Collective Variables in Applied Linguistics Research

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Abstract

This paper focuses on the key dynamic(al) systems theory concept of collective variables as it relates to developmental research in applied linguistics. Dynamic(al) systems theory is becoming prevalent in linguistic research and in the past two decades has jumped to the forefront of cutting edge in the field. One key concept in dynamic(al) systems theory is that of collective variables. In order to help properly orient this concept in the field of applied linguistics, this paper discusses the concept in three sections. The first section provides a brief theoretical background of general dynamic(al) systems theory, as well as the theory's place in linguistics. The second section introduces and provides a description of the concept of a collective variable as it exists in complexity theory. Finally, recent applications of collective variables in applied linguistics research are discussed.

Key Words: dynamic systems theory, complex systems, language development, collective variable

Introduction

As can be seen across the field of applied linguistics, a shift in the perception of the processes of language development is occurring (de Bot, Lowie, & Verspoor 2005; Dörnyei 2009; Herdina & Jessner 2002; Larsen-Freeman & Cameron 2008a). In little more than a decade, dynamic(al) systems theory (DST), also referred to as complexity theory, complex systems theory, and chaos theory, has gone from a provocative new idea to the forefront of applied linguistics research. In recent years, there have even been special journal editions and conference sessions devoted to the idea of language as a complex adaptive system (CAS)(e.g., the special supplemental issue of *Language Learning* published in 2009, and the second issue of *The Modern Language Journal* in 2008). DST, which began in mathematics (Larsen-Freeman & Cameron 2008a), has existed outside the field of applied linguistics for some time, particularly in cybernetics and artificial intelligence (Ashby 1960; Holland 1998; Wiener 1948), and has spread to fields as diverse as economics, epidemiology, ecology, and neurology. In a world that is increasingly interconnected and becoming more global and complex, DST offers researchers of many disciplines the tools to embrace the complex without the need for reductionism that has been so prevalent in experimentation for so long. Complexity, by nature, may not be easy to work with and may still be in its infancy in the field of applied linguistics, but it holds much promise in its potential to illuminate our understanding of language and its development, whether first, additional, or multilingual (Herdina & Jessner 2002).

Still, despite the attention DST is receiving in applied linguistics, the jury still seems to be out on what exactly is the best way to go about applying it to research methodology. As will be discussed below, many researchers have begun to take initial steps into developing DST methodologies in various areas (e.g., language evolution (Blythe & Croft 2009; Croft 2000), language learning motivation (Dörnyei 2005, 2009), and language acquisition and development (de Bot 2008; de Bot, Lowie, & Verspoor 2005, 2007; Verspoor, Lowie, & van Dijk 2008)), but questions still remain. While it is beyond its scope to attempt a complete justification for the application of DST to linguistics, it is my hope that this paper will help to shed light on the specific DST concept of collective variables, which, at first glance, can seem rather elusive. Thus, this paper will be divided into the following sections: first, a brief background into DST and its key concepts; second, a discussion of what collective variables mean to DST; and third, how collective variables are being and may be utilized in applied linguistics research.

Theoretical Background

Before collective variables can be properly discussed, a framework of DST is necessary. Put simply, a system is complex if it contains multiple interconnected components capable of interacting in different ways (Larsen-Freeman & Cameron 2008a). This is true on any level, from molecules to galaxies. One exemplar dynamic system is that of the double pendulum.[1] In such a system, from only a few simple components and laws (i.e., two pendulums, gravity, and thermodynamics), a nonlinear and complex pattern of behavior emerges. Such a system is nonlinear because its behavior is such that, in the case of the double pendulum, prediction becomes essentially impossible; in DST, this is a *strange attractor*, or state of chaos, where *chaos* does not refer to utter anarchy, but a state of unpredictable system change. Typically, however, complex systems tend to exist in *attractor states*, which are one of many possible such states in the full *state space* of the system. A simple visual conceptualization for an attractor state is to picture a large, slack trampoline on the surface of which several weights of different amounts have been placed to create " wells " of varying depths. If a ball is tossed onto the trampoline, it will bounce, roll around, and eventually be drawn to one of the " wells " created by one of the weights. When the ball settles into the well and stops moving, it has entered an attractor state. Keep in mind, this is a visualization of an attractor state, and is not a complex system, per se.

