

He moved the correlations, now what? On dynamics, causality and development in Wander Lowie's CDST

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Abstract The introduction of Complex Dynamic Systems Theory (CDST) marked a shift in SLA research from product-oriented outcomes to developmental processes. Building on the work of Wander Lowie and colleagues, this article adopts a dual approach. We reanalysed an existing dataset while situating the findings within a broader methodological reflection, outlining opportunities and challenges of dense longitudinal methods and identifying priorities for strengthening evidence in future CDST-oriented SLA research.

Keywords complex dynamic systems, L2 development, process-oriented research

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The introduction of Complex Dynamic Systems Theory (CDST) in second language acquisition (SLA) research marked an important conceptual shift from predominantly product-oriented descriptions of learner performance towards a sustained engagement with the developmental process. Over the past two decades, Wander Lowie and colleagues have been instrumental in translating this shift into a coherent empirical research program centered on dense longitudinal designs, non-linear modeling, and the study of intra-individual variability as core objects of inquiry (e.g. Lowie, 2017; Lowie et al., 2011). At the same time, as argued in earlier critical appraisals (Bulté & Housen, 2020), the rapid methodological expansion of CDST-inspired research has not always been matched by an equally explicit development of construct-theoretical and inferential frameworks. In this contribution, we therefore adopt a deliberately dual stance: we seek to extend and exemplify Lowie's perspective through new analyses of the Lowie and Verspoor (2019) dataset, while at the same time situating these analyses within a broader methodological reflection on how CDST-oriented research can further strengthen its evidential foundations. Specifically, we (i) operationalize key CDST claims using GAMMs and temporal network analysis, (ii) illustrate both the potential and limits of these methods using dense

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longitudinal data, and (iii) formulate a set of methodological priorities/considerations for the next phase of CDST-oriented SLA research.

1 Operationalizing process-oriented research in second language development

A focus on the language learning process requires a longitudinal perspective (Lowie, 2026, this issue; reprint of Atkinson et al., 2025). Since we are trying to understand the *how* rather than the *what*, it is recommended to conduct multiple (case) studies with dense measurements, also called microgenetic studies. The resulting time-series data enable researchers to study change as it unfolds over time. This can be done at different time scales, making sure the time scale matches the research objectives.

An important issue in doing process-oriented research is the ergodicity problem. This means that individual learners cannot be assumed to follow identical developmental trajectories, which in turn necessitates the complementary use of group-level and individual-level analyses. The ergodicity problem was explored in Lowie and Verspoor (2019) who found that development is indeed highly individual even in learners who seem very similar at first glance. Later studies have explored forming homogeneous groups rather than ergodic ensembles from the data (e.g., Peng et al., 2022; De Wilde & Lowie, 2025).

CDST also stresses that changing relationships in complex adaptive or dynamical systems requires non-linear analyses of longitudinal data. Lowie (2017) encouraged researchers to investigate trends and changes in the learning trajectory and study change as it occurs in the data. One of the methods that can be used to do this are generalized additive mixed models (GAMMs), which allow non-linear developmental trajectories to be modeled at both the group and the individual level, while explicitly accommodating individual learner differences within group-level analyses (e.g., Murakami, 2016; Pfenninger, 2020; Wirtz & Pfenninger, 2025).

CDST foregrounds the idea that second language development is not driven by isolated subsystems evolving in parallel, but by continuously changing interactions both within the learner's linguistic system and across learners embedded in shared instructional ecologies (Lowie, 2017). Capturing such interactional dynamics requires analytical techniques that are sensitive to non-linearity, temporal dependency and multicausality. Earlier CDST work has therefore relied on methods such as moving correlations, simulations and dynamic equations to trace changing relationships over time (Lowie et al., 2011; Caspi, 2010). At the same time, however, while such techniques provide powerful descriptive tools for system exploration, their outcomes should be interpreted with methodological caution. In particular, directed temporal relations derived from dynamic modeling represent probabilistic associations rather than causal mechanisms in a strong explanatory sense. As argued by Bulté and Housen (2020), the inference of developmental causality from dynamic association remains theoretically under-specified and

