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Sequence representation and cultural systems are necessary for cumulative culture

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Abstract

Chater and Christiansen explain cultural complexity as emerging through local social tinkering. We argue that this account can be complemented by two minimal principles: sequence representation as a cognitive prerequisite for cumulative culture and cultural-systems dynamics as a formal account of how interacting traits stabilize, constrain, and reshape later tinkering. Together, they explain how simple mechanisms generate complex cultural organization.

We agree with Chater and Christiansen's account of cultural complexity as emerging through local, path-dependent processes of "social tinkering," in which practices are iteratively modified rather than centrally designed. Their framework provides a powerful explanation of how large-scale cultural organization can arise without global planning. We believe this account can be further extended and sharpened by specifying both (i) a minimal cognitive prerequisite for the origin of cumulative cultural evolution and (ii) a simple, formally explicit account of how interacting cultural elements stabilize into coherent cultural systems. Across both extensions, we adopt a minimal-principles perspective: relatively simple mechanisms, when made explicit and combined, can generate the large-scale complexity described in the target article.

First, we suggest that faithful representation and mental manipulation of sequences constitute key cognitive prerequisites for cumulative culture. While many non-human animals exhibit social learning and traditions, there is substantial evidence that they are limited in their ability to represent and recall ordered sequences of stimuli (Ghirlanda, Lind, & Enquist, 2017; Lind et al., 2023; Lind et al., 2025; Reindl et al., 2025). Even in skilled learners with considerable control over vocal production, such as great apes, the absence of combinatorial, speech-like systems seems to reflect constraints on sequence representation rather than on motor abilities (Ekström et al., 2025a; Lind et al., 2023). This limitation has far-reaching consequences. Without the ability to encode and reproduce sequences faithfully, innovations cannot be reliably preserved, recombined, or built upon across generations. As a result, cultural processes remain shallow and fail to accumulate (Lind, in press).

Computational models help clarify what changes when this constraint is relaxed. Introducing mechanisms for faithful sequence representation (allowing ordered combinations of elements to be encoded and retrieved) leads to qualitatively different outcomes. While more limited approximate mechanisms perform well in environments lacking sequential structure, they fail to exploit information distributed across sequences. Sequence-based mechanisms, in contrast, can make use of such information, but at substantial learning costs, requiring constrained and flexible representations (Jon-And et al., 2023). Building on this, recent

modeling work shows that when agents equipped with such minimal sequence-representation capacities are exposed to structured input, higher-order regularities can emerge gradually, without being pre-specified (Jon-And & Michaud, 2024, 2026). These results illustrate how a minimal change in representational capacity can transform the dynamics of cultural transmission.

From this perspective, sequence representation provides a cognitive substrate that makes cumulative "tinkering" possible in the first place. It enables the faithful transmission of ordered behaviors, the recombination of existing elements into novel structures, and the emergence of hierarchical organization. The proposal that limitations in sequence representation form a bottleneck for non-human cognition synthesizes these findings and highlights their broader implications for the evolutionary transition to human culture (Enquist, Ghirlanda, & Lind, 2023; Lind & Jon-And, 2025). Importantly, this approach makes the costs and benefits of sequence representation explicit and formally tractable, providing a principled account of why such a capacity may have evolved uniquely in humans (Jon-And et al., 2023).

Second, the systemic side of social tinkering can be made formally explicit by modeling cultural systems as networks of interacting traits subject to simple local update rules (e.g., Jansson et al., 2021). Chater and Christiansen emphasize how cultural elements constrain and support one another, forming structured systems without centralized design. In a cultural-systems framework, such elements evolve not in isolation but as parts of systems in which their persistence depends on compatibility with other elements and where lower-level elements can scaffold and constrain the formation of higher-level structures. Such relations among traits may also be culturally emergent apart from logical, physical, or ecological constraints fixed in advance (Jansson & Hattiangadi, 2026).

This applies across levels of organization, from low-level elements such as phonemes in language (Ekström et al., 2025b) to higher-level systems involving traits such as norms and beliefs (Galesic et al., 2021; Jansson, in press). Interdependencies in such systems can generate stable configurations as well as sudden systemic shifts when local changes propagate through the network (Buskell, Enquist, & Jansson, 2019; Jansson et al., 2021; Jansson, in press). These dynamics provide a minimal and mechanistic account of how distinct yet coherent systems, such as languages, worldviews, and institutional structures, can emerge from decentralized processes.

A key feature of this approach is that existing cultural systems act as local compatibility filters: traits that fit with other traits are more likely to persist and spread, while incompatible traits are filtered out (Jansson et al., 2021). This creates path dependence and stability, but also the potential for rapid transformation when constraints shift. Some cultural traits may also be regulatory, reshaping the conditions for later tinkering and transmission, including the culturally acquired "cognitive gadgets" through which people learn and think (Acerbi et al., 2009; Enquist et al., 2024; Heyes, 2018). These models capture, in simplified and formal terms, how local interactions between traits and agents give rise to global structure and how existing cultural systems reshape the space of possibilities for later tinkering.