Complex systems are rarely so straightforward. More often than not, any naturally occurring system is made of many interconnected and interacting parts, themselves often made up of subsystems. In a very literal sense, the entire physical universe is a complex system. We as humans are ourselves also complex systems *nested* within the greater planetary system of Earth; but the nesting does not stop there, as any living creature is made up of many millions of complex systems, from the nervous and circulatory systems all the way down to the cellular level. Thus, when a complex system enters an attractor state, it may appear stable, even stationary. This is hardly the case on all levels, however. Picture a leafless tree in winter; it appears dormant, even dead. But on a subsystem level, the tree is very much alive and engaged in the respiration that keeps it alive until spring. The mitochondria are still hard at work. When spring does come, the entire tree system undergoes a *phase shift* and enters the attractor of its active, growing state.

What happens if a tree loses a limb during its growing state? It is unlikely that it would die. Instead, after such a *perturbation*, it redirects its energy to the remaining limbs and continues in a novel state, no longer the same tree it was before. This adaptability is another key concept in DST. When a complex system undergoes perturbation, it has the potential to self-organize. In fact, as an open system, any living thing is constantly undergoing change and in flux at some level, and in a CAS, such change is paramount (Larsen-Freeman & Cameron 2008a). Through such processes of perturbation and self-organization, complex systems can also exhibit *emergence*, in which a theretofore unknown state or behavior appears. A beautiful real world example of this is the emergence of coordinated reaching and grasping in young children documented by Thelen and Smith (1994). As children (and their brains) develop, they experiment with moving different parts of their bodies, learning how to control each through repetitive trial and error. In the children observed by Thelen and Smith, several separate systems, such as hand-eye coordination and the movement of joints, self-organized into a higher-order system through which the children were able to reach out and grasp an object that they had, until that moment, been unable to do so.

Language, situated in the incredibly complex system of the brain, is also a CAS (The " Five Graces Group " 2009) and exhibits change on many timescales: microgenetically, as interlocutors modify interaction to accommodate one another; ontologically, as a language is learned and develops in the brain; and historically (phylogenetically), as the language itself evolves (Larsen-Freeman & Cameron 2008a). Language is also made up of subsystems such as syntax, morphology, and phonology and is quite capable of change, self-organization, and emergence (Ellis 1998; Ellis & Larsen-Freeman 2006; van Geert 2008). As language is experienced, neuronal connections in the brain are strengthened with use or weakened and eventually pared from lack thereof (Dornyei 2009; Schnelle 2010). The brain receives language constructions as input and, with sufficient exposure according to laws of frequency and statistical probabilities in conjunction with the noticing of salient features, incorporates those constructions into its language system (Ellis 2006a, 2006b; Goldschneider & DeKeyser 2001; The " Five Graces Group " 2009). In this way, children construct language through use from the bottom up (Tomasello 2003). Likewise, older children and adults learning a second (or additional) language (L2) do so through use and exposure; however, for such learners, the maturity of their complete sociocognitive system as well as the first language which is largely in place make the process even more complex (Larsen-Freeman 1997, 2002, 2007).[2]

Collective Variables

With the above background in place, it is possible to consider the application of DST in linguistic research. Since prediction in the traditional sense is fundamentally impossible more than a few evolutionary time steps ahead of a system's present state due to its nonlinear nature, it is easy to feel overwhelmed in the face of such a research paradigm. This is only disheartening when thinking of research in the traditional, reductionist sense, however. In DST, the purpose is not to understand every interaction of every subcomponent and establish a model for predicting the minutiae of every aspect of an entire system. Because emergence is possible through (sometimes abrupt) system self-organization, prediction in the reductionist sense is not feasible (The " Five Graces Group " 2009; Larsen-Freeman & Cameron 2008a; Thelen & Smith 1994). This is because a CAS is more than the sum of its parts (Byrne 1998; Holland 1998; Larsen-Freeman 1997). Imagine trying to calculate and predict every component interaction of a weather system, or a language classroom! Only through observing *change* can we hope to make sense of language. In a CAS, this can be done through searching for *variability* (Larsen-Freeman 2006; Larsen-Freeman & Cameron 2008b; van Geert & van Dijk 2002; Verspoor, Lowie, & van Dijk 2008).

