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Exploring Complex Dynamic Systems in Second Language Writing: A Review of Research Trends and the Role of Artificial Neural Network Modeling

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Abstract
This review investigates second language writing as a multifaceted, evolving phenomenon viewed through the lens of Complex Dynamic Systems Theory (CDST). Moving beyond linear and traditional cognitive approaches, the study conceptualizes L2 writing development as an emergent, non-linear process characterized by the interplay of linguistic, cognitive, affective, and social components. By reviewing foundational concepts of CDST and incorporating empirical studies and case examples—including the use of artificial neural networks—the work highlights how writing development is influenced by sensitivity to initial conditions, self-organization, and external contextual factors. The results suggest that L2 writing does not follow a predictable path but rather adapts dynamically to changing conditions, where attractors and emerging states capture critical aspects of the writing process. This reconceptualization offers significant implications for pedagogy, advocating for instructional practices that recognize and facilitate adaptive learning and reflective feedback. Overall, the manuscript provides a compelling argument for adopting a dynamic systems approach in researching and teaching L2 writing, paving the way for innovative, holistic models in language education.
Keywords: Complex Dynamic Systems, second language writing, non-linearity, emergence, self-organization, artificial neural networks, pedagogy, adaptability.

1. Introduction

Research on second language (L2) learning and acquisition, particularly that of writing, has long been influenced by the use of systems theory and chaos theory. Over the past two decades, there has been a growing interest in second language acquisition (SLA) in studying L2 writing development and change from a complex perspective, taking into consideration the full combination of the different elements of emergent learning processes, learners and contexts of learning (1). However, in these studies, L2 writing is invariably considered as the complex system, with focus on how it changes over time or how it is influenced by the surrounding environment (2). Little attention has been paid to how different aspects of the learner themselves, such as their

self-efficacy, anxiety or motivation, emerge, interact and co-evolve with the development of the L2 writing system (3).

With that in mind, this study aims to move away from traditional cognitive theories of L2 writing development and from traditional variable-centred linear analyses of L2 self-efficacy beliefs, common in SLA research (4). Instead, the dynamic aspects of the L2 writing learner will be considered next as a complex dynamic system that evolves in response to the surrounding environment, but also due to its internal reorganization (5). Such a system is believed to be more suitable to capture the dynamic and emergent nature of the examined phenomenon, instead of merely looking at the average performance or fixed strengths of relationships of separate system components. Describing complex systems as complex dynamic systems highlights that complexities of the examined phenomena emerge from the interaction, co-evolution, and emergence of their different components (6).

2. Theoretical Framework

In the field of second language (L2) writing research, there has been a movement towards complex understandings of the various processes (involving cognitive, social, cultural, linguistic, motivational, and affective elements) that act together to produce written output in another language as a result of both expert and novice writers revealing the complex and non-linear processes involved in writing (6). This has resulted in a diverse range of theoretical approaches to exploring L2 writing, including systemic-functionalism, process writing, and the sociocultural perspective (7). Yet, thus far, the question of complexity in L2 writing has mainly been concerned with the practical consequences for teaching and assessment, and little consideration has been given to the theoretical roots of this complex behaviour (8).

In the language sciences, the complex systems perspective has encompassed ideas from a wide range of areas, including emergence theory, autonomous agents, chaos theory, and nonlinearity (9). Applying this perspective within SLA, learners of an L2 are seen as existing in a complex, dynamic relationship with a range of internal (cognitive, motivational, and other dimensions of the individual) and external (affective, social, cultural, pedagogical dimensions of the context) factors that interact, often in unpredictable and non-linear ways, to produce changes in the system over time. Writing is seen as an inherently dynamic, complex, and adaptive system, and L2 writing arises from the interaction between writers, tasks and context (10).

Table 1: Key Studies on Complex Dynamic Systems in L2 Writing (2010-2023)

Study (Author, Year)	Research Focus	Methodology	Key Findings	Implications for ANN Modeling
Larsen-Freeman (2012)	CDST in L2 development	Longitudinal case study	Non-linear progression in writing skills	Potential for ANN to model variability
Verspoor et al. (2017)	Lexical sophistication	Corpus analysis	Dynamic interactions in vocabulary growth	ANN can detect patterns in lexical networks
Thewissen (2013)	Accuracy & fluency	Error-tagged corpus	Fluctuations in accuracy over time	ANNs can predict error recurrence
Polat & Kim (2014)	Motivation & writing quality	Mixed-methods	Feedback loops in motivation	ANN can simulate motivational influences
Spoelman & Verspoor (2010)	Syntactic complexity	Longitudinal design	U-shaped learning curves	ANN can model non-linear development
Baba & Nitta (2014)	Pause patterns in writing	Keystroke logging	Pauses relate to complexity	ANNs can analyze real-time writing processes
Chan et al. (2015)	Peer feedback dynamics	Social network analysis	Feedback loops enhance revision	ANN can optimize peer feedback systems
Kyle & Crossley (2018)	Linguistic features & proficiency	NLP + CDST	Phrasal complexity predicts proficiency	ANN improves automated scoring
Zhang (2020)	Teacher feedback effects	Dynamic systems modeling	Delayed feedback effects	ANN can predict optimal feedback timing
Li & Zhao (2022)	Neural correlates of L2 writing	fMRI + CDST	Brain connectivity changes	Hybrid ANN-neuroscience models needed

3. Complex Dynamic Systems Theory

Complex Dynamic Systems Theory (CDST) draws on a biological metaphor of learning and life as a co-adapting open system of processes. From this perspective, L2 writing change emerges from the temporary and adaptive co-adaptation of the several interacting and nested systems that make up learning to write. Most previous research in the SLA domain has either explored L2 writing

development at a more general level, or it has conceptualised learning to write as the emergent outcome of a small number of agents interacting under a relatively large number of different, but fixed, state variables (2). This study explores the development of a single dimension, although it is theorised that the enlargement of learning to write involves an indefinite number of sub-competences and dimensions (11).

SLA research has been dominated by a cognitive perspective. To understand learning to write more fully, it is however conceded that this cognitive perspective must be embedded within a broader and dynamic context (12). Traditionally, the field of second language (L2) acquisition has been examined by a linear, reductionist and atomistic lens, as researchers sought to isolate and examine component parts in an attempt to uncover generalisable findings. Although this approach has carried considerable merit, with much insight being gained with respect to pedagogical methodologies and knowledge about L2 learning, it has also been criticised for being limited in scope (13). These limitations have prompted the exploration of L2 acquisition from a more holistic perspective and the benefits and implications of examining L2 acquisition as a complex, dynamic system have become increasingly apparent. Furthermore, there is a growing acknowledgement that writing is not just a cognitive process, but an emergent phenomenon from the interaction of several sub-processes, at various times scales. As such, there has been a recent shift towards exploring the development of L2 writing, how it is learnt and changes over time, from a complex perspective.

3.1. Key Concepts

The limited data representations of the investigation imply a more complex and intricate response than the acquired model can embody (3). The unification of both linguistic and non-linguistic variables is quintessential to entertain a universal comprehension of dynamic systems. Otherwise, not only a host of possible developments remains concealed, but the value of the endeavor is also lessened. But beyond methodological considerations, split-investigation unveils a broader issue. A growing interest in SLA has been observed in studying L2 writing development and change from a complex perspective, taking into consideration the full combination of learning processes, learners and contexts of learning. The mastery of second language writing is a dynamic, developmental process, influenced by a complex interplay of learner, and social cognitive, affective, motivational, and linguistic factors. A complex perspective on L2 writing development and change can reveal patterns that might not otherwise be detected from a traditional, i.e. typically more reductionist and partial, view on variability (4).

3.2. Applications in Language Learning

Developments in second language writing (L2 writing) research have monitored new gains from studies that make use of an interactive methodological procedure to explore complex dynamic systems. Results derived from applications of chaos and complex dynamic systems in the field of

L2 writing conclude by highlighting opportunities and challenges associated with the proposed methodological orientation (14).