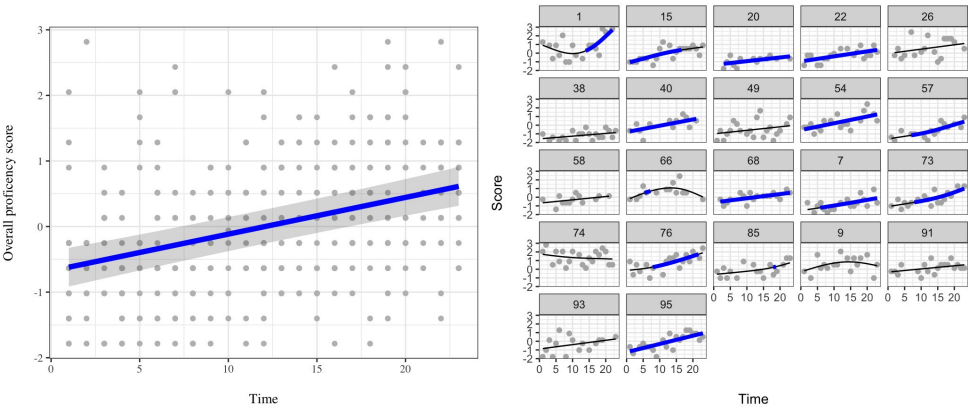
empirically under-constrained in much current CDST-oriented research. Lowie (2026) stresses that multicausality must be the norm and that researchers should investigate relationships among system components not as definitive causal architectures, but as empirically grounded hypotheses about system organization. Network-based approaches provide a principled framework for such exploratory modelling: by representing temporal, contemporaneous and between-person relations among multiple variables, they allow researchers to visualize how subsystems may co-evolve, scaffold or compete across successive measurement occasions (cf. Freeborn & Siepe, 2025; Epskamp et al., 2018). In the present contribution, we therefore use temporal network modelling to illustrate how dense longitudinal writing data from 22 Dutch-speaking learners of English, collected over 23 waves, can be leveraged to explore such hypothesized interactions between linguistic subsystems.

At the same time, CDST also calls for analytical techniques that can do justice to the non-linear and heterogeneous nature of developmental trajectories themselves. Data-driven approaches that allow patterns to emerge from observed learner behavior, rather than from strongly pre-specified parametric assumptions, are particularly well-suited to this goal (Lowie, 2026). Generalized additive mixed models (GAMMs) meet this requirement by allowing flexible, smooth, non-linear relations between time and developmental outcomes while simultaneously accommodating individual-level variation. In the short study presented below, GAMMs are therefore used to illustrate how periods of significant growth and stagnation can be identified at both the group and the individual level in densely sampled longitudinal writing data. Importantly, GAMMs are not treated as providing causal explanations of development, but as complementary heuristic instruments for system exploration and hypothesis generation, demonstrating how CDST-inspired questions about variability, non-linearity and interdependence can be empirically operationalized in richly sampled learner corpora.

2 Uncovering periods of significant growth and relationships between linguistic subsystems: A study with 22 Dutch learners from a bilingual program

In what follows we use data from Lowie and Verspoor (2019; see also Verspoor et al., 2021). The written English-L2 data were collected in the Netherlands from 22 participants (aged 12-13 years) who had just begun secondary school when the study started and who had enrolled in a Dutch-English bilingual program. Data were collected every other week, 23 times in total. The participants wrote short texts (82 to 125 words) about familiar topics. Writing was done in class, on a school computer. The texts were rated holistically (on a 5-point scale) and a set of analytical measures with established developmental sensitivity was calculated. For our analysis we will look into mean length of T-unit (MLTU), number of dependent clauses per t-unit (DC_T), mean length of word (MLW), Guiraud and number of dependents per nominal in noun phrases (NomDep). In their original

Figure 1 Development of the holistic scores for the group and the individual learners (parts highlighted in blue indicate significant growth)