When a CAS is in a relatively strong (or deep) attractor state, variability, while present, remains insufficient to cause a qualitative system change, or *phase shift*. For instance, when a person rides a bicycle, her balance is not always perfect, and the speed at which she pushes the pedals will vary. This can be caused by any number of factors, including the slope of the ground, the condition of the bicycle, or the speed and direction of the wind. Still, despite such variations in balance, speed, etc., the cyclist remains upright and progresses forward. However, as a CAS nears a system change, variability increases. Once the variability is too great for the present attractor state to maintain, the system shifts to a new attractor state somewhere else in its state space. In the system of a bicycle and its rider, it is possible to cease pedaling and continue moving forward for a time, but when the necessary amount of forward velocity is no longer present, balance is affected. Gravity overcomes the velocity of forward movement, and the bicycle/rider system falls to the ground in a potentially painful phase shift. DST language research therefore looks for variability as the key to identifying system change. While some variability is inherent to a system, even in a stable attractor state, when variability increases, it may be a sign of imminent system change.

The next logical step is, then, to determine where to look in order to find such variability. Context is a very important part of language, which is itself inherently social (The " Five Graces Group " 2009); speakers (and writers) must adapt their language use to the context at hand. An individual has an underlying language competence, of course, but this is only realized through contextualized use (Ellis & Larsen-Freeman 2006). Thus, *language performance* is key to locating variability. As Larsen-Freeman (2006: 595) puts it, we want to find " performance variability ", which is a potential indicator of system change (and not " variable performance ", which is context-specific differences within the bounds of an attractor state). Since language is emergent as a CAS, we must look to collective variables as a quantifiable metric by which to measure system variability and, by extension, change.

A collective variable is not something the researcher chooses. It is tempting to perceive the collective variable in a traditional reductionist vein and think it can be selected and tested at will. The collective variable is not the same kind of variable as the traditional independent/dependent variables. We must conceive of complex systems in complex, adaptive, and emergent ways. The *collective variable* is what emerges through interactions of system dynamics (Larsen-Freeman & Cameron 2008a) and can therefore be used to describe complex systems (Thelen & Smith 1994). By identifying collective variables, it is possible to effectively constrain the degrees of freedom of the system so that, when variability occurs, it is measurable. It is important to not forget, though, that variability does not always equal system change and is quite often " parametric " (ibid: 63-64). The collective variable can serve as an index of system stability as well as signal a system breakdown or imminent phase shift. Similar to their study of the emergence of infant grasping mentioned above, Thelen and Smith (1994) also investigated the development of foot movements leading up to the emergence of coordinated stepping-like behavior in infants (when held upright with feet placed on a moving treadmill). In that study, they measured the collective variable of the infant's kick displacement versus its velocity. This was not the only collective variable available to them, but was a construct that captured the interacting system components' properties. In doing so, Thelen and Smith were able to quantify when the separate foot movement systems self-organized into a more coordinated behavior. Thus, by using the collective variable to measure the state of a developing system at a specific point in time, then consecutively repeating that measure over a period of time, system behavior can be traced and change found via increases in variability.

In this way, variability in performance can be used to understand development. Furthermore, in order to protect against mistakenly taking variables in performance (inherent to any stable CAS) to be performance variables (key indicators of potential system change), different timescales may be used (Larsen-Freeman & Cameron 2008a). Doing so can help " muffle " the apparent effects of subsystems and perturbations which are not sufficient to cause a phase shift. For example, when dealing with an L2 classroom, the environmental conditions of the room, such as temperature, light, and facilities, may have an effect on performance at a certain time. But if performance is measured repeatedly over a sufficiently long period, such components or conditions may be able to be factored out. A caveat to this does exist, however: if microdevelopment, such as the second-to-second backchannels in a conversation dyad, is being investigated, then environmental factors such as temperature may play more of a role. Part of DST research is locating the appropriate system level's collective variable with which to measure system performance.