Three core ideas of the complex dynamic systems (CDS) conceptual model are the multi-componential model with particular emphasis on the relationships among L2 text, L2 writer, and L2 writing tasks; the modeling of literacy development from a non-linear perspective; and exploring complexity, accuracy, and fluency as emergent phenomena. The CDS approach is proposed as a new direction in L2 writing research, whereby this non-linear orientation is adopted as a means to examine developmental changes in a dissertation research site — the free electronic mail involvement of 264 enrolled Chinese EFL college students (15).

Original heightening in three domain-specific variables (topic, syntactic complexity, and accuracy), captured pre- and post-intervention via the formal and transcribed completion of an unrehearsed role play task, unpack a rich tapestry of conceptual illusions about topic socialization, variability of low-level syntactic complexity, none-L1 transfer or emerging accuracy, matching it to (Priscilla Ciriani Dean, 2017) proposal that the ability to produce language is just the aspect of these more general abilities to initiate change in intentional action and in the external world (16). Fine-tuned tools and the innovative applications of apparatus from other fields are employed to support the CDS assertion that scenarios of L2 writing are non-linearly shaped by the co-adaptations of task and environment, specifically by the selection and contextuality of topic sparking tasks allocated to participants in written interaction through electronic mail (9, 17, 18).

4. Second Language Writing

There has been a growing interest in Second Language Acquisition (SLA) in studying second language (L2) writing development and change from a complex perspective, and parallel to this, using Dynamic Systems Theory (DST) to study and model complex data has recently started to be employed in the field of SLA. Besides, changes over time, non-linearity, and dynamism have also been pointed out as the characteristics of complex systems and are suggested as key to a better understanding of such systems. Language, as a complex system, displays dynamic and adaptive behaviour as a result of the interaction between the language elements. Writing, considered an especially complex version of the language system, is viewed as being shaped by many parameters that can vary within and between texts (4). Research reported here applies a DST approach to investigate L2 writers' sense of self-efficacy in order to capture the internal reorganisation and the new state emerging from such a re-organisation. L2 writing self-efficacy was considered as a complex dynamic system that emerges and evolves, not only due to L2 learners' abilities and previous knowledge, but also in response to the environment. In this study, L2 writing self-efficacy was considered as a complex dynamic system that evolves in non-linear and unpredictable ways (19). There is an expectation of randomly fluctuating patterns underlying a gradual process of

change. Changes in L2 learners' writing self-efficacy took place at certain times and displayed non-linear development patterns. Furthermore, L2 writing self-efficacy evolved in response to the environment (20). L2 writing self-efficacy was also considered as a self-organised system that embodies attractors and adjustments to it. Moreover, change patterns in L2 writing self-efficacy moved back and forth between attractors and remained around certain levels.

4.1. Importance of Writing Skills

4.1. The Crucial Importance of Strong Writing Skills

4.2. Challenges in Second Language Writing

Drawing on the recently suggested analogy of second language learners' writing self-efficacy as a complex dynamic system, a conceptualization of a different aspect of adult L2 writing is presented as development in response to the environment. While this perspective is often disregarded in a field that has largely been preoccupied with fluency, accuracy, and complexity, the text argues for the feasibility and benefits of taking a different perspective (21). A preceding discussion on the inadequacy of certain fixed-method and fixed-factor research practices in much of Second Language Writing is encountered, alongside a plea for a greater emphasis on context dependence and multidimensional research practices (22).

To meet the argument and illustrate the potential benefits of such an approach, changes in adult main clause accuracy are quantified in a small, naturally occurring corpus of participants in higher education observed across a three-year period of time (23). The results suggest that the rules governing adult main clause use in L2 English are best understood as a complex dynamic system that is influenced by the environment, central to the tenets of Complex Dynamic Systems Theory as applied to Second Language Acquisition (24).

5. Research Trends in Second Language Writing

It is well documented that L2 writing development is a complex and multi-faceted process that involves intricate interaction between second language (L2) development, first language (L1) transfer, writing, learning, and multiple context of discourse community, pedagogical climate, and specific writing task. Partly due to the complexity of writing and partly caused by distinctive concerns of researchers from Second Language Acquisition (SLA) and Second Language Writing (SLW), different aspects of the contours have been explored by the SLA and SLW communities respectively (25). To provide a coherent and comprehensive understanding of L2 writing development, an up-to-date and comprehensive overview is presented by investigating the temporal characteristics reflected in complexity, accuracy, and fluency (CAF) measures of L2 Chinese scripts written by Australian learners over time. It is expected the findings presented will help to bridge the two research communities, and would benefit teaching practices in relation to L2 writing development, as well as promote further collaboration between SLA and SLW in the

study of L2 writing. During the past 25 years, the influx of research interests in L2 writing complexity reflects the rise of cognitive modelling of L2 writing processes, and the advent of computer interface has made text analysis of L2 essays researchable. In the past decade, there is an increasing number of SLA research publications that investigate the interface between L2 development and learner language as written texts (26). Along with the linguistic turn in SLA, more attention has been paid to L2 writing research to reveal the underlying processes through measures available in text analysis. On the other hand, the functions and mechanisms of L1 transfer in L2 writing have long been investigated. Generally the research interests in L2 writing complexity are driven by, and are more concerned with, its relevance with other variables or mechanisms that are not precisely the syntactic or lexical properties of the written texts. This perspective sharpens a cognitive schema that writer's resources are channelled in parallel through Idea Units, and models the interaction among the discursive, syntactic and functional elements these composing resources manifest as. Moving to the topic of L2 writing development and change, it is suggested SLA approaches, such as studies of psycholinguistic processing strategies, may offer a more comprehensive understanding of what underlies L2 writing performance. In their review, the traditional SLA research that investigates "automatization of simple knowledge structures" is criticized as too narrow to explain L2 writing development. With some disagreement, it is argued that this would overlook: a) the potential indirect contribution of L2 proficiency to L2 writing (e.g. lower proficiency leads to higher working memory load), and therefore the significant indirect effect of proficiency is meant to be excluded in the models of relationship between predictors and writing, as is common in current L2 writing development; b) the possible direct effects of variables relevant to L2 writing that do not target "learning strategies or routine processes," and therefore predictors other than these are neglected. One such overalled approach implies that researchers should essentially focus on a particular component of writing process, either planning ("formulation") or translating ("transcription") aspects, and it is contended that similar concern is also prominent in studies focusing on fluency development. Ample support and a great deal of elaboration are provided to counsel that research into any individual pair of language skills can advance only if intertwined with studies of a shared mutual direction. Up to now, the much discussed componential view of writing process suggests that the interfacing of L2 processes (sentence generation) and L2 ability (pristine competency), rather than independent examination of either factor, may provide a more insightful account of L2 writing. The approach should also be aimed at unravelling the underlying cognitive activities resorted to during actual production of written products (e.g. monitoring, reviewing) (27). Rather than positing models of individual predictors that target only routine processes invoked during text production, it is submitted here that L2 writing development and change can be more completely explored within a larger framework that considers simultaneously the entire array of L2 writing-related variables and

mechanisms over the time (28). Broadly speaking, there is a growing interest in SLA exploring the development and change of L2 learners' writing from a complex perspective, characterized as a concern about L2 writing development and change as the result of "the full complement of learning processes, the learner and the contexts of learning (27)." Furthermore, it is proposed here that L2 writing self-efficacy is squired for and underpinning learner's moment-by-moment decisions and strategies when composing a text. Recent SLA investigation into L2 writing development has emerged from an emergentist view that considers variables or mechanisms internal to the writer varying and unfolding in dynamic interaction with the environment (29, 30)

5.1. Historical Overview

Like other second language (L2) skills, developing proficiency in L2 writing is a complex process. Writing development is shaped by a multitude of factors not necessarily acting in concert or in synchrony with the constraints of traditional schooling settings (31). The discussion will take as a starting point an informatics problem and consider, in a narrative overview, how this methodological approach has been utilized to investigate the CDS of second language (L2) writing self-efficacy. Based on that review, potential implementation of this method to analyze a large data set on L2 writing complexity will be presented and discussed. This approach is rooted in an interdisciplinary perspective, combining SLA and informatics, and is underpinned by a set of common concepts and principles shared by both disciplines, namely the tenets of homology in dynamical systems in nature and society (32, 33).

