**The 4-Dimensional Ecology Education (4DEE) Framework**

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**I. Overview**

Here we outline the need, structure, and implications of a Four Dimensional Ecology Education (4DEE) curricular framework of essential ecological concepts and skills for undergraduates. The goal of this effort is to produce an *ESA-sanctioned* framework that can be useful to ecology educators, the ESA Board of Professional Certification process, environmental professionals, decision makers, and others.

With funding from two ESA Long-Range Planning grants, the 4DEE framework was developed over the past four years by an ESA task force comprised of current and past members of ESA’s Committee on Diversity and Education (CDE). The framework was vetted during three Special Sessions at ESA conferences, and at a Special Workshop held in Silver Spring, MD. During each session, the Task Force carefully listened to the feedback, and subsequently refined the framework to its current version.

**II. The Need for an ESA-Sanctioned Ecology Education Framework**

The need for ESA to address ecological literacy has been a significant topic of discussion and action by ESA leadership for three decades: 1986 - Paul Risser’s presidential address; 1991 - Sustainable Biosphere Initiative; and 2004 - ESA Ecological Visions Committee report. Collectively, ESA members and leaders have recognized and considered the need for guidelines for ecology curricula. The literature provides different attempts to define core ecological literacy (e.g., Klemow 1991; Orr 1992; Berkowitz et al. 1997, 2005; Jordan et al 2009; McBride et al 2013), through no consensus had emerged.

Efforts to develop a curricular framework gained urgency in the past decade. A report “Scientific Foundations for Future Physicians” (AAMC-HHMI 2009) failed to include ecology within the topics recommended for pre-med students. In 2013, a group representing ESA developed a Learning Framework for Ecology for *Course Source*, an online journal for evidence-based teaching resources for undergraduate life science, which was approved by the ESA Governing Board. The ESA Board of Professional Certification had also noted the usefulness of recognized standards for undergraduate ecology courses to streamline the review of applications for certification. During the past decade, the ESA Education and Diversity Programs Office has received requests for a society-endorsed set of concepts that should be taught, particularly at the undergraduate level. Notably, a number of other disciplinary professional societies (e.g. American Chemical Society, American Society for Microbiology, National Environmental Health Science and Protection Accreditation Council) recently posted society-sanctioned educational guidelines, including the British Ecological Society’s ecology standards.

**III. Goals and Structure of the 4DEE framework**

The 4DEE framework seeks to: 1) describe a set of concepts and practices central to ecology as requested by the membership, 2) inform students of the scope of ecology for future study and career goals, 3) describe core ideas (concepts) for practitioners seeking certification as ecologists, 4) inform and support instructors and education researchers seeking to incorporate ecology into their STEM education initiatives, 5) identify ecology practices and skills necessary for careers in today’s and tomorrow’s environmental workforce, and 6) establish ESA as the leader in ecology education. The framework focuses on undergraduate ecology in any disciplinary context and is readily scaled from K-12 to professional levels.

The four dimensions of the framework collectively contain 21 general topics (termed “*elements*”). The dimension of *Core Ecological Concepts* follows the widely recognized hierarchy of ecology presented in most ecology textbooks, including individuals, populations, communities, ecosystems, landscapes, biomes and biosphere. *Ecology Practices* include approaches and methods used in doing ecology, e.g. natural history, fieldwork, quantitative reasoning, computational thinking, designing and critiquing investigations, and collaboration. *Human-Environment Interactions* include dependence on the environment, human accelerated environmental change, how humans can use ecological systems to shape and manage resources/ecosystems/the environment, ethical dimensions and communicating and applying ecology. *Cross-Cutting Themes* include structure & function, pathways & transformations of matter and energy, systems, and spatial & temporal scales and processes (including evolution). Integration across the dimensions is a hallmark of the framework. The ultimate goal is for the four dimensions to be taught as integrated units, courses and curricula.

ESA’s 4DEE Framework is a dynamic set of ideas that must be revisited and revised periodically. It is not a mandate, but rather provides a set of recommendations for ecology curricula. The framework can be used both as a benchmark for instructors currently teaching undergraduate General Ecology and as a guide for instructors developing new courses. We look forward to learning with the community of ecology educators about the how the framework is useful and brought to life through a diversity of approaches to teaching and learning.

**IV. The Framework**

In Table 1 below, we provide an abbreviated version of the 4DEE Framework. An expanded version of the framework appears in the Appendix.