Collective Variables in Applied Linguistics Research

In an attempt to elucidate the kinds of experimentation available to the applied linguist using collective variables in DST research, this section will introduce several research designs which have been discussed in recent years to explore the potential of DST in the field. As I, myself, have only recently discovered DST in applied linguistics, the first part of this section will draw heavily on de Bot, Lowie, and Verspoor (2007), Larsen-Freeman (2006), Larsen-Freeman and Cameron (2008b), and van Geert and van Dijk (2002), all of whom have established themselves at the forefront of DST research in applied linguistics.

One possible application of a collective variable in language development is in the performance of the language classroom itself in the guise of formative experiments and design-based research (Larsen-Freeman & Cameron 2008b; Reinking & Bradley 2007). In a formative experiment, an objective is laid out and sought by introducing whatever changes are necessary to achieve it. In this way, the researcher can observe the system as new changes are introduced and track the collective variable of system performance. When the objective has been met, the trace of the system should provide insight into when the variability that brought about a system phase shift occurred. With any complex system, however, the researcher must always keep an open mind; while it may seem that a recently introduced element has had a profound impact on the system, it is possible that something previously introduced has been more of a control parameter in system change, whether through sufficient frequency of use, or simply enough time passing for it to become integrated into the system.

Similarly, 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 " (Barab 2006 as quoted in Larsen-Freeman & Cameron 2008b: 207). Instead of using any means necessary to achieve an objective, as in formative experimentation, design-based research traces the collective variable of (class) performance across time and iterations of deliberate pedagogical system change. In a sense, these experiment designs resemble ethnography (which is also a potentially valid research design within a DST paradigm (Larsen-Freeman & Cameron 2008b)); in a system as complex as a classroom, a large amount of data must be collected—typically both qualitative and quantitative—in order to fully understand the workings of the classroom system. Therein lies a potential drawback of this kind of research methodology, however. In order to obtain sufficient data, in-depth, longitudinal studies are required. This is, of course, not a weakness in the experiment itself, merely an obstacle to be overcome.

A third interesting research design in this vein is action research (Larsen-Freeman & Cameron 2008b). In this method, the researcher deliberately introduces a perturbation into the system in order to observe how the system responds. By monitoring the collective variable of system performance (whether an individual performing a task such as dyadic interaction or larger group such as in a group task), the researcher can gain " a deeper understanding of the system dynamics " (ibid. 207). This can be used to test the stability of a system. If the introduced perturbation is insufficient to provoke system change, it provides a qualitative reference point as to system stability.

As mentioned in the previous section, microdevelopment research is also a possible avenue of investigation using DST. This can be employed when the goal is to locate moments when system change is observable. Naturally, this is done by monitoring the construct of a collective variable of the system. In order to achieve such a level of tracing, however, dense corpora of performance data must be collected over a short period of time (Larsen-Freeman & Cameron 2008b). This kind of experimental design has the potential to lend the most insight into specific moment-by-moment changes and variation in language. Microdevelopmental studies may be one way to greatly deepen our understanding of the intricate processes of language development and hold much promise for DST research.

It is also beneficial to look at a few recent studies that have been conducted within a DST paradigm. In their paper on variability in L2 developmental research, Verspoor, Lowie, and van Dijk (2008) provide instances of using specific collective variables in L2 writing. One simple method is to trace the proportion of longer versus shorter sentences over time. Similarly, average sentence length for each writing event can be calculated and its change over time traced. On a more precise level, collective variables such as vocabulary use in writing and sentence complexity could be observed. Verspoor, Lowie, and van Dijk suggest using (average) word length, lexical creativity (through type-token ratio and use of Academic Word List items), and average sentence length as measures of a collective variable of vocabulary use. For the collective variable of sentence complexity, they suggest looking at (average) noun phrase (NP) length and number of words per finite verb in constructions. As an example, I have plotted the data from several aspects of a Japanese English as a foreign language (EFL) speaker's writing production on five academic essays which were written several weeks apart across the span of four months. As can be seen in Figure 1, while the Flesch-Kincaid grade level and reading ease scores—both general measures of writing—as well as sentence length and number of unique words all appear to be performance variables exhibiting what appears to be stable variability according to contextualized use (e.g., different essay topics or personal motivations at different times) without apparent trends, there may be something occurring in sentence complexity (Figure 2). Words per finite verb as well as NP length are exhibiting variability in performance with what appears to be an

