the receptive–productive gap in lexical knowledge is a temporal and developmental phenomenon. In addition, in L2 writing, she found support for a hierarchical order among the four dimensions of lexical complexity, lexical accuracy, syntactic complexity, and syntactic accuracy, and importantly demonstrated that these four categories can arise without postulating separate developmental mechanisms for each.

Differences vis-á-vis Other Alternative Approaches

Complexity theory shares features with other approaches discussed in this volume, such as the unified view of the social and cognitive of the sociocognitive and sociocultural approaches and the groundedness in data and attention to detail of conversation analysis. However, while complexity theory shares with the Vygotskyan perspective the view that cognition (or higher mental functions) emerges from ongoing social interaction, it is also interested in how minds affect the social contexts they operate in. Complexity theory thus supports ecological accounts of learning that place its locus exclusively neither in the brain/body nor social interaction, but in their intersection.

Complexity theory may also differ from other approaches in this volume in that complex systems display behavior over a wide range of timescales. It may further differ in rejecting the subjective/objective dichotomy—complexity theorists understand that they are part of the system they are attempting to explain. There is no standing outside and viewing it with objectivity. Cilliers is worth quoting at length in this regard:

> An understanding of knowledge as constituted within a complex system of interactions would, on the one hand, deny that knowledge can be seen as atomized "facts" that have objective meaning. Knowledge comes to be in a dynamic network of interactions, a network that does not have distinctive borders. On the other hand, this perspective would also deny that knowledge is something purely subjective, mainly because one cannot conceive of the subject as something *prior* to the "network of knowledge," but rather as something constituted *within* that network. The argument from complexity thus wants to move beyond the objective/subjective dichotomy, as Morin (2007) also argues. The dialectical relationship between knowledge and the system within which it is constituted has to be acknowledged. The two do not exist independently, thus making it impossible to first sort out the system (or context), and then to identify the knowledge within the system. This co-determination also means that knowledge and the system within which it is constituted is in constant transformation.
>
> (2008, p. 48)

One other obvious difference from the alternative approaches featured here is that complexity theory is transdisciplinary (Larsen-Freeman, forthcoming). It has informed such disparate fields as physics, biology, the social sciences, engineering, management, economics, medicine, education, literature, etc. Its power comes not only from its application to many different disciplines, but also from its application at many different levels: neurons in the human brain, cells and microbes in the human body, and flora and fauna in an ecosystem, as well as more social activities such as information flow in social or computer networks, infectious disease transmission, the economic behavior of consumers and firms, and now language and language development. Each of these phenomena works as a "complex system."

Kramsch summarized complexity theory's uniqueness in theorizing language behavior in SLA in particular:

> Complexity theory, which originated in the physical sciences, has been used as a productive metaphor in SLA to stress the relativity of self and other, the need to consider events on more than one timescale and to take into account the fractal nature and unfinalizability of events.
>
> (2009, p. 247)

Future Directions

Whiteside (in press) observed that, with increasing global communication and migration, speakers of the world's languages are encountering each other in ways never before imagined. Given the current reality of transnational flows of language and people, it is not surprising that the holistic view provided by complex, dynamic systems would attract multilingualism researchers (de Bot et al., 2007; Herdina & Jessner, 2002; Kramsch & Whiteside, 2008; Leather & van Dam, 2003; van Lier, 2004). As Jessner (2008) pointed out, it makes little sense to look at linguistic systems in isolation when studying multilingualism, because the behavior of each system largely depends on the behavior of previous and subsequent systems. Thus, Kramsch and Whiteside encouraged researchers "to see interactions in multilingual environments as complex dynamic systems where the usual axes of space and time are reordered along the lines of various historicities and subjectivities among the participants" (2008, p. 667).

Of course, there is still much yet to be learned about L2 development from a complexity theory perspective. A few examples must suffice:

1. As is well-documented, individual variation pervades L2 development. However, to what extent, if any, is this variation patterned? Researchers are obliged to account for regularities as well as uniqueness.
2. How best to adopt a complexity theory perspective that "allows us to consider simultaneously the ongoing multiple influences between environmental and learner factors in all their componential complexity and the emerging changes in both the learner *and* the environment as a result of this development" (Dörnyei, 2009b, p. 251), a process referred to above as co-adaptation?

3. Co-adaptation appears to skew language use in accordance with Zipf's Law. What happens if the skewing is even more exaggerated, e.g., by the teacher in the classroom? Can adaptive imitation of language-use patterns be promoted, thereby accelerating L2 development?

Above all, complexity theory argues for epistemological modesty. To understand L2 development more completely, we must resist the arrogance of certainty and premature closure (Larsen-Freeman, 2002b). Indeed, complexity theory "should . . . be seen not as aiming at a new 'synthetic theory' of complexity of any kind, but a cross-disciplinary field of research and a meeting place for dialogue" (Emmeche, 1997, in Cilliers, 2001, p. 137).

Notes

1 See Leopold (1939–1949) for an earlier example.
2 However, recent meta-analyses show some promise in this regard (e.g., Norris & Ortega, 2000).
3 Chaos theory and dynamic systems theory share a great deal with complexity theory, but have more of a mathematical lineage than a scientific one.
4 These days, I prefer "development" to "acquisition." While I note that the latter is well established, it suggests to me a commodification of language—a static entity that once taken in, remains in a static state (Larsen-Freeman, 2010). See a further comment on this distinction later in the main body of the text.
5 This depends on what one attends to and the limits of one's memory.
6 A fractal is a pattern that is self-similar at all levels of scale.

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