
Complexity Science Analysis of Social Cultural Theory in Second Language Development with Focus on van Compernelle

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Abstract

Using complexity theory, this paper analyzes the ideas put forth by van Compernelle (2015) on applying Vygotsky to second language development, establishing a physical basis for Social Cultural Theory (SCT). SCT posits L2 can mediate L2 learning through using L2 as the means of social interaction, not only communication. An instructor-student pair can enter the Zone of Proximal Development, where through minimal guidance the student can be led to using better L2; from the complexity science perspective, this is a co-adaptation to the edge of chaos, a regime between orderly and chaotic behavior of a complex adaptive system (CAS). Minimal guidance can also lead students to explore what is known as a fitness landscape, the set of fitness values of every state a CAS can exist in. The exploration can draw in various interactional competencies that help in the development of L2 usage. Further, feedback sensitivity, also a chief CAS characteristic, becomes important for the instructor to determine when to give guidance and for the student to pick up instructional clues, not necessarily verbal. This paper goes through van Compernelle (2015) in chapter order, showing how each section has connections with complexity theory concepts.

1 Introduction

Social Cultural Theory (SCT) emerged out of the ideas of Vygotsky (1978) and van Compernelle (2015) applies it to second language development in order to merge the interactionist strand (Hatch, 1978; Long, 1996; Kumai, 2014) and the strong socio-interactionist strand (van Compernelle, 2015, p. 5) in second language

acquisition. The interactionist perspective (of which negotiation of meaning is the best example) focuses on the individual learner; it is a cognitivist orientation “wherein the individual mind/brain is seen as the sole locus of thinking and learning, which are matters of computational information processing” (van Compernelle, 2015, p. 4). The strong socio-interactionist view of second language acquisition has cognitive processes “situated and co-constructed in social interaction” (p. 5) and has context shaping and being shaped by social interaction (p. 5). How Vygotskian SCT merges these two strands is by positing that language mediates learning, starting as a means of social interaction that eventually will be internalized (p. 7). A consequence is that not only is L2 communication developed but also “conceptual thinking, perceiving and representing things and events in the external world” (p. 7). This paper argues that there is a physical basis underlying van Compernelle’s ideas found in complexity science. The lens of complexity science will be used to analyze the theory introduced by van Compernelle (2015) in chapter sequence. First, however, key concepts from complexity theory used in the analysis will be described.

2 Complexity Theory

This section will quickly cover the key concepts in complexity theory used in the analysis of van Compernelle SCT (2015). Complexity theory studies the behavior of complex adaptive systems (CAS), where the trajectory of the systems cannot be determined from examination of their elements but must include the interactions of these elements, out of which new behavior may emerge (a common example is the bee colony which cannot be predicted from the observations of a solitary bee). Another type of emergence is that of self-organized criticality, where the system dynamically tries to maintain a pattern, like a sand pile does with avalanches as more sand is piled on it (Bak & Chen, 1991).

The definition of CAS used in this paper relies heavily on Larsen-Freeman (1997) and Holland (1995). Larsen-Freeman (1997) has 10 features of CAS, that CAS “can be characterized to varying degrees by the following features: they are dynamic, complex, nonlinear, chaotic, unpredictable, sensitive to initial conditions, open, self-organizing, feedback sensitive, and adaptive” (p. 142). Holland (1995, pp. 10–37) lists “seven basics” shared by CAS: Aggregation, how elements

organize themselves; Tagging, which aids in aggregation and selective interactions; Nonlinearity, where outcomes are nonproportional to input; Flows, the flow of information, energy, resources, and so on in the system; Diversity, as exhibited in system elements; Internal Models, how systems can anticipate patterns; and Building Blocks, the component parts of an internal model.

The state of a CAS can be measured along a fitness scale (as in the Darwinian survival of the fittest), and the set of all fitness points corresponding to all the different states a CAS can be in creates an abstract landscape in phase space known as a fitness landscape (Kauffman, 1995, p. 26); peaks represent high fitness and valleys low fitness. Fitness landscapes can be smooth or rugged, random or correlated (dependent on the system's elements), which affects the ease a system can explore, or in complexity parlance, take an adaptive walk (p. 167) across, the fitness landscape in order to achieve higher fitness. Each element of a CAS can strive for a higher fitness in the context of its environs and its neighbors; the co-adaptation will change the shape of the fitness landscape dynamically (p. 208).