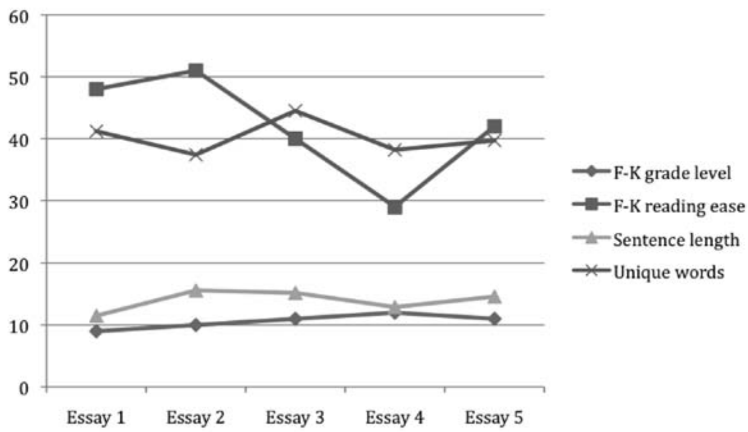

Figure 1: Writing performance traced across four variables

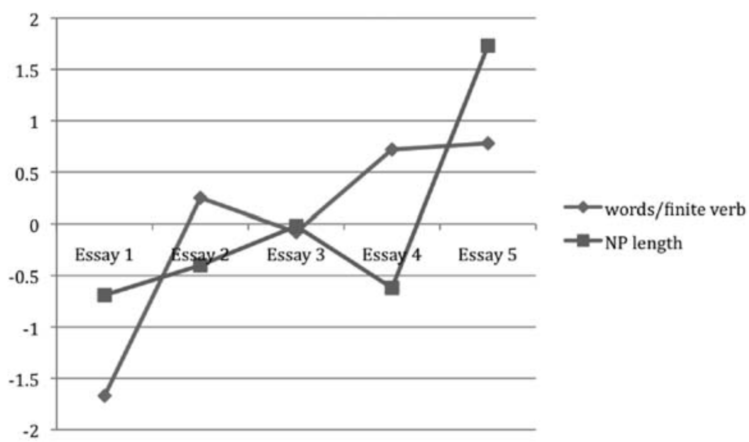

Figure 2: A z-score plot of the change in average words per finite verb and average noun phrase (NP) length across five essays.

upward trend. Obviously, the data presented here are insufficient to draw any real conclusions, but it would seem that over the course of the period of data collection, this learner's language system was near or experiencing a possible phase shift in its sentence complexity. As a subsystem, a change in sentence complexity in writing could lead to a greater system-wide phase shift, perhaps with a positive knock-on effect in sentence complexity in spoken language as well. In this particular learner, tracing sentence complexity until a greater system change occurs could provide valuable insight into the role of sentence complexity in higher-level (academic) writing.

In her paper on the development of five English as an L2 speakers, Larsen-Freeman (2006) used t-units to quantitatively measure learners' performances in four subsystems of language as a collective variable: fluency, grammatical complexity, accuracy, and vocabulary complexity. She defines a t-unit as " a minimal terminal unit or independent clause with whatever dependent clauses, phrases, and words are attached to or embedded within it " (597). Fluency was measured as the average number of words per t-unit, grammatical complexity as the average number of clauses per t-unit, accuracy as the amount of t-units without errors versus those with them, and vocabulary complexity through a type-token ratio. Through her analysis, Larsen-Freeman was able to demonstrate that, while all the learners were progressing toward fluency in a traditional sense, each learner was following her own path of language development. This is an important feature of DST research; because variability is key to system change, setting outliers aside and averaging across individuals can effectively hide the very data for which we are searching. As Larsen-Freeman's study was not intended to track the evolution of a collective variable of the language class/group of learners, separating the data to examine intra-individual variation was necessary. She was able to use the construct of *expressiveness* as a collective variable to describe learners' writing literacy system.