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| **Table 1. The overall 4DEE Framework**, comprising four dimensions and elements within each. |
| Dimension 1. Core Ecology Concepts |
| 1. Autecology |
| 1. Populations |
| 1. Communities |
| 1. Ecosystems |
| 1. Landscapes |
| 1. Biomes |
| 1. Biosphere |
| Dimension 2. Ecology Practices |
| * + 1. Natural history approach |
| * + 1. Fieldwork |
| * + 1. Quantitative reasoning and computational thinking |
| * + 1. Designing and critiquing investigations |
| * + 1. Working collaboratively |
| * + 1. Communicating and applying ecology |
| Dimension 3. Human-Environment Interactions |
| * + 1. Human dependence on the environment |
| * + 1. Human accelerated environmental change |
| * + 1. How humans can shape and manage resources/ecosystems/the environment |
| * + 1. Critical thinking about the values underlying environmental problems, challenges and opportunities |
| Dimension 4. Cross-Cutting Themes |
| * + 1. Structure & function |
| * + 1. Pathways & transformations of matter and energy |
| * + 1. Systems |
| * + 1. Space & time – Evolution, scale, stability and change, biogeography |

**V. Value of the 4DEE framework to the ESA membership and environmental workforce**

The 4DEE framework for undergraduate ecology curriculum addresses the requests from ESA members for teaching guidelines and guidelines for career preparation for a broad range of environmental careers. The framework not only guides instructors in developing curricula but also provides justification for associated laboratory materials and expenses (e.g., field trips). By providing explicit delineation of the ecological knowledge and skills expected, the model can be used in ESA’s professional certification process as a guideline for the type of information required of applicants to document their abilities.

For society in general, the 4DEE model communicates to the general public what ecology is, its interdisciplinary nature, and its use in policy and management. The model fosters an understanding of the role of science in critical public issues such as climate change and environmental justice. Importantly, the model is intended to increase the expectation of students and society, that ecological science is useful in developing and implementing public policy. The model allows ESA to be positioned as a leader in educational programming and professional development by 1) expanding membership and partnerships, 2) providing a foundation for the development of K-12 standards moving forward, and 3) helping to focus the development of ecology textbooks that include multiple dimensions in the teaching and use of ecology.

**V. Appendix: Detailed 4-DEE Framework**

In this section we provide a more detailed version of the 4DEE framework, with the sub-elements shown. A brief narrative describing and explaining each dimension is also given.

**A. Core Ecology Concepts** -

The list below covers an array of concepts critical to understanding ecology. It is based, in large part, on material presented in introductory ecology textbooks and thus, represents an inventory of core ecology concepts recognized a large number of authors (historical and current; see for instance almost every edition of Begon et al., Krebs, Molles, Odum, Ricklefs, Smith & Smith, etc). These concepts are used by many of us to construct our syllabi, to test student learning, and to shape our degree programs. This list of concepts is divided into seven groups: individuals, populations, communities, ecosystems, landscapes, biomes, and biosphere. Within each group is a set of related concepts, e.g. trophic levels, predation, food chain/web, energy flow, nutrient cycling, regulators.

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| Table 1. Core Ecology Concepts |
| 1. Autecology |
| * 1. Abiotic and biotic features of environment |
| * 1. Resources and regulators |
| * 1. Habitat and niche: fundamental – realized |
| 1. Population |
| * 1. Population dispersion |
| * 1. Exponential and logistic growth – cycles |
| * 1. Demography – life history |
| 1. Community |
| * 1. Habitat types: terrestrial – marine – aquatic – wetlands – soils |
| * 1. Species diversity – biodiversity – dominance |
| * 1. Competition – exploitation – interference – predation – mutualism |
| * 1. Stability – resistance – resilience – disturbance – steady state – fluctuate |
| * 1. Succession |
| * 1. Behavioral ecology |
| 1. Ecosystems |
| * 1. Trophic levels: Producers – consumers – decomposers |
| * 1. Predation: predator – prey – herbivore – carnivores |
| * 1. Food chain – food web – networks – grazing – detritus |
| * 1. Energy flow – productivity |
| * 1. Nutrient cycling – nutrients |
| * 1. Regulators – control from below/above – trophic cascades |
| 1. Landscapes |
| * 1. Patches – corridors – barriers |
| * 1. Gradients |
| c. Watersheds |
| 1. Biomes |
| * 1. Biome types: tundra, boreal forest, deciduous forest, grassland, shrubland, desert, tropical rainforest |
| * 1. Ecological consequences of latitude and elevation |
| 1. Biosphere |
| * 1. Biogeography at global level |
| * 1. Global climate change |

**B. Ecology Practices** -

This list of practices elucidates the basic components associated with the scientific process, e.g. making observations, collecting data, and generating and testing hypotheses (Moore 1993). It represents an essential description of approaches and skills used in and necessary for doing science, with particular attention to how ecological science is conducted. Clearly, many of these practices reflect general approaches used in most scientific disciplines (ref Brewer and Smith 2011, Table 2.1; NRC 2013) with some components unique to ecology.