These two extensions – sequence representation and the cultural-systems view – are closely linked. Sequence representation enables the faithful transmission and recombination of cultural elements at the individual level, while system-level interactions determine which combinations persist, stabilize, and scale. Together, they provide a multi-level account, grounded in a complex-systems perspective, in which minimal cognitive assumptions and simple interaction rules are sufficient to generate complex cultural organization (Michaud & Enquist, in press).

A central implication of this approach is the value of minimal, explicit modeling. By specifying assumptions clearly, whether about cognitive representations or social interactions, we can test whether they are sufficient to generate the observed cultural phenomena. In this way, complex cultural organization can be understood as emerging from simple mechanisms through bottom-up processes, without invoking rich innate structure or centralized control. This is fully consistent with Chater and Christiansen's account of social tinkering while adding two complementary principles: the minimal cognitive ingredients required for cumulative culture and the formal interaction principles by which cultural elements become organized into systems.

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Beyond social tinkering: Toward a mechanistic and multilevel theory of cultural complexity

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Abstract

Chater and Christiansen argue that cultural complexity arises through social "tinkering." While compelling, this framework remains mechanistically underspecified. Integrating recent empirical and theoretical advances, this commentary proposes that cultural complexity emerges from interactions among transmission dynamics, cognitive constraints, social network structure, and environmental pressures and calls for a formalized, testable multilevel theory.

Chater and Christiansen propose that cultural complexity emerges primarily through processes of "social tinkering," rather than from individual cognitive sophistication. This perspective aligns with a substantial body of research demonstrating that cumulative culture arises through repeated cycles of social transmission and refinement (Caldwell, Renner, & Atkinson, 2018; Derex & Boyd, 2016). These findings support the view that complex cultural systems can emerge even when individual cognitive capacities are limited, shifting the explanatory focus from individual intelligence to collective dynamics.

A key strength of the target article is its emphasis on distributed processes. By framing cultural evolution as an emergent property of population-level interactions, the authors challenge accounts that locate complexity within individual cognition. Experimental work shows that iterative transmission can generate increasingly structured cultural forms (Caldwell et al., 2018), while partially connected networks can optimize the balance between innovation and retention (Derex & Boyd, 2016). Together, these findings suggest that cultural complexity depends less on individual brilliance than on the structure and dynamics of social interaction.

The concept of "social tinkering" also effectively captures the incremental and path-dependent nature of cultural change. Cultural traits are rarely engineered de novo; instead, they are modified, recombined, and repurposed over time. This framing resonates with broader evolutionary principles, emphasizing gradual adaptation through variation and selective retention. As a descriptive metaphor, it provides an intuitively appealing account of how complex systems can emerge from simple, local adjustments.

However, the concept remains theoretically under-specified. As presented, "social tinkering" functions more as a heuristic than a formal explanatory framework. Existing cultural evolution theory offers more explicit accounts of variation, selection, and retention (Acerbi & Mesoudi, 2015; Wilson, 2016), whereas the present framework lacks comparable mechanistic detail. It does not clearly specify when tinkering leads to cumulative complexity versus stagnation or loss, nor how different sources of variation – such as innovation, error, or recombination – interact with selective pressures. Without such specification, it is difficult to derive testable predictions or evaluate the theory's explanatory scope.

A second limitation concerns the role of individual cognition. Although the authors intentionally downplay cognitive sophistication, individuals do not passively transmit information; they actively transform it through biases in memory, inference, and learning. These transformations introduce systematic structure into cultural transmission, shaping both its direction and stability. Empirical studies show that cognitive constraints influence which cultural variants are generated and retained (Gutchess & Rajaram, 2023). For example, memory biases can favor certain patterns, while inferential processes may regularize noisy inputs. Cultural complexity, therefore, reflects not only social processes but also the structured ways in which individuals process and reproduce information.

Third, cultural dynamics are strongly shaped by social network structure. Transmission occurs within networks that constrain who interacts with whom and how information flows. Network properties – such as clustering, modularity, and centralization – can significantly influence cultural accumulation (Cantor et al., 2021). Highly clustered networks may stabilize local traditions, whereas more diffuse networks may accelerate diffusion. Central individuals may disproportionately shape outcomes by acting as hubs of transmission. These findings suggest that social tinkering is not uniform but depends on underlying interaction structures, which should be incorporated into the framework.

Fourth, the framework does not sufficiently account for environmental and ecological influences. Cultural evolution is increasingly understood as an adaptive process shaped by interactions between social learning and environmental pressures. Cultural traits often persist because they solve context-specific problems, and their transmission depends on ecological relevance. Empirical evidence shows that resource constraints and environmental conditions shape cultural practices (Meehan et al., 2023),

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