Finally, as a method to augment investigation of variability in language performance, van Geert and van Dijk (2002) have introduced the moving min-max graph, which displays data points in a bandwidth, much like the growth percentile chart one would see in a pediatrician's office. Through such graphical depiction, it is easy to see at first glance how much variability is present in the system at any given time. If a period of increased variability in the collective variable in question is followed by one of less variability, then it would suggest a system self-organization or phase shift had occurred.

It should be clear, at this point, that collective variables are an incredibly important and valuable conceptual construct in DST research. When applied appropriately, they can point the way to past system change that has taken place or current system change that may be underway. While they are not the be-all-end-all of DST research, the constructs of collective variables that emerge from the interactions of system components can be a powerful tool in the search for the processes of language development.

Conclusion

This paper has focused on the dynamic systems construct of collective variables, which has the potential to be invaluable in linguistic research, particularly in the area of language development and evolution. By not being trapped in a reductionist mentality, we can avoid the seemingly impossible task of attempting to define and model every subsystem aspect of language. This is, of course, still the ultimate goal of linguistic science; however, until our understanding of the brain and has progressed, complexity theory allows us to observe the mind in action and draw conclusions from its performance. Thus, we can look to the collective variables that emerge from language through interactions of system components and dynamics to better understand language as a complex adaptive system.

It is an exciting time in the field of applied linguistics; indeed, dynamic systems theory has spread to many disciplines and is shedding new light and providing new insight into how the world works. It would not seem premature to say that science has entered a new age beyond the tradition of reductionist, controlled experimentation. We, as the world we live in, are highly complex, and language, as our sociocognitive tool for interacting with one another (Larsen-Freeman 2007), reflects that complexity. Only by embracing the naturally occurring complex systems of language and the mind will we truly be able to increase our understanding of the complex processes of language development and change.

Notes

[1] For a demonstration of a double pendulum system (among others), see Lynch's (2001) website at http://mathsci.ucd.ie/¯plynch/SwingingSpring/doublependulum.html

[2] For a more in-depth background into DST and its introduction and spread in the field of applied linguistics, refer to Hensley (2010). For a much more complete discussion of the above ideas, refer to Larsen-Freeman and Cameron's (2008a) definitive book.

References

Ashby, W. R. (1960). *Design for a Brain*. London: Chapman & Hall.

Blythe, R. A. & Croft, W. A. (2009). The speech community in evolutionary language dynamics. *Language Learning 59*, *Suppl. 1*, 47-63.

Byrne, D. (1998). *Complexity Theory and the Social Sciences*. New York, NY: Routledge.

De Bot, K. (2008). Introduction: Second language development as a dynamic process. *The Modern Language Journal*, *92*, *ii*, 166-178.

De Bot, K., Lowie, W., & Verspoor, M. (2005). *Second Language Acquisition: An Advanced Resource Book*. London: Routledge.

De Bot, K., Lowie, W., & Verspoor, M. (2007). A dynamic systems theory approach to second language acquisition. *Bilingualism: Language and Cognition*, *10, 1*, 7-21.

Dörnyei, Z. (2000). Motivation in action: Towards a process-oriented conceptualization of student motvation. *British Journal of Educational Psychology*, *70*, 519-538.

Dörnyei, Z. (2005). *The psychology of the language learner: Individual differences in second language acquisition*. Mahwah, NJ: Lawrence Erlbaum.

Dörnyei, Z. (2009a). Individual differences: Interplay of learner characteristics and learning environment. *Language Learning 59*, *Suppl. 1*, 230-248.

Dörnyei, Z. (2009b). *The psychology of second language acquisition*. Oxford: Oxford University

Press.

Ellis, N. (1998). Emergentism, connectionism and language learning. *Language Learning*, *48*, *4*, 631-664.

Ellis, N. (2006a). Language acquisition as rational contingency learning. *Applied Linguistics*, *27*, *1*, 1-24.

Ellis, N. (2006b). Selective attention and transfer phenomena in L2 acquisition: Contingency, cue competition, salience, interference, overshadowing, blocking, and perceptual learning. *Applied Linguistics*, *27*, *2*, 164-194.

