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Editorial: Systems thinking in biology teaching and learning

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Editorial on the Research Topic
Systems thinking in biology teaching and learning

Biology is, without question, uniquely challenging to teach. Of the core STEM fields represented in most K-12 and college curricula - chemistry, physics, math, and biology - only biology requires foundational principles from the other three to explain its concepts and phenomena, while none of the others requires biology to understand theirs. In addition, biology stands alone in terms of its pace of discovery and innovation. In recent decades, high throughput technologies and transformative research methods have amplified our capacity to conduct research that simultaneously spans scales of molecules to ecosystems and seconds to millenia, creating a perpetual surge of information that is transforming our understanding about how life works. At the same time, we have been witness to the unfolding of global-scale crises, such as pandemics, climate change, and food insecurity, that share in common having foundations in biological principles. This confluence of factors has led to increasingly unrealistic expectations in terms of the number and breadth of concepts we feel compelled to teach in biology classrooms. Indeed, the sheer volume of concepts contained in most introductory texts now exceeds the capacity of most humans to know and understand. Our instructional paradigm must therefore shift from one that aspires to cover ever larger swaths of content to one that focuses on developing skills that enable students to manage the complexity of the discipline, its rapid evolution, and its connections with complex socio-scientific issues.

For biology, systems thinking represents a way of leveraging the unique attributes of the discipline itself to describe the most productive ways of thinking about it. As "the study of living systems," we might reasonably expect biology to privilege systems perspectives and systems thinking as explicit educational aims. Although guiding frameworks such as Vision and Change (Brewer and Smith, 2011) and Next Generation Science Standards (National Research Council, 2013) identify thinking in and about systems as uniquely important for training in life sciences, these remain underrepresented in biology curricula and classrooms, particularly in the United States. We believe this has much to do with a lack of consensus about what systems thinking is and what it means to teach and assess it.

Frameworks have been published for biology that aim to define systems thinking in terms of the constituent skills that comprise it (e.g., Assaraf and Orion, 2005; Sommer and Lücken, 2010; Momsen et al., 2022). However, system thinking is not merely a set of skills to be taught, but a way of thinking that emerges from explicitly framing biological problems from a systems perspective (Verhoeff et al., 2018). This means thinking beyond the agents and players of a system to focus, instead, on their interactions, the contexts in which they occur, and the processes that govern them. In this Research Topic, we sought to build on the momentum for generating clarity about what systems thinking means in biology education and how we might consider modifying our instructional approaches to promote it. The four papers we include here represent diverse approaches to the subject and appear to lend support for Gouvea's argument about the necessity of divergent thinking as a precursor to convergence.

Gouvea and Chi approach the subject of what it means to think in systems from a mechanistic perspective and describe models of learning that explain how systems thinking could manifest. While both leverage misconceptions as a contrast with systems thinking, each takes a very different view of how and why these forms of thinking arise and persist. Gouvea describes a fundamental model of learning that aligns biology and cognition using a dynamic systems perspective. She expands on Di Sessa's Knowledge in Pieces (Di Sessa, 1988, 2018) by emphasizing the role of contextual sensitivity and dynamic nature of relationships among conceptions. Concepts reside in broader, complex systems of ideas that vary in the strengths of their connections and scientific plausibility. Patterns (whether misconceptions or canonical knowledge) emerge when networks of ideas are elicited together in response to contextual cues. In contrast, Chi argues that misconceptions are linked to fundamental misunderstandings about the nature of biological processes. She proposes a generalizable knowledge structure in which learners intuitively reason about biological processes as series of sequential events that unfold in response to a singular driver or agent, rather than complex networks where processes emerge from the collective actions of multiple interacting components.

Yoon et al. and Jordan et al. approached the subject from a different perspective - that of the biology classroom. Yoon et al. focus on practical applications of systems thinking aimed at developing student reasoning about biological problems in the broader context of complex socioscientific issues (SSIs). Their work identifies challenges with reasoning about SSIs stemming from the inherent nature of complex systems and contributes a suite of evidence-based design principles that intentionally foster students' engagement with systems thinking. Jordan et al. similarly point to the ideological and emotional power of SSIs as well as the additional cognitive complexity they bring to biological science. Their work explores the use of MentalModeler, a fuzzy cognitive mapping software, as an educational tool for supporting learners as they grapple with multifaceted, and often, emotionally-charged environmental issues by considering problems from multiple perspectives and across temporal and spatial scales.

The diverse views and perspectives reflected in the four works of this Research Topic suggest we are only in the earliest phases of understanding how systems thinking develops and how best to integrate it as a core feature of biology instruction. Despite this variation, we see strong consensus about the value of building biology learners' capacities for thinking and reasoning from a systems perspective. Systems-centric approaches emphasize connecting ideas rather than amassing them, and can situate concepts within larger social contexts where students' individual values and experiences can expand a system's boundaries and provide multiple access points from which they can engage. We look forward to moving the field forward through continuing conversations that link theory and practice, inform best practices in biology classrooms, and foster opportunities for meaningful sense-making in an increasingly complex milieu of biological systems.

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Conflict of interest

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