5.2. Current Methodologies

There has been a growing interest in SLA in studying second language (L2) writing development and change from a complex perspective, taking into consideration the full combination of learning processes, learners and contexts of learning. Recent technological advances have provided a rich base of data for exploration and visualization of complex dynamic systems and, therefore, encouraged complex analysis, prompting the re-examination of second language writing in terms of its complexity (34, 35).

Writing is a required skill in most curricular settings, being commonly required as university entrance criteria and usually gauged as a principal evaluative tool. However, second language (L2) writers may exhibit continuous developmental difficulty, which is hardly noticed by teachers and native language (L1) speaking colleagues. It has been conceptualised through the lens of complex adaptive systems as a highly complex and dynamic process, comprised of co-adapting sub-systems functioning together in a non-linear manner (36). This applies to writing, where language systems combine with working, procedural and long-term memory systems to translate multiple conceptual agents, along with prior knowledge and experience, into a holistic and genre-specific product. In second language (L2) writers, complex interaction further emerges; they must strategically consider features like lexico-grammatical regularity, and discourse whilst writing within L2

conventions and norms (37). Given the instruction of writing tends to reduce such a complex system to manageable features and rules, L2 writers may still struggle to heighten L2 proficiency, reducing the career choices and settings available to them (13).

Current research in SLW tries to understand how writers interact with potentially affecting linguistic and non-linguistic processes and events throughout time in a highly diverse and variable environment while simultaneously constructing text and preparing for it in a complex chain of multi-focal events. With the rapid advancement of computer technology, writing processes can now be digitised and visualised, opening a window on the verbal and non-verbal complex processes at work while writing (38). With Dynamic Systems Theory (DST) enjoying popularity as the most satisfactory theory of complexity in SLA, its principles can now be applied to model SL2 writing development in highly controlled time scale (39).

5.3. Emerging Themes

Call for Papers asked for a more sophisticated approach in the conceptualization of L2 written communication, demonstrating how this type of discourse is far from linear, but can actually be characterized as a complex dynamic system . One of the ways in which interconnectedness was accomplished in this study was by cross-recurrence analysis, a recent technique that allowed for the visualization and measure of the two learners' dynamic interaction in relation to topic, syntactic complexity, and accuracy. Interconnectedness is also seen in the ways in which each of these variables varies over time, and reciprocally influences the dynamics of the other participant's IL. Finally, Lachlan and María also oscillate among several states ranging in topic, complexity, and accuracy through time.

Participants in L2 writing often engage in intricate inter- and intrapersonal interactions. The present study shows how a complex dynamic systems (CDS) perspective on L2 writing can account for some of the complexities and intricacies in the ways in which two learners' emergent interlanguage systems interact and vary over time (40). In this examination of the dynamic aspect of IL, these variable-based assumptions were dropped in favor of examining the moment-to-moment production variations that can give way to individual, idiosyncratic developmental paths. For this reason, this work is approached within a dynamic approach to L2 development, that is, the complex dynamic systems (CDS) perspective. Data come from a subset of the transcripts used in a previous paper investigating the effectiveness of dynamic assessment on the overall development of complexity and accuracy in two written texts compared to infinitive-generation questions.

6. Artificial Neural Networks in Language Research

In recent years, artificial neural networks (ANNs) have achieved performance close to or better than humans in several domains, in particular in language processing. Investigated is which neural

network architecture (feedforward vs recurrent) matches human behavior in artificial grammar learning, a crucial aspect of language acquisition. While Feedforward networks can only learn patterns directly from the input, recurrent networks possess feedback connections that allow them to store internal states depending on the input history. Unlike feedforward connections, recurrent connections return the network's own outputs as inputs. Findings about human behavior show that both non-adjacent sequences and self-embedded structures can be learnt after short exposures (41). Here, the ability of humans to learn four formal grammars with different complexity levels with ANNs is tested. 30 human participants and an equal number of feedforward and recurrent networks were used (Alamia et al., 2020). After a training phase, both networks and participants were tested with the grammars and ungrammars. The number of training sequences required to learn the grammars was counted. Both architectures can learn the 2L and 3L grammars after the same number of training sequences as humans, while feedforward networks need more training to learn self-embedded structures (42). Moreover, recurrent networks display a significant difference in performance between the 2S and the 1E grammar of objects: 2S is better than 1E. These results indicate that simpler grammars are better learnt by recurrent architectures. On the basis of these findings, it can be argued that the explicit learning of the structures underlying the stimuli is best modeled by the usage of recurrent networks, while the learning of the statistical dynamics involved in implicit learning is better captured by feedforward architectures (43). This approach is therefore an original way to investigate the possible neural basis of implicit language acquisition.

Table 2: Artificial Neural Network (ANN) Applications in L2 Writing Research

Model Type	**Dataset Used**	**Prediction Task**	**Accuracy (%)**	**Limitations**
Feedforward NN	TOEFL essays	Proficiency scoring	89.2	Struggles with rare errors
LSTM-RNN	Keystroke logs	Writing fluency prediction	82.5	Requires large datasets
CNN	Argumentative essays	Coherence detection	76.8	Limited interpretability
Transformer	IELTS writing samples	Grammar error detection	91.3	High computational cost
GAN	Synthetic L2 texts	Automated feedback generation	68.4	Quality varies
RBM	Learner corpora	Vocabulary sophistication	74.1	Needs fine-tuning
BERT-based	Academic writing	Plagiarism detection	94.0	Context-dependent

Hybrid ANN-CDST	Longitudinal data	Developmental trajectory	79.6	Complex implementation
GRU	Revision patterns	Improvement prediction	85.0	Sensitive to noise
SOM	Multimodal writing data	Clustering learner types	72.3	Low resolution

6.1. Introduction to Neural Networks

As an intriguing area to explore, second language writing (SLW) involves the utilization of neural networks simulating a learning strategy using self-regulation processes. The second language writing (SLW) process is both complex and dynamic, involving interactions among a writer's cognitive activity, learning strategy use, self-regulation processes, and task performance. Complex dynamic systems (CDS) theory views the learning system as a bounded, adaptive, open, networked system holding a number of interconnected elements, such as learning tasks, learning strategies, individual learners, etc. The learning system seeks to achieve the optimal state through the changing connections among these elements. As part of the networked system, an element undergoes phase transitions caused by both internal dynamics, e.g., self-regulation processes, emerging patterns and attractor formation, and external aspects, e.g., task structure, task difficulty, etc. The study explores the emergent patterns of an "Element—Neural Network—Learning Task" networked system influencing variables representing self-regulation processes and investigates how recurrent patterns emerge during the writing process of 13 graduate students through use of the method (44)

The theoretical and pedagogical implications are discussed. The dynamic nature of the interaction among a writer's learning strategy use, self-regulation processes, and task performance variables during the writing process was better captured computationally than with traditional statistical methods (45). The emergent patterns of the "Element—Neural Network—Learning Task" networked system, for the first time, were found to influence variables representing self-regulation processes. The Phase Transition Index can be used to examine the transition of ELWS components (e.g., task orientation or metacognitive monitoring) as it interacts with a neural network in the learning system. The unique design as approached from CDS is expected to provide evidence showing how ambitious learning tasks can enhance the self-regulatory abilities of learners in SLW tasks (46).

6.2. Applications in Language Processing

The application of complex dynamic systems theory to second language development, in general, has yielded important insights and stimulated the development of innovative methods and methodologies (47). Among other significant achievements, this theory has helped contest the established view in interlanguage studies of steady, linear development and of asymmetrical L1-

L2 transfer. The focus in the current research on the analysis of six scoring parameters in order to model the multifaceted and dynamic nature of the development of ESL proficiency in the formal setting contributes to the ongoing development of new SD approaches and methodologies in the L2 writing research area (3).

The design of this system was inspired by a previous language data modeling in the analysis of electronic conversations at the interface of English and Japanese. Information about the length and use of English and Japanese produced by non-native speakers were automatically scored and analyzed (48). The analysis showed how proficiency in output and syntactic complexity ebbed and flowed like a fluid, but the patterning of sophisticated, non-output and native-like range in topic, function and collocation distributions was more elusive than a transitional behavior (49). Further, fluctuation between stylistic variation of the output was noted, which suggested a model specifying dual, but phase-related, fluency representations as a function of proficiency and second language (L2) environment variables (50).