In complexity theory there is a transition that CAS can undergo and enter what is known as the edge of chaos. A CAS can have orderly states and chaotic states; the edge of chaos (Kauffman, 1995, p. 26) lies between these. An important characteristic of the edge of chaos is that the highest fitness levels are achieved despite the many competing constraints of a CAS (p. 228). Kauffman proposes a hypothesis that CAS naturally evolve to the edge of chaos: "the reason complex systems exist on, or in the ordered regime near, the edge of chaos is because evolution takes them there" (p. 90).

3 van Compernelle Chapter 2

Chapter 2, entitled "Key concepts and theoretical considerations," addresses the topics of mediation and the zone of proximal development. Van Compernelle states (2015, p. 9), "The key concept within Vygotskian SCT is that culturally constructed tools or artifacts, also known as mediational means, mediate higher psychological functions." Culturally constructed tools such as language can help the emergence of the higher psychological function of better L2 competence. An example given in the text demonstrates how through an instructor's mediation in the form of prompts (a pause with a questioning look and a repetition of

the ungrammatical phrase with a question intonation), an initially mistaken L2 utterance is produced correctly by the student (p. 12). The errors in L2 indicate a lower fitness but the prompts show the student, as a CAS, how to gain higher fitness, a quicker process than a completely random walk on the fitness landscape. The prompts direct the student's attention to the problem area, which narrows the possible paths to be explored on the fitness landscape, or alternatively, makes the desired fitness peak easier to reach through deforming the fitness landscape. Further, when the instructor is prompting the student, that student is in a feedback sensitive context (unless the student deliberately ignores the instructor); this helps the rapid fitness landscape climbing because the student CAS is open to change (and at the edge of chaos). At the same time, the instructor is a CAS, so the instructor's prompts adapt to the changing fitness of the student's output. Taking the instructor-student pair as one CAS, we can say that the mediation process in Vygotskian SCT is a co-adaptive phenomenon in fitness landscape climbing.

Van Compernelle (2015, p. 13) introduces the following quote from Vygotsky (1978) to support the idea that social relations mediated by communicative interaction drives mental development:

Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, *between* people (*interpsychological*) and then *inside* the child (*intrapsychological*). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals. (p. 57; italics in original)

Clearly there are two CAS under consideration, one in which the child is embedded in a social interaction context where every interlocutor in the interaction becomes part of the CAS, and one where the child is alone. Van Compernelle (p. 13) cites Cazden's (1981) concept of performance before competence, where through communicative interaction with "more capable persons" (p. 13) that learners "are able to perform (i.e., use mediational means) in ways that exceed their current independent capabilities" (p. 13). From the larger CAS of interacting interlocutors, a local fitness landscape peak emerges that is not present when the learners are considered independent CAS.

Grammar as an emergent phenomenon falls clearly under the mantle of complexity science. Van Compernelle (2015, p. 16) has grammar emerging out of interaction, citing Hopper (1998) that grammar is a “collection of prefabricated particulars, available for use in appropriate contexts and language games” (p. 164). The building blocks mechanism (Holland, 1995, pp. 34–37), one of Holland’s seven basics, is a way to analyze the “prefabricated particulars.” Building blocks invite reusability and repetition, as Holland states, “We gain experience through repeated use of the building blocks, even though they may never twice appear in exactly the same combination” (p. 34). Van Compernelle (2015, p. 16) then goes on to cite Tomasello (2003) who shows first language acquisition in children involves learning patterns of unanalyzed word chunks or supra-word constructions (such as “I wanna”). Later children do “attempt to analyze the utterances they hear and partition them into constituents both structurally and functionally” (Tomasello, 2003, p. 41). Let us compare this to another of the seven basics of Holland’s, the property of aggregation (Holland, 1995, pp. 10–12). Aggregation can hide details, making chunks. As Holland writes, “We decide which details are irrelevant for the questions of interest and proceed to ignore them” (p. 11). The following sentence in Holland clearly states that these chunks become building blocks: “This has the effect of collecting into a category things that differ only in the abandoned details; the category becomes a building block for the model” (p. 11). Indeed, this is what van Compernelle is proposing, where the model under consideration is communication: “From the perspective of [sociocultural theory], it is in our interactions with others that these supra-word constructions become available as mediational means in and for the accomplishment of interactions” (2015, p. 16).

