FEATURE ARTICLE

Ways of Knowing in the Life Sciences and Connections to the NGSS Practice-Crosscutting Concept Pairs and Groups

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Abstract

The Next Generation Science Standards (NGSS) engage students in the epistemic, or knowledge building, components of science through three-dimensional learning. Each scientific domain has its own epistemic aspects that result from different social groups going about science in different ways to conceptualize different bodies of knowledge; education researchers recommend that these be included in science education. While the Science & Engineering Practices and Crosscutting Concepts of the NGSS apply to all sciences, they can be combined in ways that reflect the domain-specific aspects of the life sciences. In this paper, we define and describe simplified epistemic themes, or ways of knowing, within the life sciences for educators to use as a guide when creating lessons and units. Then, we outline example Practice-Crosscutting Concept pairs and groups that curriculum developers can use in learning performance statements to reflect these ways of knowing.

Key Words: *NGSS; curriculum development; science education; life sciences; learning performance statement.*

○ Introduction

The Next Generation Science Standards (NGSS; NRC, 2012; NGSS Lead States, 2013) define statements of student performance that integrate one Disciplinary Core Idea (DCI), one Science & Engineering Practice (Practice), and one Crosscutting Concept (CCC). This is the basis of three-dimensional learning (Krajcik et al., 2014).

Three-dimensional learning engages students in the epistemic components of the scientific process, or the knowledge building aspects of science (Duschl, 2008; Jiménez-Aleixandre & Crujeiras, 2016; NGSS Lead States, 2013). These include how scientists perceive the world, and the methods and cognitive tools that they use in inquiry. Different social groups go about science in different ways to conceptualize various bodies of knowledge, so each scientific domain has their own epistemic aspects (e.g., Erduran & Dagher, 2014; Kelly & Licona, 2018; MacLeod, 2018; Stroupe, 2015). We refer to these as the ways of knowing for each scientific domain (after Price, 2023). Some researchers suggest that these domain-specific epistemic aspects are essential for knowledge building in science and should be included in science education and curriculum development (e.g., Duschl, 2008; Erduran, 2007; Goldman et al., 2018; Kelly & Licona, 2018). Further, Kelly and Licona (2018) state that “domain-specific epistemic practices necessitate different pedagogical methods” (p. 151).

Three-dimensional learning engages students in the epistemic components of the scientific process, or the knowledge building aspects of science.

Best practices for making NGSS-aligned curricular materials advocate for each lesson to have a learning performance statement (Krajcik et al., 2014; NSTA, 2014). A lesson will target an NGSS performance expectation as the standard, but the lesson should not directly teach to that performance expectation. Instead, teachers and curriculum developers commonly choose a CCC and/or Practice different from those used for the NGSS performance expectation standard. They then combine the DCI of the standard with their chosen CCC and Practice to make a new three-dimensional learning statement, referred to as the learning performance statement, that more closely matches what students are doing and learning in their lesson.

Price (2023) argues that the domain-specific epistemic aspects of science can be incorporated into lessons and units through the choice of Practices and CCCs in the learning performance statements. They detail the ways of knowing for the Earth & Space Sciences and provide Practice-CCC pairs and groups that represent these. In this paper, we extend this idea to the life sciences. We define domain-specific aspects of biology that represent themes in the ways of knowing in the life sciences. Then we propose Practice-CCC pairs and groups to reflect these.

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○ Ways of Knowing Themes in the Life Sciences

Using the philosophy of science, nature of science, and biology education literature, we grouped the ways of knowing for the life sciences into eight themes that represent epistemic aspects of biology (Kelly & Licona, 2018). We summarize these below.