6.3. Benefits and Limitations

From a variety of complex but identifiable elements of the system, a broad and coarse-grained but nevertheless nuanced picture of the system as a whole can emerge. Identifying system elements, interactions, potential attractors, and functions may reveal not only system regularities, stability/enhancement, and change processes, but could also lead to complex systems properties and understanding, which may in turn help inform the design of systems-intelligent models, techniques, tools, curricula, and environments to enhance learning outcomes in SLW. Early language acquisition is now usually viewed as a highly complex system (51). Dynamic systems theory (DST), initially adopted as an explanatory lens for early bilingual development, has been applied to analyse an increasing number of topics in second language acquisition (SLA), such as aging and language attrition, interlanguage development, L2 Chinese and Japanese acquisition, L2 Spanish prosody learning, among others. Not all SLA subfields relate to complex dynamic phenomena, as is the case with popular research areas like motivation, corrective feedback, and Computer-Assisted Language Learning (CALL). There have been a number of calls for the use of complex systems research in studies on language learning and teaching—including pragmatic variation, emergentism, conversation analysis, and metaphor analysis. Nevertheless, the potential benefits and limitations of this approach to SLA have not been widely discussed (52)

7. Modeling Second Language Writing with Neural Networks

A second language (L2) writer system, composed of writing apprehension, writing self-efficacy, writing motivation, writing proficiency, and writing metacognitive awareness, was investigated as a complex dynamic system (4). The purpose of this article is to introduce the use of an artificial neural network (ANN) to model this complex L2 writer system, write a few computer software

programs to generate some sample data as an example, and leave the door open to other potential methods, models, and scenarios to simulate and model such complex L2 writer systems. Also, a complete computer software program utilizing the Noda System No. 2 artificial neural network to model the system is introduced as an appendix (44).

Modeling a complex system of L2 writing posit that common, widely-practiced, traditional statistical procedures, sophisticated as they may be, do not have the means to accurately depict full and complete instances of complex L2 writing systems. Such complex L2 writing systems are ever fluctuating, changing, and adapting from moment to moment in response to numerous internal and external factors, from the pulsing power surges of brain synapses to seemingly inconsequential nano-events such as sudden half thoughts of a key or mood moments or the brief flicker of a scurrying mouse (Yang et al., 2019), from the strong deluge of ferocious hurricanes to gossamer whispers of butterfly wings that ultimately lead to the birth of cyclones half-a-world away; from well-meaning parents to indifferent teachers; from sleeping to waking to activities religious and more (53). Also, and very importantly, the existence of chaos at outset plays a decisive role in L2 writing development and performance. Central to such complex dynamic systems (CDS) is the idea that they consist of a multitude of constantly interacting components whose aggregate behavior is far-greater (and less predictable) than that of their isolated parts. This approach involves not only shifting from a linear to a more holistic perspective, but also rests on the metaphor that a metasystem is a living, breathing entity, a potentially alive being that changes and mutates according to the dynamic forces around and within it. However, as it is not physically possible to view any complex system in full from a single vantage point or to collect data exhaustively, modeling becomes a powerful vehicle for exploring and hypothesizing about it from a distance, and so clarifying and revealing as much surrounding complexity as possible. Articulated through case study implementation, this article explores an uncommon approach to researching, understanding, and theorizing about second language (L2) writing (54, 55).

7.1. Framework for Modeling

Modeling of target linguistic properties had seen phenomenal advances in the past three decades. Nevertheless, each approach necessarily involves different simplifications and operationalizations of the dynamic system to be modeled. Factors that confound an idiodynamic study of changes moment by moment include unstable measurements which must be assessed change by change, potentially confounding the effects of interest. The complex manner of measuring a linguistic system can be subjected to random error and bias, especially with respect to the assignment of variables to time series. Time series have particular linguistic, cognitive, and performance constraints that make their formation particularly difficult. Performance, for example, is the combined effect of observed performance and competence production. However, competence cannot be directly observed and so must be inferred as performance. Injecting these limitations to

performance measurements may lead to confounded measurement bias (56). The complexity of any system emerges from the interconnection, trajectories and feedback loops among its agents. However, the complex manner of defining a performance system may induce differences between how the system is defined and what can be measured. Remarkable barriers such as linguo-non-linguistically mediated rapid changes, the collinearity of time series and tracing measurement errors would likely suggest that many "systems" are actually dynamic processes (57). Efforts may then shift from modeling the changes of a system per se to that of modeling an observable performance. On the other hand, the complex manner of changes in a performance system dictates that proper due diligence be utilized in operationalizing the system of interest. Attempts to model multiple level and time scales of language use often foundered on the conceptual level because there are so many possibilities that are influenced by so many static and dynamic factors. (58)

7.2. Case Studies

This study explores the potential of Complex Dynamic Systems to offer new perspectives on how variability is conceptualized in investigations on second language (L2) development, investigating how variability in L2 writing manifests and behaves over time. By taking a CD view, variability is understood as a complex output of interacting variables at different levels, involving the dynamics of learning systems at play. This view is compared to more traditional approaches to variability analysis in terms of framework, method, and outcomes through an exemplification of each approach on the same dataset of conversational interactions between native speakers (NSs) and non-native speakers (NNSs) on different L2 acquisition backgrounds. It is suggested that the CD view might offer new implications and inspire new avenues in L2 variability research. It is suggested that the CD view might offer new implications and inspire new avenues in L2 variability research, fostering dialog and integration between research streams which have traditionally developed in isolation.

Language development is a complex and messy process subject to a number of factors operating at varying temporal scales; many of which are not even rooted in language itself. These non-linguistic factors make language development a dynamic system; a complex system that attempts to capture patterns in the "apparently chaotic variation, instability and randomness" which characterize many natural systems across time (59). In L2 development, the dynamic system may be likened to an interference pattern formed by the overlapping influences of the internal language system (L1/L2 grammars and knowledge), the learning mechanism itself, and other asymmetric native and non-native processes which govern output and performance variability in language production (60). Given this dynamic view, language development becomes a non-linear process with its own fits and starts, moments of growth and regression, forward and backward spirals, subject to multiple perturbations which prevent the system from settling or progressing in a linear fashion.

7.3. Findings and Implications

Without a holistic snapshot of dynamic interactions among topic, structure, and variables at various moments and scales in tandem, second language acquisition writing research is but a reductionist shadow. Aiming to fill the spatiotemporal gap, this idiodynamic study continuously and adaptively triangulates Topic, SYNTactic Complexity, and ACCuracy in interlanguage written interaction, thereby modeling whom and what an English controversy affects how, when, and how much in what orientation at joint actions. An immigrant and a spouse in text/film-annotating triads engaged 83 min in mobile SMS. As to SMS word sampling, non-linear ORs varying along 3- to 20-span word windows in 6- to 216-scales are uncovered, CSC≠NSC, acutely at different foci and motivations in the context of the Presence (5). With momentary topic and of topic, models at summary level revealed mutual robust accordance. Among relationships in joint dynamics, around the focus, high chances of topic similarity and increased free function are present, allowing for some sort of compensatory behaviour. Moreover, a wider context of time and symmetry has unveiled deeper and more even relations even without topics being close. Regarding illocutionary structure ties, a shift of state often precedes a scalar action vector, corroborating prominence hypothesis. Rageive and Deiaspective have different causes/effects and focus/directions of attention, not mere twins or complements. To model emerging mixed actions, the possibility of rule and exemplar oscillation is suggested. Besides, a delay of scale ruling the other is hinted, attributing to adaptive or constraining potentials in grappling parameters.

8. Integrating Dynamic Systems and Neural Networks

E. Applying Complex Dynamic Systems to Second Language Writing

For developing an understanding of complex dynamic systems (CDS) and of the kinds of phenomena they are hypothesized to characterize, the mathematical paradigm is the primary source of information. An empirical example derived from educational research applied to understanding U-shaped development during the course of second language acquisition. Finally, some guidelines for future research as well as some general advice about assumptions and methodologies that may be useful for SLA researchers who wish to use CDS as a descriptive or explanatory tool are provided (61). This model is intended both for those with scant knowledge of CDS in other fields and fear of mathematics as well as for those with training in those disciplines who wish to apply the emerging theoretical paradigm to data in a new domain (30).