Internalization (van Compernelle, 2015, p. 17) is a key concept in Vygotsky’s theory, where the mediational means are appropriated and incorporated internally. In particular, let us examine the following statement: “With regard to L2 learning, internalization involves much more than the mastery of linguistic structures. It is about ‘gaining the freedom to create’ (Dunn & Lantolf, 1998, p. 427), or the capacity to manipulate L2 semiotic artifacts to accomplish one’s communicative intentions” (p. 17). Compare this to Holland (1995), that “the use of building blocks to generate internal models is a pervasive feature of complex adaptive systems” (p. 37). Once an internal model is created, the CAS can react to new

situations (the freedom to create). Holland states that internal models can determine the behavior of a CAS or agent, and “if the resulting actions anticipate useful future consequences, the agent has an effective internal model” (p. 34). In other words, the building blocks of supra-word constructions can help a learner achieve communication.

Vygotsky’s zone of proximal development (ZPD) is “one of the most widely cited of Vygotsky’s proposals” (van Compernelle, 2015, p. 19). For the definition of ZPD¹ van Compernelle (2015) writes, “Vygotsky (1978) spoke of the difference between what a person is able to do alone (i.e., intrapersonal functioning, which reveals completed development) and what becomes possible with external mediation (i.e., interpersonal functioning, which may reveal the ZPD)” (pp. 18–19). ZPD defines two distinct CAS, the individual learner and the learner in communication with others. The individual learner is at a particular fitness level which is stable as a result of his or her development (though imperfect) being completed. In the situation of external mediation, the multi-person CAS is in the process of landscape exploration and peak climbing, a dynamic situation. Indeed, the ZPD is an example of the edge of chaos (Kauffman, 1995, pp. 86–92). The completed development represents order in the system, whereas the landscape exploration during mediation represents the chaos. It is in the ZPD that the learner can achieve a higher development level, and it is at the edge of chaos that systems are best able to adapt to find higher fitness. Indeed, it may not be the highest fitness; L2 learners do not become fluent speakers overnight. But in the ZPD as in the edge of chaos the learner can reach the best compromise, but one that accomplishes the L2 communicative goal. Kauffman writes, “the transition between order and chaos appears to be the regime that optimizes average fitness for the whole ecosystem” (p. 230).

As for the pedagogical implications of the preceding key concepts, van Compernelle (2015) writes about the importance of providing graduated and contingent support during interaction:

The concept of graduated and contingent support compels us to withhold directive and corrective feedback at the outset and instead to engage with learners to position them to contribute maximally to the task at hand by providing the least explicit form of support that the learner is able to benefit

from. In other words, from the SCT perspective, providing support for the learner is not simply about correcting an error; rather, it entails being sensitive to a learner[’s] current needs, providing just enough assistance for the learner to succeed without over-assisting the performance. (p. 31)

This statement shows how the instructor, through mediation, can alter the fitness landscape so that the learner can find a higher fitness peak (for example, by correcting an error the learner’s fitness is raised). More important is providing the “least explicit form of support” and “just enough assistance” (p. 31) to help (or force²) the learner to take an adaptive walk (Kauffman, 1995, p. 166) across the fitness landscape. If the explicit form is given, certainly the higher fitness peak is achieved but certain developmental processes active during the adaptive walk are skipped. For Vygotsky (1978), this type of learning “awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers” (p. 90). Van Compernelle (2015) explains development, which in our case is second language acquisition, in the following way: “Development, for Vygotsky, entailed the emergence of a qualitatively new form, or a re-organization, of mental activity” (p. 20). In comparison, note that new forms are created best by CAS at the edge of chaos, as we see from Miller & Page (2007), “Systems that are too simple are static and those that are too active are chaotic, and thus it is only on the edge between these two behaviors where a system can undertake productive activity” (p. 129).

4 van Compernelle Chapter 3

Chapter 3, entitled “Communicative interaction as a source and driver of development,” takes a closer look at mediation’s role in development, that indeed it is the primary player. Van Compernelle (2015) notes that “The L2 is not a ready-made linguistic system to be acquired as is, but rather a set of open and malleable set of resources that may increasingly be used to regulate a learner’s communicative and mental activity” (p. 36). This is in line with Holland’s (1995) internal models: CAS use them for anticipation and prediction (p. 31). Indeed, the two key requirements of an internal model are not only that the structure of the model infers something about what is being modeled (the L2 resources), but also

“actively determine” the CAS’s behavior (pp. 33–34).