Multiple Modes of Inquiry

Biological investigations involve the study of life over a range of temporal and spatial scales and processes that occur in cycles and within systems. This broad range requires different investigation methods, or modes of inquiry. Laboratory-based or controlled variable experiments are relevant for present life forms or systems at temporal or spatial scales that can be directly manipulated (Mayr, 2004). Observational investigations are important for life forms or systems that existed in the past, experienced change over a longer time scale, or that cannot be directly or easily manipulated in the present because of complexity or size (Turner, 2021). In model-based investigations, biologists use conceptual or computational models to represent and test complex biological systems as well as to simulate and manipulate life components not appropriate for laboratory investigation (e.g., too small, ethical concerns) (Takacs & Ruse, 2013). Finally, math-based investigations are important for defining, predicting, and understanding change through probability and statistics, such as for population dynamics, genetics, and evolution/cladistics.

Order & Classification

It is necessary to define, group, and separate aspects of life in order to investigate similarities and differences, functions, and relationships (Bard & Rhee, 2004). Human brains have a natural tendency for organization, to make groupings based on such things as similarity, proximity, and continuity (Wagemans et al., 2012). Ultimately, these orders and classifications must have a scientifically meaningful basis. The evidence-based process of creating and then evaluating groupings is an important sense-making step. Discussions on the scientific meaning of observational groupings (i.e., perceptual organizations) was a point of discussion for early biologists, anatomists, and naturalists (e.g., Huxley vs. Darwin; Winsor, 2021). Biologists define individual parts of systems so that they can investigate the features and functions of each part and interrelationships among parts (Frost & Kluge, 1994). Classifications help to define and contextualize similarities and differences among the units of life, such as species and populations, which is important for documenting change through time (Hoehndorf et al., 2015). Finally, the act of organizing life and its systems is essential for investigating the hierarchical nature of life (Moore, 1993).

Systems Thinking

Systems thinking is present in numerous areas of biology. In systems thinking, biologists conceptualize aspects of life as interconnected parts that have their own characteristics and functions that work together to contribute to the larger network or entity. Mapping the components, relationships, and pathways of the system, including between scales, helps biologists to both compartmentalize and study the parts as well as investigate the functioning of the whole (Guo, 2006). Biologists use system maps to study the energy and matter transfer within the system. Systems thinking helps biologists to conceptualize how the many individual parts work together to produce a result, such as human life functions from smaller-scale biochemical processes and the functioning of an ecosystem (Chamany et al., 2017). Systems thinking also helps biologists understand how instability in those parts leads to change within the larger system.

Causal & Functional Relationships

The aspects of the living world are commonly viewed through a causal or functional lens. This shapes how investigations are designed, models are structured, and data are analyzed. Parts of a living system or ecosystem serve a function, and that function shapes both the nature of the part and the functioning of the whole. If there is a change in a system, then there is some cause for that effect. Biologists look for, test for, and explain life relative to these causal and functional relationships (Bard & Rhee, 2004; Turner, 2021). Once defined, they can look for the mechanisms and drivers of those relationships. Applying an understanding of functional and causal relationships allows biologists to deduce past and predict future change as well as to investigate the reason for instability in a system (Freese et al., 2003).

Scales & Hierarchy

Scalar thinking in biology is important for understanding life within and between different spatial scales and organizational scales (Jin & Liu, 2021). Life systems have parts at the finer scales that progressively combine to contribute to the functioning of the system at larger spatial scales (e.g., cells, organs, systems, body) (Chamany et al., 2017). Because the properties and functions of the parts are unique to each spatial scale, a scale-specific perspective is important when studying each part and how they relate to the whole. Hierarchy-based organizational scales are a fundamental aspect of organizing and classifying life systems. Organizational structure is also important in ecology, where use of a hierarchy aids in the study of the larger ecosystem (i.e., organism, population, community, biome, biosphere; Miller, 2008).

Scalar thinking also involves the scale of time, both for defining the time scale of observation and investigating change over time. The time scale at or over which an observation is made is an important consideration for analyzing patterns that cross different dimensions of time and when distinguishing the driving forces behind phenomena that span short- and long-term time scales (Valde, 2019). Ecosystem studies analyze a mixture of time scales to represent change within parts of the whole, connecting micro- and deep-time scales that describe two levels of change that occur simultaneously (Levin, 1992).