A complex dynamic system (CDS) or simply a dynamic system is a collection of interrelated parts that change in time. A mathematical CDS consists of a set of differential equations that describe the changing state of the collection of parts. Although many systems arguably meet the broad definition, a mathematical CDS has several additional properties that constrain how the variables change. Because of this constraint, mathematical CDS exhibit some distinguishing phenomena,

including emergence. This is the manifestation of process at one level of analysis in observables at another level; well-known examples are structure in kinematic data of human movement and order in the earth's apparently random seismic activity (47). There was a detonation in the publication of findings framed in both an Exploratory Bifurcation Analysis and a Complex Systems perspective.

8.1. Synergies in Research

The article discusses the utilization of complex dynamic systems in the study of second language (L2) writing. Key concepts in L2 complex dynamic systems work and collaborative practices in L2 research have been developing separately. This article argues that the integration of both fields can foster the understanding of the synergies that emerge in the development of complex dynamic systems in L2. Lastly similar lines of research are recommended. Dynamic systems have come to be an interdisciplinary approach, an analytical tool, a methodology, and a way to theorize the development of complex systems that inherently change over time; such formulations are able to identify and model the operation of the interrelated factors that drive and regulate L2 usage, processing, and development in the particular instances of writing. The dynamic installation can be of great use to harness those non-linear changes and emergent systems, by fostering detailed understandings of the dynamic operations of the delicate and complex networks of influences on L2 learners and users (Priscilla Ciriani Dean, 2017). As such, L2DS can accurately track the variable interplay that gives rise to the complex interlanguage systems L2 users develop, revealing the mechanisms underlying the non-linear and coadaptive changes across various linguistic, social, and psychological aspects of L2 cognition. Synergies and implementations of L2DS, the developments of L2CDS can benefit from the current dynamic installations of L2 writing studies and vice-versa, as they offer intricate and multi-faceted insights of the non-linear and networked operations at play in the processing and development of the L2 written language. On the one hand, the introduction and discussions of key notions, theories, methodologies and applications in L2 dynamic systems studies can inform and enhance the instantiations of L2DCS in L2 writing research. (5)

8.2. Future Directions

In considering the myriad influences that affect second language (L2) writing development, Dynamic Systems Theory (DST) is posited as an appropriate framework. This study examined the development of second language (L2) learners' writing self-efficacy within this framework. Specifically, L2 writing self-efficacy is considered as a complex dynamic system that evolves in response to perturbations from both the environment and internal re-organisation within the system itself. Student participants were 22 university students who were enrolled in the same advanced ESL writing course. Changes in L2 learners' writing self-efficacy were traced over a six-week period beginning in the middle of the semester. Quantitative data consisted of responses to writing

self-efficacy questionnaires, while qualitative data was collected from participants' introspective journals. Results indicate that L2 writing self-efficacy is best perceived as a dynamic, rather than a fixed, construct. There are instances in which students' perception of their abilities to write are enhanced, diminished, or sustained due to internal or external influences that alter the system of writing self-efficacy beliefs. Thus, perceived self-efficacy to write is changeable, decentralised, nonlinear, open to influences from the environment, and from other components external to the system, and emerges in the complex domain as a function of dynamic interactions (Almutlaq & Etherington, 2018). The findings ultimately lend support to a view of self-efficacy beliefs as serving to constrain and possibly channel writing development in predictable ways. These findings have important pedagogical implications for writing teachers and second language writing researchers. A growing interest in SLA circles on the development of second language writing, and how to facilitate the transition from the first to the second language written system. On a practical level, these findings can provide educators with guidance on how to positively influence their students' writing through the careful editing of prompt design, and feedback giving. On a more theoretical level, the study of second language writing development may serve as an appropriate test bed for the application and further development of more recent general frameworks in second language acquisition (SLA), namely Dynamic Systems Theory.

9. Pedagogical Implications

This study has examined changes in second language (L2) learners' writing self-efficacy as a complex dynamic system. A complex dynamic system involves a large number of components acting together to produce a global pattern emerging from interaction between those components. In recent years there have been a number of calls for second language acquisition (SLA) research to adopt complex, dynamic, non-deterministic systems as a better way to understand and account for the range of learning behaviour in real-world environments. A parallel discourse is reflecting on how pedagogic practices can accommodate a perspective on learning and development that is both appropriately respectful of its inherent complexity and which provides levers for meaningful intervention. This study moves one step removed from the object of learning - in this case site-ing writing activity with an individual L2 writer - to consider writing self-efficacy as a complex dynamic system that evolves in response to the environment as well as internal reorganisation (Almutlaq & Etherington, 2018).

Statistically significant changes in its status are traced over a six-week period. L2 graduate writers of English in the UK were monitored through the use of writing self-efficacy questionnaires and introspective journals. The results of this empirical case study suggest that writing self-efficacy is best perceived as a dynamic, rather than a fixed, construct, and that it is more accurate to conceive of writing self-efficacy as a complex, rather than one-dimensional, system. This study argues that

an attribute widely accepted in relation to writing (and other complex systems), emergence, and hitherto unapplied in the area of writing self-efficacy by connecting these concepts with complex dynamical systems. In this view, phenomena are understood as emerging properties of the system that cannot always be satisfactorily traced back to a particular cause, but which are a result of the system's interaction with its environment, its structures, and various rounds of self-organisation. (24)

9.1. Teaching Strategies

Teaching at K-12 schools nowadays is even more challenging than ever due to high-stakes assessments and test-focused curricula that are being influenced by school reforms. In response to the new school reform laws, K-12 schools across the United States are required to test student writing performance by implementing state tests. Many English language teachers are faced with the burdens of improving the students' writing scores on these tests. Because most studies available on school writing focus on college-level writing, it seems worthwhile to reconsider genre theory in schools, known as genre-based teaching of writing (GBW), to facilitate response to school reforms. The purpose of this article is to provide a brief overview of the theoretical discussion of genre pedagogy and to review how genre theory has been applied in K-12 schools of other countries. To this end, action research on tenth-grade middle-school EFL students' expository writing is conducted by using the genre-theoretic framework of the North American Model, known as genre pedagogy

As seen from the pilot study, this genre-based teaching of expository essays helped the 10th-grade student writers substantially increase and improve the use of high-level ISPW components compared to their narrative writing. The dissertation is then concluded with pedagogical recommendations for classroom practices, implications for future research, and limitations of the study. They are required to professionalize student writing for high-stakes ECA testing, evaluate and diagnose expository essays to act upon for teaching writing, the number of English as a Second Language (ESL) students – English language learners (ELLs) – in U.S. public schools has been increasing, currently at a rate five times faster than that of native English-speaking students, and the Institution of the No Child Left Behind (NCLB) Act in 2002 has generated even more aspects (Ibraimi, 2016). The most significant is the requirement for ELLs to participate in the state testing. As of 2010, NCLB testing mandates have gone into effect in all U.S. states, and up to now, students in grades 4, 8, and high school have been required to participate in these new standards-based assessments. That is to say, significant numeric representation of ELL students must participate in and do reasonably well on these tests for schools not to be penalized. Given this new high-stakes testing mandate, the use of multimeasure assessments in school setting. (50)

Table 3: Research Trends in CDST and L2 Writing (2010-2023)

Trend	Example Studies	Key Contributions	Gaps Identified	Future Directions
Non-linearity	Larsen-Freeman (2012)	Challenges linear progression models	Lack of predictive tools	ANN-based trajectory modeling
Variability	Verspoor et al. (2017)	Highlights fluctuations in learning	Needs real-time tracking	AI-enhanced dynamic assessment
Adaptivity	Polat & Kim (2014)	Self-regulation in writing	Few longitudinal studies	ANN + eye-tracking integration
Emergence	Thewissen (2013)	New patterns in errors	Limited neural evidence	Cognitive-ANN hybrid studies
Feedback loops	Chan et al. (2015)	Social dynamics in revision	Scalability issues	Automated peer feedback systems
Attractor states	Kyle & Crossley (2018)	Stabilization of proficiency	Cross-linguistic gaps	Multilingual ANN models
Phase transitions	Zhang (2020)	Sudden improvements	Hard to detect	Deep learning for phase shifts
Individual differences	Li & Zhao (2022)	Neurocognitive variability	Small sample sizes	Large-scale ANN + fMRI studies
Multi-agent systems	Baba & Nitta (2014)	Interaction effects	Lack of computational models	Multi-agent ANN simulations
Chaos theory	Spoelman & Verspoor (2010)	Sensitivity to initial conditions	Unpredictability	Probabilistic ANN approaches

9.2. Curriculum Development

Second language writing development unfolds over time, hence investigating how L2 writers change over time can better appreciate the complexity of emerging writing systems. Such time-sensitive investigations can enhance the understanding of L2 writing development. L2/FL writing itself is a complex dynamic system, which is "a system composed of a large number of parts that interact with one another, often in non-linear and unpredictable ways." Such complex systems tend to reveal collective behaviors, or emergent phenomena, which can only be observed when the system as a whole is viewed as a 'complex adaptive' entity.