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| Table 2. Ecology Practices |
| * + 1. Natural history |
| * + - 1. As an approach |
| * + - 1. Making observations and connections |
| * + 1. Fieldwork |
| * + - 1. Habitat assessment |
| * + - 1. Field identification and preservation (of at least one large taxon) |
| * + - 1. Spatial analysis (GIS, remote sensing) |
| * + 1. Quantitative reasoning and computational thinking |
| * + - 1. Statistics |
| * + - 1. Data skills: inputting and data-mining / meta-analysis/ data visualization |
| * + - 1. Computer skills: spreadsheets, “R” |
| * + - 1. Modeling and simulation |
| * + - 1. Informatics |
| * + 1. Designing and critiquing investigations |
| * + - 1. Study design, familiarity with basic modes of ecological inquiry (description, comparison, experimentation, modeling) |
| * + - 1. Evaluating claims |
| * + - 1. Argument from evidence |
| * + 1. Working collaboratively |
| * + 1. Communicating and applying ecology |

**C. Human-Environment Interactions** -

All of us acknowledge that every place on earth is impacted to some degree by humans (see Commoner 1971). The connections between humans and the environment were a unifying theme of ESA’s Sustainable Biosphere report (Lubchenco et al. 1991). In 2000, Crutzen and Stoermer suggested that the human effect on the environment was sufficiently significant as to constitute a new geological epoch, the Anthropocene. Recognizing this, Palmer et al. (2005) noted a "need to refocus the discipline towards research that ensures a future in which natural systems and the humans they include coexist..."and further, that "...ecologists must play a greatly expanded role in communicating their research and influencing policy and decisions that affect the environment." Over 1000 ESA members responded to the 2007 Vice Presidents’ Survey on Ecological Literacy, and nearly half of the essential elements of ecological literacy mentioned were related to human/environment interactions (McBride 2011). More recently, Lubchenco (2017) pointed to the need for greater engagement by scientists in addressing societal problems, e.g. “We must engage more vigorously with society to address the intertwined environmental and social problems that many have ignored, to find solutions, and to help create a better world.” To that end, educational efforts must ensure that ecology students- and even the discipline itself - attends to the interaction between humans and the environment.

The ideas listed here emphasize that bi-directional interrelationship between humans and the Earth’s biota and physical environment, with particular attention to the normative values underlying decision-making and policy (Collins et al. 2011, Jablonski, et al. 2015). Incorporating the human-environment interactions into the 4DEE framework recognizes that every place is shaped by humans and every human need is shaped by the environment. In order to address and solve today’s problems, this understanding is necessary--and critical.

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| Table 3. Human-Environment Interactions |
| * + 1. Human dependence on the environment |
| * + - 1. Ecosystem services (Daily 1997) |
| * + 1. Human accelerated environmental change - there is no pristine ecosystem nor total equilibrium |
| * + - 1. Anthropogenic impacts, intentional and unintentional |
| * + - 1. Global climate change |
| * + - 1. Environmental toxicology: biomagnification – bioconcentration |
| * + 1. How humans shape and manage resources/ecosystems/the environment |
| * + - 1. Urban ecosystems, urban ecology, urban-rural gradient |
| * + - 1. Agricultural ecosystems, agroecology, fisheries, forestry |
| * + - 1. Ecological engineering - biomimicry, ecology of gene drive systems |
| * + - 1. Natural resource management |
| * + - 1. Conservation biology |
| * + - 1. Ecological restoration |
| * + - 1. Ecological stewardship |
| * + 1. Ethical dimensions - critical thinking about the values underlying how we approach and address environmental problems, challenges and opportunities in environmental decision-making and policy |
| * + - 1. Environmental ethics - basic types of ethics and their sources/foundations (includes ecological |
| * + - 1. Sustainability as a normative, socially constructed, aspirational goal |
| * + - 1. Environmental justice |
| * + - 1. Ecological economics (Daly and Cobb 1990) |

**D. Cross-Cutting Themes -**

Many ecologically-related ideas and approaches do not fall neatly along the other three dimensions - interactions, practices, and especially the hierarchy of core concepts. Some interrelate to other areas of science, while others, although ecologically related, place different demands in how they are studied. Vision and Change in Undergraduate Biology Education (Brewer and Smith 2011) recommended that “all undergraduates need to understand” evolution, pathways and transformations of energy and matter, information flow, exchange, and storage, structure and function, and systems. Here, we focus on four elements that are often thought of as approaches or ways of thinking: pathways and transformations of matter and energy, structure and function, systems, and spatial and temporal. Because evolution is itself change over space and time, it has been placed within spatial and temporal.

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| Table 4. Cross-Cutting Themes |
| * + 1. Structure & Function |
| * + 1. Pathways & Transformations of Matter and energy |
| * + 1. Systems |
| * + 1. Spatial & Temporal |
| Scales |
| Stability & change |
| Evolution |
| Mutation |
| Microevolution |
| Macroevolution |
| Biogeography |
| Range – cosmopolitan / endemic |
| Native / alien / invasives |

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