Representation & Visualization

Representational models and other visualizations are tools for studying life systems and communicating biological concepts. System models show the components, relationships, and pathways in a life system in a way that can make abstract conceptions visible (Kosslyn et al., 2002). These models also help biologists deal with system complexity in a way that focuses their inquiry and helps them identify emergent properties of the system (Jin & Liu, 2021). Similarly, representations of taxonomic or ecological hierarchies not only show the relational levels but are also tools for biologists to work out evolutionary relationships (e.g., evolutionary trees, cladograms). Finally, many biological processes involve scales that are not directly observable (e.g., molecules, cells) or involve changes over time, aspects best communicated with a representation or visualization.

Ethical Thinking

Biological investigations have direct application and implications for human society. Because of this, biologists bring philosophical and social considerations to the way they conduct investigations and how knowledge is applied. This ethical thinking stems from how we define our role and connection as humans to the environment, other people, and society as a whole. Guidelines are in place for ethical laboratory methods, use of test subjects, and for how and when an experiment or procedure might continue after negative impacts are identified. Ethical thinking around applied biological knowledge (e.g., genetic engineering) involves determining the likely impact from each option or solution, determining which values are upheld through each choice, evaluating and deciding which choice is best, and defending the decision (Johansen & Harris, 2000). Because different sets of beliefs are considered, ethical decisions do not always have a right or correct answer. Ethical thinking can influence student perspectives on the knowledge being presented and change how students choose to learn biology (Dedecker, 1986), and teachers can help students develop an ethical decision-making process.

Historical Change in Inquiry & Concepts

The life sciences and biological investigations have been around since the time of the Roman and Greek civilizations. Over that time, philosophical, social, and cultural considerations have repeatedly changed, influencing how investigations were done, and how data and observations were interpreted. Since biology has no definite end and continuously develops through time, ways of studying life have progressed systematically alongside human beliefs (Mayr, 2004; Turner, 2021). Methods of inquiry have also changed with technological innovation (Takacs & Ruse, 2013), introducing new fields of study (e.g., genetics), expanding the scale of investigation (e.g., nanotechnology to satellites), providing new investigative capabilities (e.g., computational methods), and increasing the interdisciplinary nature of the field. When studying biology, a historical perspective is needed in order to appreciate how our understanding of phenomena and life processes has developed and changed alongside changes in human attitudes and beliefs as well as changes and innovations in inquiry methods (Lombrozo et al., 2006).

○ Suggested Practice-CCC Pairs & Groups for the Life Sciences Ways of Knowing Themes

We provide example Practice-CCC pairs and groups in Table 2 that communicate the ways of knowing in the life sciences. See Table 1 for abbreviations. For each example pair or group, we provide a lesson idea to show how that pair or group can be combined with a DCI topic category (as outlined in NSTA, 2023; after NGSS Lead States, 2013). Curriculum developers and educators can use these Practice-CCC pairs and groups as a starting point or guide when choosing Practices and CCCs for a lesson and when writing learning performance statements. We also include suggested Practice-CCC groups for when a variety of Practices and CCCs might be more appropriate, as is consistent with recommendations for NGSS lesson development (e.g., Krajcik et al., 2014). Curriculum developers and educators can achieve these by weaving learning performance statements together in an inquiry pathway from lesson to lesson in a larger unit.

Table 1. Abbreviations for the NGSS Science & Engineering Practices and Crosscutting Concepts.

Science & Engineering Practice (Practice)	**Abbreviation**
Asking Questions & Defining Problems	Questions
Developing & Using Models	Models
Planning & Carrying Out Investigations	PCOI
Analyzing & Interpreting Data	Data
Using Mathematics & Computational Thinking	Math-Comp
Constructing Explanations & Designing Solutions	Explanations
Engaging in Argument from Evidence	Argument
Obtaining, Evaluating, & Communicating Information	OECI
Crosscutting Concept (CCC)	**Abbreviation**
Patterns	Patterns
Cause & Effect	C&E
Scale, Proportion, & Quantity	SP&Q
Energy & Matter	E&M
Systems & System Models	Systems
Stability & Change	St&Ch
Structure & Function	S&F

Table 2. Suggested Practices, Crosscutting Concepts, and Practice-Crosscutting Concept Pairs and Groups for the Life Sciences Ways of Knowing.