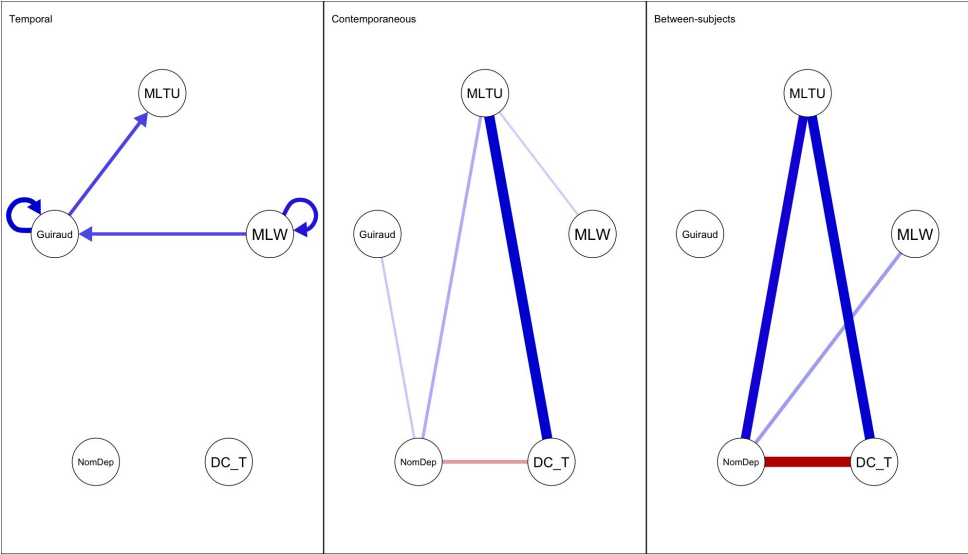


analyses, Lowie and Verspoor (2019) found that even highly similar learners followed clearly different learning trajectories. Verspoor and colleagues (2021) further explored the data using generalized additive mixed models for the analytical measures. We investigate overall development (holistic scores) at the group level and the individual level. We aim to map whether and when we see periods of significant growth in the group and in individual learners. To do this, we followed the procedure outlined in Wirtz and Pfenninger (2025). We then also conducted a temporal network analysis (cf. Freeborn & Siepe, 2025) to investigate relationships between linguistic subsystems. Temporal network analysis results in three different networks. The *temporal network* is a directed network that shows changes in variables within individuals over time. It shows how variables predict one another at the next time point. The *contemporaneous network* estimates how variables are related within the same timeframe (within subjects). Finally, the *between subjects-network* shows the relationship between the means of the variables. With this analysis we aim to explore how the various subsystems are interrelated over time and at one timepoint. Data and code can be found on <https://osf.io/yw5ra>.

Figure 1 shows that holistic writing proficiency seems to increase in a smooth linear fashion across the 23 measurement occasions but also shows large differences between individual scores at all timepoints. The group-level learning trajectory is not mirrored at the level of individual learners. For 13 of the 22 learners, development is characterized by longer or shorter periods of significant growth. Importantly, the timing and magnitude of growth spurts and the shape of the learning trajectory vary considerably across learners, even within a highly homogeneous instructional context. This pattern underscores the CDST claim that inter-individual variability is not noise around a common trajectory, but a core property of the developmental process itself.

Figure 2 complements this picture by visualizing how multiple linguistic subsystems (operationalized through syntactic and lexical measures) are dynamically interrelated

Figure 2 Temporal, contemporaneous and between-subjects networks showing the relationships between the various analytical measures



over time. The *temporal* network indicates that changes in certain subsystems systematically precede changes in others. Two positive self-loops (MLW and Guiraud) indicate that participants who use longer words and write more diverse texts do this throughout the study. Furthermore, participants who produce longer words at one timepoint, produce more diverse texts at the next time point and higher lexical diversity precedes changes in length of T-unit. The results suggest that syntactic and lexical measures do not develop in isolation; there appear to be interdependent relationships between aspects of L2 writing over time. The *contemporaneous* network shows that various subsystems are related *within learners* at any given time point, reflecting momentary structural coupling within the learner system. For example, at any given time point, individual learners who produce longer utterances also tend to use longer words. Finally, the *between-subjects* network reveals associations between proficiency measures *across individuals* and time. For example, when utterances become longer, they contain more dependent clauses per T-unit and more dependents per nominal in noun phrases. Taken together, these networks illustrate that development emerges from an evolving web of interdependent subsystems, rather than from additive growth in isolated components, thereby providing an empirical instantiation of CDST notions of interdependence, co-adaptation and multicausality in L2 development.