Van Compernelle (2015) makes the following statement about interlanguage: “L2 development may entail divergences from (idealized) native speaker norms as learners appropriate and manipulate L2 forms and meanings to meet their communicative and/or intrapersonal (psychological) needs” (p. 36). From the complexity theory viewpoint, the learner’s L2 has reached a particular fitness peak that satisfies (that is, meeting the L2 communicative needs), though imperfectly (from the viewpoint of native speaker level being the highest fitness), the constraints and challenges of negotiating in an L2 environment.

The rest of this chapter looks at how SCT explains L2 acquisition in terms of control over tools, imitation, noticing, and metalinguistic knowledge. Van Compernelle (2015) writes,

From a Vygotskian perspective, L2 abilities are forged in social interaction where mediational means are made available to learners who are supported in further developing control over the patterns of use of, and the meaning potentials afforded by, the language they are learning. Vygotsky’s (1978) historical, or genetic, method compels us to trace the origins of L2 abilities—that is, how control over language use moves from the *interpersonal* to the *intrapersonal* domain. (p. 43; italics in original)

The word control appears twice here, which suggests an additional dimension to the multi-dimensional fitness landscape, that of control over language use. The control metaphor accords well with another metaphor, that of tools. One way the ZPD differs from scaffolding is its emphasis on “human mediation centered on the appropriation of psychological tools” (p. 41), as opposed to completing a task. Another aspect of acquisition is casting conscious knowledge of language as a tool: “Forging the link between a learner’s conscious knowledge of language is essentially about making such conscious knowledge available as a psychological tool that mediates L2 use” (p. 44). The internal model (Holland, 1995, pp. 31–34) constructed would therefore have a tool-based orientation. Imitation is similar to the earlier performance before competence; here, unlike emulation or mimicry, “there is an understanding of the goal(s) of one’s activity as well as the relevance of the mediational means available” (van Compernelle, 2015, pp. 46–

47). The imitation allows a higher fitness while the accompanying understanding indicates pathways to be taken on the fitness landscape toward a higher competence peak. In addition, learners may start to manipulate the imitated L2, a step towards appropriating it as their own (that is, acquisition) (p. 47); from the CAS perspective, this is adding the imitated L2 to the internal model. Another important phenomenon arising from interaction is the opportunity for the learners to notice the gap (Schmidt & Frota, 1986, pp. 310–315) in their linguistic knowledge. Van Compernelle (2015) writes, “communicative pressures (e.g., negotiation for meaning, corrective feedback) push learners to attend consciously to their language use and, potentially, to notice gaps in their competence and/or novel L2 forms, which in turn may lead to acquisition” (p. 51). This is an example of feedback sensitivity (Larsen-Freeman, 1997, p 145; Gell-Mann, 1994, p. 25) that is characteristic of CAS. Finally, interlocutors can share and discuss metalinguistic knowledge about L2 (van Compernelle, 2015, pp. 54–55) which in essence is negotiating the most likely directions to take on the fitness landscape to reach higher ground.

5 van Compernelle Chapters 4, 5, 6, and 8

Let us now turn to Chapter 4, “L2 interaction and negotiation for meaning,” Chapter 5, “The role of L1 interaction in L2 development,” Chapter 6, “Participation and active reception,” and Chapter 8, “The mediational nature of interactional competence” which can be treated by shorter analysis³. For van Compernelle, there are three central themes in negotiation for meaning (2015, p. 84): co-regulation, mediation sequences, and incidental microgenesis. Co-regulation is basically a type of co-evolution described in Kauffman (1995, pp. 215–221), where changes in one CAS will initiate changes in another CAS, resulting in a “coevolutionary dance” (p. 215). Van Compernelle (2015) writes,

Co-regulation implies that the negotiation for meaning involves an ongoing process of maintaining intersubjectivity through participants’ attunement to, and adjustment of, their talk-in-interaction. This is to say that each utterance. Including its content, form, timing, delivery, and so on, shapes what follows it, because each utterance variably affords and constrains possible next

utterances. (p. 84)

This maintenance of intersubjectivity, defined as “mutual understanding of co-participants’ intentions (p. 65), can be seen as a variation of the Red Queen Effect, where “all species keep changing and changing their genotypes indefinitely in a never-ending race merely to sustain their fitness level” (Kauffman, 1995, p. 216). Here we understand fitness level to be the interlocutors’ mutual understanding. Mediation sequences are pedagogical supports inserted during task-work in order to overcome a problem (van Compernelle, 2015, p. 72). This is a process of targeted mutual fitness peak searching and climbing. Feedback sensitivity is enhanced as a resolution to a clearly defined problem is sought, either by instructor or learner. Incidental microgenesis is distinguished from simple incidental learning because it “entails a qualitative transformation of a mental function that is, the process of internalization is evident” (p. 79). This is basically finding unexpected areas of the fitness landscape using the freedom to create (and explore) mentioned earlier. This occurs when the interactional environment “afford[s] learners opportunities to comprehend, use, and creatively modify the word, meaning, or construction in their own discourse (e.g., repurposing or recycling)” (pp. 85–86).