Multiple Modes of Inquiry
Practices: Models, PCOI, Data, Math-Comp *CCCs:* Patterns, C&E, SP&Q, St&Ch, S&F *Example Pairs & Groups:* • Math-Comp/Data + Patterns: Observational or statistical investigation of existing datasets Example for DCI-Interdependent Relationships in Ecosystems: Query population survey datasets to show how population numbers are connected to changes in resource availability. • PCOI/Data + C&E/E&M: Plan an investigation/Use existing datasets to test cause and effect relationships or the movement of matter and energy in life systems Example for DCI-Interdependent Relationships in Ecosystems: Investigate data from population survey datasets to test a prediction about predator-prey relationships. • PCOI + Patterns + S&F: Observational investigation of fossils or biological specimens Example for DCI-Natural Selection & Evolution: Document the morphological characteristics of fossil specimens and make comparisons to modern organisms to predict their adaptive function. • Math-Comp/Models + Systems/SP&Q: Computational/model-based investigation of a system Example for DCI-Structure & Function: Use a representative model to map the ways in which feedback mechanisms affect the body system.
Order & Classification
Practice: Questions, Data, Explanations, Argument, OECI *CCC:* Patterns, C&E, SP&Q, Systems, S&F *Example Pairs & Groups:* • Data + Patterns: Use data to define, organize, or revise groupings of order and classification Example for DCI-Natural Selection & Evolution: Use new population data or fossil samples to evaluate/revise species groupings and their defining criteria. • Data/Argument + SP&Q: Consider scale in the construction and evaluation of orders and classification Example for DCI-Interdependent Relationships in Ecosystems: Evaluate how scale affects what is included in an ecosystem and how it is defined. • Explanations/Argument + C&E/S&F/Systems: Explain/justify groupings into orders or classifications relative to scientific phenomena Example for DCI-Inheritance & Variation of Traits: Argue that two populations should be divided into two separate species based on morphological, behavioral, and/or genetic differences.
Causal & Functional Relationships
Practice: Questions, Models, PCOI, Data, Explanations, Argument *CCC:* Patterns, C&E, E&M, Systems, St&Ch, S&F *Example Pairs & Groups:* • Argument + St&Ch + C&E/S&F: Explain/Predict change in a life system using knowledge of causal and functional relationships. Example for DCI-Natural Selection & Evolution: Make an argument for how natural selection on structural or behavioral adaptations could drive evolutionary changes. • Questions + C&E/S&F: Explain/Ask questions about how and where causal and functional relationships play a role in life systems. Example for DCI-Structure & Function: Ask questions about how human body systems work through positive and negative feedback to maintain homeostasis. • Explanations + Patterns + C&E/S&F: Explain how patterns in data indicate causal or functional relationships in life systems. Example for DCI-Matter & Energy in Organisms & Ecosystems: Use protein presence/abundance data to make connections between patterns of DNA expression and the production of proteins.