3 Challenges and future directions

As van Dijk and colleagues (2024) have argued, process-oriented approaches to SLA do not require a “one-model-fits-all” conception of development, nor do they presuppose that generalization must be grounded exclusively in population-level averages. At the same time, for CDST-inspired research to mature into a cumulative empirical program, a number of methodological and conceptual challenges need to be addressed more explicitly than has often been the case.

A first priority concerns measurement theory and construct specification. While CDST research has productively foregrounded variability, non-linearity and interdependence as defining properties of L2 development, it has been comparatively less explicit about the construct-theoretical foundations of the measures used to operationalize these properties. Complexity, in particular, continues to be operationalized through heterogeneous collections of surface-level indices whose relations to underlying linguistic representations and communicative capacities remain only partially specified (Bulté et al., 2025). Future CDST-oriented research would therefore benefit from the development of explicit measurement models that separate construct variance from task, genre and noise variance, and that allow alternative operationalizations of complexity (or, for that matter, fluency, accuracy and functional adequacy) to be systematically compared. Without such models, dynamic patterns risk remaining descriptively compelling but theoretically underdetermined.

A second priority concerns robustness, replication and inferential discipline (cf. Van Dijk et al., 2024). Much CDST-inspired work has been unabashedly exploratory, which has been crucial in opening new empirical windows on developmental processes. However, exploratory modeling must be complemented by confirmatory research designs if dynamic regularities are to be established as more than context-bound descriptive artefacts. We therefore advocate the wider adoption of preregistered analysis plans, multi-operational replication designs (Al Hoorie et al., 2023), and systematic robustness checks across alternative measurement specifications. Such practices would make it possible to distinguish stable developmental dynamics from those that are contingent on specific tasks, corpora or analytic choices, and would substantially strengthen the cumulative evidential base of CDST-oriented SLA research.

A third priority concerns the integration of CDST-inspired modeling with established longitudinal growth modeling traditions. Non-linear smoothers, temporal networks and other CDST-compatible techniques offer powerful tools for capturing local developmental dynamics, but they should not be treated as methodological islands. Their integration with confirmatory approaches and multilevel longitudinal designs would allow researchers to link individual-level dynamics to population-level regularities without reverting to ergodic assumptions. Such integration would also facilitate principled comparisons between CDST-inspired and more conventional longitudinal models, thereby clarifying the specific explanatory added value of a CDST perspective.

Taken together, these directions point toward a next phase of CDST-oriented SLA research that retains the conceptual richness and process sensitivity championed by Wander Lowie, while embedding them in a more explicit framework of measurement theory, inferential discipline and cumulative empirical testing. It is precisely at this interface – between dynamic description and methodological consolidation – that we believe Lowie's legacy can continue to shape the future of SLA research in the Netherlands and beyond.

Personal note

Each of us have had the pleasure of engaging with Wander Lowie in different capacities and on different occasions – as student, collaborator, interlocutor, editor, colleague, critical discussant and/or table companion. Across these encounters, a constant has been Wander's insistence that methodological innovation in SLA begins not with techniques, but with data, and that development must be studied as it unfolds, in all its variability, complexity and unpredictability. His commitment to taking empirical complexity seriously, coupled with an intellectual openness to being challenged by one's own analyses, has profoundly shaped how many of us think about variability, non-linearity and explanation in SLA, and has always gone hand in hand with a remarkable conviviality and an unmistakable Dutch sense of humour that made even the most technical epistemological or methodological discussions both engaging and genuinely enjoyable. In this spirit, we offer the present contribution not as a tribute in the narrow sense, but as a dialogue: an extension of ideas that have shaped our work, and an invitation to continue refining, together with Wander, how we study development as a complex, empirical phenomenon.

Author contributions

Vanessa De Wilde: conceptualization, formal analysis, writing original draft, writing review and editing; Lani Freeborn: conceptualization, writing original draft, writing review and editing; May Y. Wu: conceptualization, writing original draft, writing review and editing; Alex Housen: conceptualization, writing original draft, writing review and editing.

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Statement of technology use

No AI-based generative technology was used in the preparation of this manuscript and the execution of the research that the manuscript reports upon.

Supporting information

None.

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