Ellis, N. (2008). The dynamics of language use, language change, and first and second language acquisition. *The Modern Language Journal*, *41*, *3*, 232-249.

Ellis, N. & Larsen-Freeman, D. (2006). Language emergence: Implications for applied linguistics. Introduction to the special issue. *Applied Linguistics*, *27*, *4*, 558-589.

Ellis, N. & Larsen-Freeman, D. (2009). Constructing a second language: Analyses and computational simulations of the emergence of linguistic constructions from usage. *Language Learning 59*, *Suppl. 1*, 90-125.

The Five Graces Group. (2009). Language is a complex adaptive system: Position paper. *Language Learning 59*, *Suppl. 1*, 1-26.

Goldschneider, J. M. & DeKeyser, R. M. (2001). Explaining the " natural order of L2 morpheme acquisition " in English: A meta-analysis of multiple determinants. *Language Learning*, *51*, *1*, 1-50.

Hensley, J. (2010). A brief introduction and overview of complex systems in applied linguistics. *Journal of the Faculty of Global Communication*, *11*, 83-96.

Herdina, P. & Jessner, U. (2002). *A Dynamic Model of Multilingualism*. Clevedon, UK: Multilingual Matters.

Holland, J. (1995). *Hidden Order: How Adaptation Builds Complexity*. Reading, MA: Perseus Books.

Holland, J. (1998). *Emergence: From Chaos to Order*. New York, NY: Oxford University Press.

Larsen-Freeman, D. (1997). Chaos/complexity science and second language acquisition. *Applied Linguistics*, *18*, *2*, 141-165.

Larsen-Freeman, D. (2002). Language acquisition and language use from a chaos/complexity theory perspective. In C. Kramsch (Ed.) *Language Acquisition and Language Socialization*. London: Continuum.

Larsen-Freeman, D. (2006). The emergence of complexity, fluency, and accuracy in the oral and written production of five Chinese learners of English. *Applied Linguistics*, *27*, 590-619.

Larsen-Freeman, D. (2007). Reflecting on the cognitive-social debate in second language acquisition. *The Modern Language Journal*, *91*, Focus Issue, 773-87.

Larsen-Freeman, D. & Cameron, L. (2008a). *Complex Systems and Applied Linguistics*. Oxford: Oxford University Press.

Larsen-Freeman, D. & Cameron, L. (2008b). Research methodology on language development from a complex systems perspective. *The Modern Language Journal*, *92*, *ii*, 200-213.

Lynch, P. (2001). Double pendulum. Retrieved from
http://mathsci.ucd.ie/~plynch/SwingingSpring/doublependulum.html

Schnelle, H. (2010). *Language in the Brain*. Cambridge, UK: Cambridge University Press.

Thelen, E. & Smith, L. (1994). *A Dynamic Systems Approach to the Development of Cognition and Action*. Cambridge, MA: MIT Press.

Tomasello, M. (2003). *Constructing a Language*. Cambridge, MA: Harvard University Press.

Van Geert, P. (1991). A dynamic systems model of cognitive and language growth. *Psychological Review*, 98, 3-53.

Van Geert, P. (2003). Dynamic systems approaches and modeling of developmental processes. In J. Valsiner & K. J. Conolly (Eds.) *Handbook of Developmental Psychology*. London: Sage.

Van Geert, P. (2008). The dynamic systems approach in the study of L1 and L2 acquisition: An introduction. *The Modern Language Journal*, *92*, *2*, 179-199.

Van Geert, P. & van Dijk, M. (2002). Focus on variability: New tools to study intra-individual variability in developmental data. *Infant Behavior and Development*, *25*, 340-374.

Van Gelder, T. (1998). The dynamical hypothesis in cognitive science. *Behavioral and Brain Sciences*, *21*, 615-666.

Verspoor, M. H., Lowie, W. M., & van Dijk, M. W. G. (2008). Variability in second language development from a dynamic systems perspective. *The Modern Language Journal*, *92*, *2*, 214-231.

Wiener, N. (1948). *Cybernetics or Control and Communication in the Animal and the Machine*. New York: John Wiley and Sons.