Table 2. *Continued*

Scales & Hierarchy
Practice: Models, Data, Math-Comp, Explanations *CCC:* Patterns, C&E, SP&Q, E&M, Systems, St&Ch, S&F *Example Pairs & Groups:* • Explanations/Models + Patterns + SP&Q: Define the characteristics of each scale in the body system and distinguish how they are different. Example for DCI-Structure & Function: Use a model to define the features of the cellular, tissue, and organ scales within a body and to explain the differences among them. • Explanations/Models/Math-Comp + SP&Q + St&Ch/C&E: Use a model to show/explain how changes in phenomena of one scale impact results of phenomena in a different scale. Example for DCI-Matter & Energy in Organisms & Ecosystems: Use a model of energy flow within a food web to show the impact of food availability and predation on the whole ecosystem. • Math-Comp/Models + E&M/Systems: Show how energy and matter move within and between scale levels of a system. Example for DCI-Matter & Energy in Organisms & Ecosystems: Using algebraic expressions (i.e., mathematical model) to represent the movement of energy within and between trophic levels of an ecosystem.
Representation & Visualization
Practice: Models, Data, Math-Comp, Explanations, OECI *CCC:* Patterns, C&E, SP&Q, Systems, E&M, St&Ch, S&F *Example Pairs & Groups:* • OECI/Models + Systems/E&M: Create a representation of a complex life system to show pathways and connections within the system. Example for DCI-Interdependent Relationships in Ecosystems: Create a system model to show the interdependent pathways of energy and matter movement in an ecosystem. • Math-Comp + SP&Q + St&Ch: Create a mathematical or computational model to show the scale of change in a disturbed ecosystem or other life system. Example for DCI-Interdependent Relationships in Ecosystems: Use an algebraic model (or computational simulation) to investigate how the scale of a natural or anthropogenic disturbance impacts the floral and faunal composition in an ecosystem. • Explanations/OECI + C&E/SP&Q: Use visual representations to show and explain causal pathways in biological processes between scales. Example for DCI-Matter & Energy in Organisms & Ecosystems: Create a visual representation to show the functional connections among the different scales in the body (i.e., cells, tissues, organs). • OECI + Patterns: Visually represent the organization and relationships within hierarchies. Example for DCI-Natural Selection & Evolution: Use phylogenetic trees to represent the relationships among organisms.
Ethical Thinking
Practice: Questions, PCOI, Explanations, Argument, OECI *CCC:* Patterns, C&E, SP&Q, Systems, St&Ch *Example Pairs & Groups:* • PCOI + C&E: Evaluate an investigation plan taking into account ethical considerations. Example for DCI-Inheritance & Variation of Traits: Evaluate the experimental design for tests of drug effectiveness relative to the choice of test subjects and their safety. • Explanations + C&E: Take into account ethical considerations when designing solutions. Example for DCI-Interdependent Relationships in Ecosystems: Consider environmental impacts when designing food production systems (i.e., artificial ecosystems for food production). • Explanations/Argument + St&Ch/Systems: Explain how choices in inquiry methods or human actions may have positively or negatively affected the body system or the environment. Example for DCI-Interdependent Relationships in Ecosystems: Explain how and why the evidence-based argument against the widespread use of DDT changed public policy. • Questions/OECI/Argument + Systems/C&E: Ask questions about the role of humans and human actions on the environment or life systems. Example for DCI-Structure & Function: Ask questions about the types of data patterns that could represent negative impacts of smoking or certain foods on the body systems.

Table 2. *Continued*

Historical Change in Inquiry & Concepts
Practice: Questions, Models, Math-Comp, Explanations, Argument, OECI *CCC:* Patterns, St&Ch *Example Pairs & Groups:* • Explanations + Patterns: Compare cross-breeding methods with newer DNA-based investigation methods to explain how changes in populations were documented over time. Example for DCI-Natural Selection & Evolution: Explain how the divisions of species/subspecies (pedigree analysis) have changed over time with the incorporation of genetic analysis (e.g., dogs, giraffes). • Models + Math-Comp + St&Ch: Show how computational models of ecosystems support model-based explanations of stability and change. Example for DCI-Matter & Energy in Organism & Ecosystems: Use data from computational carbon cycle models as evidence to show how increasing atmospheric carbon will affect the biosphere. • OECI + Explanations/Argument + St&Ch: Research and explain how the understanding of a taxonomic characterization changed or was updated with new genetic information. Example for DCI-Natural Selection & Evolution: Research and explain how the morphological-based classification of birds was changed by new genomic analyses. • Questions/OECI + Patterns: Ask questions about how the patterns observed in fossils were used to argue for a model of life development in different historical times. Example for DCI-Natural Selection & Evolution: Ask questions about how a catastrophism viewpoint (e.g., global flood) would lead to a different interpretation of a fossil sequence than a uniformitarianism viewpoint.