Van Compernelle (2015) makes two statements regarding L1 usage (Chapter 5) that demonstrate its utility in efficiently directing learners toward fitness peaks: “somewhat paradoxically, optimizing L2 use may in fact involve L1 use precisely because the L1 can support learners in their L2 abilities or because it can be used to learn about the L2 and how it works, knowledge that can later be deployed during L2 communication” (p. 106); teachers should consider “whether or not (or to what extent) L1 use is serving a *metacommunicative* function during a given task or task component” (p. 107; italics in original). Reformulating these ideas in terms of complexity science, L1 use can encourage long jumps (Kauffman, 1995, p. 193) across a fitness landscape, a faster process involving changing many characteristics at once in larger increments. One finding of long jumps is that there is an exponential slowing (p. 193) in making further long jumps that result in higher fitness, implying that reliance on L1 should be limited.

Feedback sensitivity (that is, “active reception”) is the main focus of Chapter 6. Active reception means “a person’s active engagement in observing and attending to the talk-in-interaction, artifacts, and activities of others that are present in

their environment” (van Compernelle, 2015, p. 113), in particular eye gaze, body posture, and gestures (p. 131). Small details can create large-scale effects in CAS, known as the butterfly effect (Kauffman, 1995, p. 17; Lorenz, 1972), hence the need to observe the minutiae involved in interaction, taking the entire communicative activity as a CAS. Footing (van Compernelle, 2015, p. 114) is the major concept introduced in Chapter 6 involving the dynamic shift of participant roles in a communicative interaction, such as switching between participants in a role play to that of instructor and student (pp. 118–119). Switching is usually triggered when a learner enters a fitness valley; van Compernelle provides an example where a student learning French “struggle[s] to use the concepts of self-presentation, social distance, and power as tools for thinking through, and for solving, the problem at hand” (p. 115). The sudden shifts are known as bifurcations or phase transitions (Larsen-Freeman & Cameron, 2008, p. 45, p. 128) and can be represented in fitness landscapes as follows, but note that here the authors are describing a state space, an upside-down fitness landscape: “The landscape includes areas where the system hovers on the edge of various, very different possibilities. Ridges between very different valleys reflect sudden changes in the state of the system” (p. 46). Another perspective by van Geert (2003) on bifurcations brings relevance to footing: “Bifurcations occur whenever the system can be in two qualitatively different states or stages at the same time” (p. 658). In the case of a CAS consisting of student and instructor engaging in a role play, the roles undertaken as well as their identities as student and instructor exist simultaneously, matching the condition in van Geert.

To have a successful interaction, interactional competencies are needed both on the learner’s side and instructor’s (van Compernelle, 2015, p. 184) (Chapter 8). Competencies include topic management, action sequencing (speech acts and formulas), participant frameworks (roles), turn-taking, and register (p. 173). From the complexity science perspective, these are ways in which the CAS can evolve to the edge of chaos. Interactional competencies “become available in interaction” (p. 175), as a result of either the context of the interaction or as a result of recall of previous interactions. As resources/competencies (p. 175) are drawn into the interaction, the interaction system exhibits a type of self-organized criticality. The system is dynamically reacting in order to sustain the interaction. Finally, in addition to interactional competencies, van Compernelle discusses classroom

interactional competencies, divided into teacher and student interactional competencies (such as how to assist learners, the use of body language, learners' soliciting of the instructor's attention). These will help in achieving the edge of chaos regime efficiently (resulting in fewer fruitless explorations of the fitness landscape).