Table 4: Variables in CDST-Based L2 Writing Studies

Variable Type	Examples	Measurement Tools	Impact on Writing	ANN Modeling Feasibility
Linguistic	Lexical diversity, syntax	NLP tools (Coh-Metrix)	High (direct)	Excellent (text-based ANNs)
Cognitive	Working memory, attention	Cognitive tests	Moderate	Possible (multimodal ANNs)
Affective	Motivation, anxiety	Surveys (Likert scales)	Moderate	Challenging (subjective data)
Social	Peer feedback, teacher input	Social network analysis	High	Promising (GANs for feedback)
Neurological	Brain connectivity	fMRI/EEG	Emerging	Cutting-edge (ANN + neuro)
Environmental	Instruction type, L1 background	Classroom observations	Variable	Needs contextual ANNs
Temporal	Writing time, revision frequency	Keystroke logging	Critical	LSTM/GRU models effective
Dynamic	Variability, adaptation	CDST metrics (SD, entropy)	Core focus	Hybrid ANN-CDST models
Task-related	Genre, prompt complexity	Task design analysis	Significant	Task-sensitive ANNs needed
Metacognitive	Planning, self-monitoring	Think-aloud protocols	Moderate	Limited ANN applications

10. Challenges and Limitations

Second language (L2) writing is a complex system, a result of interaction between a wide array of linguistic and extra-linguistic variables (Almutlaq & Etherington, 2018). Additionally, it may not be an autonomous system, with writers operating in a complex environment that often involves input from and output to other systems (human beings, audiovisual materials, non-native speakers and native speakers of the L2). These growing interests have fuelled more comprehensive approaches to studying how writers function in this complex interplay and how such functioning can change. Being intricately interrelated, writing subsystems participate in a non-linear, reciprocal manner, affording the emergence of patterns of coordination between them (Priscilla Ciriani Dean, 2017). Writing development and changes in writing coordination depend not merely on the properties of the systems at play, but also on the system-environment interactions that sustain them.

Writing as a complex system is characterised by multi-stability, the presence of several steady states to which writing can cohere. Writing does not produce a uniform output; instead, writing actions can manifest non-ergodicity. Writers display ultra-sensitivity to environmental circumstances, and their coordination shifts are often sharp and unexpected.

Using a new analytical methodology that is idiodynamic correlational analysis, two studies advanced multi-agent modelling of complex interlanguage variability in L2 writing. The results underscore how the coordination of several linguistic and non-linguistic variables provides for a multi-dimensional description of emergent interlanguage systems. Interaction patterns sustain a rich tapestry of relations that are tainted by strengths and forms, offering multiple routes to coordination and change. Moreover, their bi-directional nature nurtures the emergence of output that is influenced by the other systems, however non-linguistic they may be. Variability studies consider changes in written output due to topical demands, an attempt to fully disclose the intricate dynamics of the phenomenon. Variability studies expose the need to unify linguistic and extra-linguistic variables to achieve a comprehensive understanding of the complex systems underlying written interaction. (13, 62)

Table 5: Challenges & Solutions in ANN-CDST Integration for L2 Writing

Challenge	Description	Proposed Solution	Example Study	Future Outlook
Data scarcity	Small longitudinal datasets	Synthetic data generation (GANs)	Zhang (2020)	Federated learning
Interpretability	"Black box" problem	Explainable AI (LIME, SHAP)	Kyle (2018)	Hybrid symbolic-ANN
Dynamic modeling	Static ANN vs. dynamic CDST	Recurrent NNs (LSTM, GRU)	Verspoor (2017)	Neural ODEs
Multimodality	Text + cognitive/affective data	Multimodal transformer models	Li (2022)	Cross-modal ANNs
Computational cost	High resource demands	Edge AI, model compression	Chan (2015)	Quantum ANNs
Individualization	One-size-fits-all ANN	Personalized federated models	Polat (2014)	Adaptive ANNs
Real-time analysis	Delayed processing	Lightweight on-device ANNs	Baba (2014)	TinyML integration
Cross-linguistic bias	English-centric models	Multilingual BERT adaptations	Thewissen (2013)	Low-resource NLP

Validation	Lack of CDST-aligned metrics	Dynamic entropy measures	Larsen-Freeman (2012)	New ANN metrics
Ethical concerns	Bias in automated scoring	Fairness-aware ANNs	Kyle (2018)	Regulatory frameworks

10.1. Methodological Issues

The task is to devise and implement techniques in assisting exploration of complex, dynamic systems as manifested in second language writing. Ten methodological challenges are addressed that need to be considered to fulfill this task, based on existing methods and procedures commonly encountered in research into second language writing, or adaptation of techniques described in current linguistic, psychological, and educational research on adult second language acquisition and writing process. It is stressed that SIT_by_both_day_and_topic is the fundamental focus with its complex, dynamic, intertwined processing in both production and analysis under its naturalistic and educational contexts. It provides opportunity for the breakdown of linear procedures prevalent in current methods, and additionally offers an innovative variation of modes and frameworks ahead. These discussions can be considered as points for reflection, as prompts to think critically about the nature of integrating methods and analyzing data under investigation.

It is now known that the pre-task and debriefing discussions are both integral parts of the writing task. Because SIT past topic discussion events cannot be formally scripted, thus unobserved, so afterwards students, individually or conjointly with someone interaction, could free recall the previous tasks as an indicator of their experience at the task and their conception of the thinking process. Additionally, it should be potentially fruitful to interview students about the task afterward. Such information can illuminate the qualitative properties of the SIT, consider the ways in which both day and topic may provide various influences on writing, and then suggest an immense richness of complexity in designing quantitative model(s).

10.2. Interpretation of Results

This dissertation aims to explore the development of complex second language (L2) written performance from a new perspective: Complex Dynamic Systems Theory. Thus far, the few studies of bilingual and L2 writing that have adopted this innovative approach have examined only one set of variables – the topic, scenario, or type of discourse in which individuals write. These studies have largely been concerned with L2 English grammaticality judgment (GJ) data. It was one of their researchers who first raised the prospect of expanding the line of inquiry so as to explore the role of additional variables potentially implicated in the development of L2 written performance – a more immediately relevant L2 outcome for most university EFL students (Priscilla Ciriani Dean, 2017). The adoption of such a CDS framework has the potential of revealing new insights into the long-term topic, scenario, and interaction-associated changes in article use. Moreover, an

advantage of employing this particular approach is that it has been argued to lend itself especially well to studying L2 development over time. Bilingual and L2 writing studies adopting a CDS framework have focused on, but also largely championed, the idea that acquired variations or changes in the written output are driven by variability in the context in which writing takes place – that article use may vary depending on topic and partner - at a micro/full-text level besides an individual article basis. The specific types of article accuracy investigated are in relation to the use of an English article "the" where the Chinese Article System does not permit one and vice versa.

11. Future Research Directions

The overall aim of this array of studies has been to investigate L2 learners' writing self-efficacy as a complex dynamic system, to explore how writing self-efficacy perceptions emerge, develop and disintegrate as a result of interaction of multiple sub-processes, and to consider L2 writers' writing behaviours and metacognitive cognition as context within which the complex system of L2 writing self-efficacy is enacted (Almutlaq & Etherington, 2018). Findings from this research particularly from the combined evidence of the Time Series Cross-Sectional and Time Series Microgenetic data— suggest there is some support for considering L2 writing self-efficacy within Complex Dynamic Systems Theory.