○ Conclusions

The NGSS incorporate the epistemic components of science through three-dimensional learning. The Practice and CCCs apply to all of the scientific domains, but educators and curriculum developers still can capture the epistemic aspects of each individual scientific domain in the way they pair or group the Practices and CCCs in the learning performance statements of lessons and units. While the ways of knowing themes that we present here are simplified, our list and the descriptions can serve as a starting resource for those who want to incorporate the domain-specific epistemic components of the life sciences into lesson plans. In providing suggested Practice-CCC pairs and groups, we show the ways that the structure of the NGSS itself can be utilized in achieving this.

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References

Bard, J. B. L., & Rhee, S. Y. (2004). Ontologies in biology: Design, applications and future challenges. *Nature Reviews Genetics*, *5*, 213–222. https://doi.org/10.1038/nrg1295

Chamany, K., Allen, D., & Tanner, K. (2017). Making biology learning relevant to students: Integrating people, history, and context into college biology teaching. *CBE - Life Sciences Education*, 7(3), 267–278. https://doi.org/10.1187/cbe.08-06-0029

Dedecker, P. F. (1986). Biology and ethics: Their role in education for the 80s and beyond. *The American Biology Teacher*, *48*(5), 285–286. https://doi.org/10.2307/4448293

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education*, *32*(1), 268–291. https://doi.org/10.3102/0091732X07309371

Erduran, S. (2007). Breaking the law: Promoting domain-specificity in chemical education in the context of arguing about the periodic law. *Foundations of Chemistry*, *9*(3), 247–263. https://doi.org/10.1007/s10698-007-9036-z

Erduran, S., & Dagher, Z. (2014). *Reconceptualizing the nature of science for science education*. Springer.

Freese, J., Allen Li, J. C., & Wade, L. D. (2003). The potential relevances of biology to social inquiry. *Annual Review of Sociology*, *29*, 233–256. https://doi.org/10.1146/annurev.soc.29.010202.100012

Frost, D. R., & Kluge, A. G. (1994). A consideration of epistemology in systematic biology, with special reference to species. *Cladistics*, *10*(3), 259–294. https://doi.org/10.1006/clad.1994.1018

Goldman, S. R., Ko, M-L. M, Greenleaf, C., & Brown, W. (2018). Domain-specificity in the practices of explanation, modeling, and argument in the sciences. In F. Fischer, C. A. Chinn, K. Engelmann, & J. Osborne (Eds.), *Scientific reasoning and argumentation: The roles of domain-specific and domain-general knowledge* (pp. 121–141). Routledge. https://doi.org/10.4324/9780203731826

Guo, G. (2006). The linking of sociology and biology. *Social Forces*, *85*(1), 145–149. https://doi.org/10.1353/sof.2006.0126

Hoehndorf, R., Schofield, P. N., & Gkoutos, G. V. (2015). The role of ontologies in biological and biomedical research: A functional perspective. *Briefings in Bioinformatics*, *16*(6), 1069–1080. https://doi.org/10.1093/bib/bbv011

Jiménez-Aleixandre, M. P., & Crujeiras, B. (2016). Epistemic practices and scientific practices in science education. In K. S. Taber & Akpan B (Eds.), *Science education: An international course companion* (pp. 69–80). Sense Publishers. https://doi.org/10.1007/978-94-6300-749-8_5

Jin, D., & Liu, E. (2021). Designing a coherence- & concept based modular course to facilitate students' understanding of crosscutting concepts. *The American Biology Teacher*, *83*(5), 291–297. https://doi.org/10.1525/abt.2021.83.5.291

Johansen, C. K., & Harris, D. E. (2000). Teaching the ethics of biology. *The American Biology Teacher, 62*(5), 352–358. https://doi.org/10.2307/4450918