6 Conclusion

Vygotsky's SCT can be shown to have deep connections to complexity theory. The minimalist approach to instruction forces students to take adaptive walks across the fitness landscape. This engages higher psychological functions (van Compernelle, 2015, p. 1) that make various competencies available in the interaction. The zone of proximal development is related to the edge of chaos and the co-adapting system of student-instructor self-organizes such that it naturally evolves to edge of chaos, the characteristic behavior of CAS. With this understanding, we might tune Vygotskian interactions to include, for example, long jumps on the fitness landscape (simultaneously changing many parts of an L2 utterance), the Red Queen effect (rapid and continuous evolution of interaction between instructor and student), the butterfly effect (varying the initial conditions), tool-oriented internal models, and correlated fitness landscapes (Kauffman, 1995, p. 169) (control of the ruggedness of a fitness landscape and thus its ease of exploration).

Notes

- 1 Vygotsky's own definition: the ZPD is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (1978, p. 86).
- 2 This is a key difference between the ZPD and the $i+1$ concept of Krashen's: the ZPD requires minimalist guidance so the learner explores the fitness landscape whereas Krashen's theory relies on the language acquisition device to pick up $i+1$ subconsciously from comprehensible input (Dunn & Lantolf, 1998, p. 423). Yet both can be seen as edge of chaos phenomena: the orderly regime is represented by one's current competence or i , whereas the chaotic regime is represented by the dynamic flow of information (Holland,

1995, pp. 23–27; Gell-Mann, 1994, pp. 24–25), especially that which is unknown to the learner, during interaction.

- 3 Chapter 7, “Diagnosis-through-intervention: Dynamic assessment” will not be analyzed here as it is not directly related to second language development/acquisition.

References

- Bak, P., & Chen, K. (1991). Self-organized criticality. *Scientific American* 264(1), 46–53.
- Cazden, C. (1981). Performance before competence: Assistance to child discourse in the zone of proximal development. *Quarterly Newsletter of the Laboratory of Comparative Human Cognition*, 3(1), 5–8.
- Dunn, W., & Lantolf, J. P. (1998). Vygotsky’s zone of proximal development and Krashen’s *i+1*: Incommensurable constructs; incommensurable theories. *Language Learning*, 48, 411–442.
- Gell-Mann, M. (1994). *The quark and the jaguar: Adventures of the simple and complex*. New York: W. H. Freeman and Co.
- Hatch, E. (1978). Discourse analysis and second language acquisition. In E. Hatch (Ed.), *Second language acquisition: A book of readings* (pp. 401–435). Rowley, MA: Newbury House.
- Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Reading, MA: Addison-Wesley.
- Hopper, P. J. (1988). Emergent grammar. In M. Tomasello (Ed.), *The new psychology of language: Cognitive and functional approaches to language structure* (pp. 155–176). Mahwah, NJ: Lawrence Erlbaum Associates.
- Kauffman, S. (1995). *At home in the universe: The search for the laws of self-organization and complexity*. Oxford: Oxford University Press.
- Kumai, W. N. (2014). A complex adaptive systems perspective of Long’s Interaction Hypothesis. *Academia: Literature and Language*, 95, 171–178.
- Larsen-Freeman, D. (1997). Chaos/complexity science and second language acquisition. *Applied Linguistics*, 18(2), 141–165.
- Larsen-Freeman, D., & Cameron, L. (2008). *Complex systems and applied linguistics*. Oxford: Oxford University Press.
- Long, M. H. (1996). The role of the linguistic environment in second language acquisition. In W. C. Ritchie, & T. K. Bhatia (Eds.), *Handbook of second language acquisition* (pp. 413–468). San Diego, CA: Academic Press.
- Lorenz, E. N. (1972). *Predictability; Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?* Paper presented at 139th Annual Meeting of the American Association for the Advancement of Science, Washington, DC.
- Miller, J. H., & Page, S. E. (2007). *Complex adaptive systems: An introduction to computational models of social life*. Princeton, NJ: Princeton University Press.

- Schmidt, R. W., & Frota, S. N. (1986). Developing basic conversational ability in a second language: A case study of an adult learner of Portuguese. In R. R. Day (Ed.), *Talking to learn: Conversation in second language acquisition* (pp. 237–326). Rowley, MA: Newbury House.
- Tomasello, M. (2003). *Constructing a language: A usage-based theory of language acquisition*. Cambridge, MA: Harvard University Press.
- van Compernelle, R. A. (2015). *Interaction and second language development: A Vygotskian perspective*. Amsterdam: John Benjamins Publishing Company.
- van Geert, P. (2003). Dynamic systems approaches and modeling of developmental processes. In J. Valsiner, & K. Connolly, *Handbook of developmental psychology* (pp. 640–672). London: Sage.
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.