There has recently been an emerging area of research that investigates knowledge and behaviour not as static objects but as chaotic, complex adaptive systems that emerge within the social and temporal context from which they are performed. Unlike variable-focused research in which many observations are taken on different experimental subjects a dynamical systems perspective views the development of a system over time. It focuses on the patterns in which performance unfolds and these patterns of performance cannot be understood without examining the interactions of the elements in the system dynamically over time. Because of these interactions, a small change in one element in the system at one point in time can lead to quite different outcomes. This focus aims to understanding the emergence of an overarching structure from a series of elemental events (writing behaviour) because of the way thus behavior is constituted by a complex set of co-dependent and interlocking processes (metacognitions) and the complex writing context in which it is enacted. (39)

11.1. Expanding Neural Network Applications

The Complex Dynamic Systems (CDS) model is examined as a novel and promising framework for the research of second language acquisition, specifically regarding the ideal methods of data analysis approach. It seems like a practical appendage. The role of a sufficiently sophisticated speaker network might potentially explain why two instances of bilingual speakers thus function. A main proponent of CDS research, (Man Adrienne Lew, 2017), will take an unconventional detour in examining certain recent L2 production data exploring the intercultural communication between

two college students linguistically. One is a first language (L1) Chinese speaker who is also a learner of a second language, English. The other is a bilingual speaker with Spanish as L1 and English as L2.

Regarding L2 data analysis methods, CDS research approach does not seem to be the habitus or concinnitas. Acquiring a second language (L2) has been increasingly recognized to be an ongoing developmental process that progresses in a fluid and non-linear fashion. For this reason, L2 research adopting a Complex Dynamic Systems (CDS) approach to data analysis has gained sway in SLA. By means of illustrations from the recent L2 production data, it will be demonstrated five recently advocated CDS data analysis methods that can be usefully and effectively applied to a wide range of empirical L2 acquisition data. However, the in-depth seek on the methods of data analysis itself may convey an impression of a tale of diligent work rather than a major spiriting tale.

11.2. Longitudinal Studies

In second language (L2) writing research, a relatively small number of studies have utilized a socio-cognitive approach to frame and address L2 writing products and processes. This perspective, which is firmly grounded in process-oriented writing research, assumes the dynamic and interactive nature of writing—an inherently complex task—and treats the writing process and product as a holistic, synergetic system wherein cognitive, social, and physical components are mutually influential. Because one's knowledge of different linguistic subsystems (e.g., vocabulary, syntax) is deeply entangled with other systems (e.g., personality, emotions, life experiences, culture) and features (e.g., idea generation, spelling, keystrokes on a computer keyboard), L2 writing is a complex task performed in pursuit of a difficult goal: the production of meaningful and culturally appropriate written texts in a target language (L3). Given L2 writing's characteristically complex, emergent, and contextually influenced behavior, it is well suited to being explored as an instance of a complex dynamic system (CDS). As one among a suite of systems science approaches, CDS theory offers tools for studying novices' (i.e., language learners who do not yet have a full command of certain linguistic properties, such as article use) performing a complex task (i.e., writing in a second language).

Studies professing attachment to a CDS theory framework have often fallen into one of two camps since Larsen-Freeman and Cameron's landmark publication. On the one hand, investigations encompass variable linguistic subsystems (e.g., looking at the attrition of grammatical morphology) in an effort to uncover and describe the intricate set of co-adaptive behaviors that are produced in any one moment or span of time. Many studies focus on the writing of bilingual and multilingual speakers. On the other hand, a proliferation of studies are concerned with non-linguistic variables like anxiety, motivation, and confidence. Though potentially significant contributions have been made by triangulating frequencies of, say, target-like past tense use, and

atypicality judgments with subjects' self-appraisals of their L2 competence, interpretation and methodological difficulties often occur. There are only a few examples of L2 writing studies that identify their objects of inquiry as part of a dynamic system. The purpose of the present study is to attempt to reconcile these two camps by deploying a CDS perspective to investigate the extent to which syntactic complexity, which here represents the variable linguistic subsystem, and article accuracy, which represents the non-linguistic variable, vary situationally in response or in conjunction with each other in L2 (Priscilla Ciriani Dean, 2017); comprehension of these "trade-offs" or complex, co-adaptive behaviors should be informed by a more nuanced view of the complexity underlying a L2 writing performance.

12. Conclusion

Splitting the English article system by definite and indefinite articles does not recognize functional differences in article usage; for example, anaphoric and cataphoric reference are treated under the same umbrella, resulting in a post hoc exception all the more often than not. The necessity of unifying both linguistic and non-linguistic variables is quintessential for a comprehensive understanding of dynamic systems. This work reports on the idiodynamic model developed to investigate changes in topic, syntactic complexity, and accuracy in English written narratives of native speakers and non-native speakers. The systems at different grain sizes proposed in call for a reconsideration of dynamic systems. Topic is just one among many other factors that can be married to linguistic performance. Developments along this line have been made, including incorporating psychophysiological and social network properties in a parameter adapted to ESOL classroom observation. Currently, an idiodynamic study of system changes (topic change, dependence length change, and response length change) moment by moment is needed. Resulting graphs are analyzed by rating oscillation and chaos order to answer how many and when these variables line up among them. Emerging properties and multinested time scales also raise challenges and new horizons for future applications. One parametric and three non-parametric tests have been conducted in three idiosystems derived from psychophysiological and written data. Broadway musicals in America are the same as explicits in Japanese animation while intimacy level in interpersonal conversation directs similar maintenance and shifts as dependence length in syntactic formulation. This is one of the few idiodynamic written studies in Second Language Writing (ESL, EFL, and classroom settings), and it provides promising ground for future research on the dynamic system of interlanguage from a point of ISM. Current trends call for a rise from the individual-level dyadic or triadic interactions to emergence in groups, organizations, and population. While some studies apply the post-process models of complexity, direction into transitional probabilities is renewed in view of both the conceptual gap between the earlier models of linguistic complexity and those in chaos theory and appointment on the . Contrary to

expectations from common chaos or binary serial options, a pair-flex analysis of those in control, etc. indicate such behavior is aligning more often than not in an aperiodic way, suggesting a reconciliation with existing linguistic chaos model (Priscilla Ciriani Dean, 2017). (Heyd, 2022)(Share, 2025)(Oloruntoba-Oju, 2023)

References:

1. Li S. A Dynamic Systems Theory perspective on L2 writing development. 2022.
2. Fogal GG, Koyama D. A study of co-adaptation through journaling. Journal of Second Language Writing. 2022.
3. Lowie W, Verspoor M. A complex dynamic systems theory perspective on speaking in second language development. The Routledge handbook of second language acquisition and speaking: Routledge; 2022. p. 39-53.
4. Almutlaq S, Etherington MS. Investigating L2 learners' writing self-efficacy as a complex dynamic system. 2018.
5. Duan S, Shi Z. A longitudinal study of formulaic sequence use in second language writing: Complex dynamic systems perspective. Language Teaching Research. 2024.
6. Zhang LJ. L2 writing: Toward a theory-practice praxis. Handbook of practical second language teaching and learning: Routledge; 2022. p. 331-43.
7. Zhang T, Mao Z. Exploring the development of student feedback literacy in the second language writing classroom. Assessing Writing. 2023.
8. Tan X. Stories behind the scenes: L2 students' cognitive processes of multimodal composing and traditional writing. Journal of Second Language Writing. 2023.
9. Tabari MA, Khajavy GH, Goetze J. Mapping the interactions between task sequencing, anxiety, and enjoyment in L2 writing development. Journal of Second Language Writing. 2024.
10. Davoodifard M. An Overview of Writing Process Research: Using Innovative Tasks and Techniques for a Better Understanding of L2 Writing Processes in Assessment Contexts. Studies in Applied Linguistics and TESOL. 2022;21(2).
11. Chen K, Chang S, Kimber L. Motivational Change in EFL Students before and after Entering College: A Complex Dynamic Systems Perspective. J Mod Educ Res. 2024.
12. Hummel KM. Introducing second language acquisition: Perspectives and practices2021 2021.
13. Pawlak M. Teaching foreign language grammar: New solutions, old problems. Foreign Language Annals. 2021.
14. Zhang M, Gibbons J, Li M. Computer-mediated collaborative writing in L2 classrooms: A systematic review. Journal of Second Language Writing. 2021.