Kelly, G. J., & Licona, P. (2018). Epistemic practices and science education. In M. R. Matthews (Ed.), *History, philosophy and science teaching* (pp. 139–165). Springer. https://doi.org/10.1007/978-3-319-62616-1_5

Kosslyn, S. M., Cacioppo, J. T., Davidson, R. J., Hugdahl, K., Lovallo, W. R., Spiegel, D., & Rose, R. (2002). Bridging psychology and biology: The analysis of individuals in groups. *American Psychologist*, *57*(5), 341–351. https://doi.org/10.1037/0003-066X.57.5.341

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the next generation science standards. *Journal of Science Teacher Education*, *25*, 157–175. https://doi.org/10.1007/s10972-014-9383-2

Levin, S. A. (1992). The problem of pattern and scale in ecology: The Robert H. MacArthur award lecture. *Ecology*, *73*(6), 1943–1967.

Lombrozo, T., Shtulman, A., & Weisberg, M. (2006). The intelligent design controversy: Lesson from psychology and education. *Trends in Cognitive Science*, *10*(2), 56–57. https://doi.org/10.1016/j.tics.2005.12.001

MacLeod, M. (2018). What makes interdisciplinarity difficult? Some consequences of domain specificity in interdisciplinary practice. *Synthese*, *195*(2), 697–720. https://doi.org/10.1007/s11229-016-1236-4

Mayr, E. (2004). *What makes biology unique?: Considerations on the autonomy of a scientific discipline*. Cambridge University Press.

Miller III, W. (2008). The hierarchical structure of ecosystems: Connections to evolution. *Evolution: Education and Outreach*, *1*, 16–24. https://doi.org/10.1007/s12052-007-0016-5

Moore, J. A. (1993). *Science as a way of knowing: The foundations of modern biology*. Harvard University Press.

National Research Council (NRC). (2012). *A framework for K–12 science education: Practices, crosscutting themes, and core ideas*. National Academies Press.

National Science Teachers Association (NSTA). (2014). Designing units and lessons. Retrieved from https://www.nsta.org/designing-units-and-lessons. Accessed November 3, 2023.

National Science Teachers Association (NSTA). (2023). Access the next generation science standards by topic. Retrieved from https://my.nsta.org/ngss/AccessStandardsByTopic. Accessed November 3, 2023.

Next Generation Science Standards Lead States (NGSS Lead States). (2013). *Next generation science standards: For states, by states*. The National Academies Press.

Price, N. A. (2023). Practice-crosscutting concept pairs of the NGSS and ways of knowing in the earth & space sciences. *Journal of Geoscience Education*, *71*(2), 253–265. https://doi.org/10.1080/10899995.2022.2126652

Stroupe, D. (2015). Describing "science practice" in learning settings. *Science Education*, *99*(6), 1033–1040. https://doi.org/10.1002/sce.21191

Takacs, P., & Ruse, M. (2013). The current status of the philosophy of biology. *Science & Education*, *22*(1), 5–48. https://doi.org/10.1007/s11191-011-9356-1

Turner, J. H. (2021). *On human nature: The biology and sociology of what made us human*. Routledge.

Valde, K. G. (2019). *Philosophical perspectives on time in biology*. [Doctoral dissertation, Boston University]. OpenBU. https://hdl.handle.net/2144/39587

Wagemans, J., Elder, J. H., Kubovy, M., Palmer, S. E., Peterson, M. A., Singh, M., & Von der Heydt, R. (2012). A century of Gestalt psychology in visual perception: I. Perceptual grouping and figure–ground organization. *Psychological Bulletin*, *138*(6), 1172–1217. https://doi.org/10.1037/a0029333

Winsor, M. P. (2021). "I would sooner die than give up": Huxley and Darwin's deep disagreement. *History and Philosophy of the Life Sciences*, *43*(2), 53. https://doi.org/10.1007/s40656-021-00409-3

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