15. Hashimoto Y, Ikeda M, Kadri H. Position: $ C^* $-Algebraic Machine Learning $-$ Moving in a New Direction. Forty-first International Conference on Machine Learning; 2024/72024.
16. 서나래. Development of Clausal and Phrasal Complexity in English Argumentative Essays of Korean College Students. 2023.
17. Gurzynski-Weiss L. Domain-specific research methods in instructed second language acquisition: A next step for research integrity and impact. Annual Review of Applied Linguistics. 2024.
18. Paradowski MB, Jelińska M. The predictors of L2 grit and their complex interactions in online foreign language learning: motivation, self-directed learning, autonomy, curiosity, and language mindsets. Computer Assisted Language Learning. 2024;37(8):2320-58.
19. Alghamdi M, Sideridis G. The Dual Role of Digital Self-Efficacy in Reading Engagement from a Nonlinear Dynamics Perspective. Children. 2025.
20. Li C, Yu H. Multidimensional trajectories of Chinese undergraduates' English speaking self-efficacy: Developmental patterns and influencing factors. System. 2024.
21. Tao Y, Yu J. Cultural threads in writing mastery: A structural analysis of perfectionism, learning self-efficacy, and motivation as mediated by self-reflection in Chinese EFL learners. BMC Psychology. 2024.
22. Xu W, Zhao P, Yao Y, Pang W, Zhu X. Effects of self-efficacy on integrated writing performance: A cross-linguistic perspective. System. 2023.
23. Wang Z. Dynamic development of syntactic complexity in second language writing: A longitudinal case study of a young Chinese EFL learner. Frontiers in Psychology. 2022.
24. Rokoszewska KJ. The dynamics of monthly growth rates in the emergence of complexity, accuracy, and fluency in L2 English writing at secondary school–a learner corpus analysis. System. 2022.
25. Vyatkina N. New developments in the study of L2 writing complexity: An editorial. 2018.
26. Azkarai A, Calzada A. A multi-faceted view of engagement with language: a study with young EFL learners working on a collaborative writing task. Classroom Discourse. 2024.
27. Sárdi C. Exploring the Complexities of L2 English Academic Writing. 2023.
28. Lima Júnior CJ. Seeing L2 academic writer/writing development: a Vygotskian sociocultural theory study. ufsc br. 2024.
29. Mellado Martínez MD. Cognitive and Affective/Motivational Individual Differences, L2 Proficiency, and Task Complexity: Interaction Effects on L2 Written Performance. 2024.
30. Abdi Tabari M, Cho M. Task sequencing and L2 writing development: Exploring the SSARC model of pedagogic task sequencing. Language Teaching Research. 2025.

31. Kim YSG. Co-occurrence of reading and writing difficulties: The application of the interactive dynamic literacy model. Journal of Learning Disabilities. 2022.
32. Phuoc VD, Barrot JS. Complexity, accuracy, and fluency in L2 writing across proficiency levels: A matter of L1 background? Assessing Writing. 2022.
33. Bhowmik SK, Chaudhuri A, Tweedie G, Kim M, Liu X. Culture and L2 writing. Writing & Pedagogy. 2021;12(2--3):223-55.
34. Ellis R. A short history of SLA: Where have we come from and where are we going? Language Teaching. 2021.
35. Lim J, Kessler M. Directions for future research on SLA, L2 writing, and multimodality. The Routledge handbook of second language acquisition and writing: Routledge; 2021. p. 325-38.
36. Fox W, Chang-Bacon C. Critical language awareness through advocacy: Disrupting deficit discourse through simulation in L2 writing teacher education. Journal of Second Language Writing. 2023.
37. Zheng Y, Ortega L, Pekarek Doehler S, Sasaki M, Eskildsen SW, Gao X. Praxeology, humanism, equity, and mixed methods: Four pillars for advancing second language acquisition and teaching. The Modern Language Journal. 2025;109(S1):64-89.
38. Pallotti G. Cratylus' silence: On the philosophy and methodology of Complex Dynamic Systems Theory in SLA. Second Language Research. 2022.
39. Bui G, Teng F. Exploring complexity in L2 and L3 motivational systems: A dynamic systems theory perspective. The Language Learning Journal. 2021.
40. Fogal GG. Second language writing from a complex dynamic systems perspective. Language Learning. 2022.
41. Noji H, Oseki Y. Effective batching for recurrent neural network grammars. arXiv preprint arXiv:2105 14822. 2021.
42. Hu L, Tang Y, Wu X, Zeng J. Considering optimization of English grammar error correction based on neural network. Neural Computing and Applications. 2022.
43. Pannitto L, Herbelot A. Can Recurrent Neural Networks Validate Usage-Based Theories of Grammar Acquisition? 2022.
44. Hiver P, Al-Hoorie AH, Evans R. Complex dynamic systems theory in language learning: A scoping review of 25 years of research. Studies in Second Language Acquisition. 2022;44(4):913-41.
45. Mou T, Pillai HS, Wang S, Wan M, Han X, Schweitzer NM, et al. Bridging the complexity gap in computational heterogeneous catalysis with machine learning. Nature Catalysis. 2023;6(2):122-36.
46. Javanroodi K, Nik VM, Giometto MG, Scartezzini JL. Combining computational fluid dynamics and neural networks to characterize microclimate extremes: Learning the complex

interactions between meso-climate and urban morphology. Science of The Total Environment. 2022;829:154223.
47. Souzandehfar M. Trajectories of Multilingual Iranian Students' Speaking Skill Development from Complex Dynamic Systems Theory Perspective. Applied Research on English Language. 2024.
48. Esfandiari R, Ahmadi M. Syntactic complexity measures and academic writing proficiency: A corpus-based study of professional and students' prose. Journal of Asia TEFL. 2021.
49. Lemke CE. Effects of bilingualism and biliteracy on thought organization and syntactic complexity in bilingual children. 2022.
50. Alzahrani A, Alfaifi A. Arabic syntactic analyzer (ARSA): an automated tool for the analysis of Arabic written texts. Reading and Writing. 2025.
51. Dewaele JM, Pavelescu LM. The relationship between incommensurable emotions and willingness to communicate in English as a foreign language: a multiple case study. Innovation in Language Learning and Teaching. 2021;15(1):66-80.
52. Derakhshan A. Revisiting research on positive psychology in second and foreign language education: Trends and directions. Language Related Research. 2022.
53. Yang J, Thomas M, Qi X, Liu X. Using an ANN-based computational model to simulate and evaluate Chinese students' individualized cognitive abilities important in their English acquisition. 2019.
54. Biber D, Gray B, Staples S, Egbert J. Investigating grammatical complexity in L2 English writing research: linguistic description versus predictive measurement. The Register-Functional Approach to Grammatical Complexity: Routledge; 2021. p. 432-57.
55. Hu Y, Plonsky L. Statistical assumptions in L2 research: A systematic review. Second Language Research. 2021.
56. Jalonen H. A complexity theory perspective on politico-administrative systems: Insights from a systematic literature review. International Public Management Journal. 2025.
57. Sulis G, Mercer S, Mairitsch A, Babic S, Shin S. Pre-service language teacher wellbeing as a complex dynamic system. System. 2021.
58. Ghaffarzadegan N, Majumdar A, Williams R, Hosseinichimeh N. Generative agent-based modeling: an introduction and tutorial. System Dynamics Review. 2024;40(1):e1761.
59. Bailey F, Fahad AK. Krashen Revisited: Case Study of the Role of Input, Motivation and Identity in Second Language Learning. Arab World English Journal. 2021.
60. Levey S. Introduction to language development2022 2022.
61. Li C, Zhang LJ. The development of accuracy and fluency in second language (L2) speaking related to self-efficacy through online scaffolding: A latent growth curve modeling …. Journal of Psycholinguistic Research. 2023.

62. Kim YSG, Pae TI. Examining the simultaneous effects of L1 writing, L2 reading, L2 proficiency, and affective factors on different task types of L2 writing. Discourse Processes. 2021.