Environmental Literacy Learning Progressions

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Abstract

In this paper we describe an iterative process that leads to successive "drafts" of three interconnected learning progressions, all sharing the goal of *environmental science literacy*—the capacity to understand and participate in evidence-based discussions of socio-ecological systems. This process involves three major components, each interdependent on the other two.

- *Defining the domain.* We define the domain in terms of (a) roles and practices associated with environmentally responsible citizenship, (b) processes involving changes at multiple scales in socio-ecological systems, and (c) identifying intellectual resources and habits of mind that support the practices of environmentally responsible citizenship.
- *Developing frameworks for data collection and analysis.* We want our learning progressions to describe student performances in this domain from upper elementary through high school. We have defined an "upper anchor" or target performances based on our reasoning about environmental science literacy and on student performance data. We have developed a framework for data analysis based on levels of student achievement and important practices.
- *Using data to identify trends and levels of student achievement.* Our analyses of student written assessment and interview data and our reading of relevant literature leads us to characterize the development of student performances in term of three general trends and seven levels of achievement. The trends include (a) becoming more aware of hidden mechanisms and larger systems, (b) developing better resources for measurement, classification, and description, and (c) learning to use scientific models and principles.

The primary purpose of our work so far has been to develop empirically grounded descriptions of trends and levels of student achievement. The papers presented at this conference report our progress. These papers also show how challenging it will be to develop a learning progression that leads to environmental science literacy. The current national standards are generally written about our Level 5 of student achievement. Level 5 falls short of fully functional environmental science literacy, yet virtually all the students in our samples fall short of Level 5.

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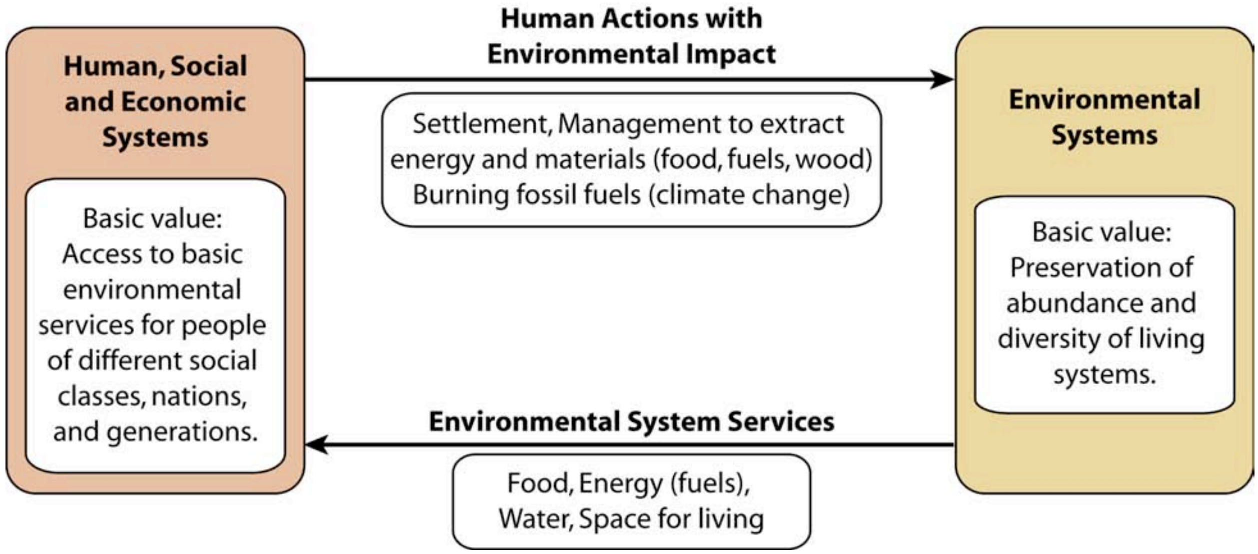

Figure 1: Structures and Processes of Socio-ecological Systems (Loop Diagram)

I. Accounts: Practices of developing accounts (e.g., narratives, models, principles) and using them to explain and predict phenomena in the domain)
   A. Carbon: Accounts of processes that create, transform, and oxidize organic carbon compounds in socio-ecological systems
      1. Tracing matter: Accounting for what happens to the "stuff" in these processes (Mohan, Chen, & Anderson, 2007; Wilson & Mohan, 2007)
      2. Tracing energy: Accounting for what makes things happen—or not happen (Jin & Anderson, 2007)
   B. Water: Accounts of processes that produce, move, and consume fresh water—and materials carried by fresh water (Gunckel, Covitt, Abdel-Kareem, & Anderson, 2007)
   C. Biodiversity: Accounts of processes that create, modify, and reduce genetic diversity in populations and species diversity in communities (Wilson, Zesaguli, Tsurusaki, Wilke, & Anderson, 2007)

II. Citizenship: Practices of making decisions about human actions that use environmental system services or have environmental impact.
   A. Knowledge: Connecting human actions with environmental systems (Tsurusaki & Anderson, 2007; Tsurusaki, Covitt, & Anderson, 2007)
   B. Practice: Making decisions about human actions (Tsurusaki, Covitt,& Anderson, 2007)

Figure 2: Framework for Organizing Student Practices

Table 1: Loop Diagrams for Carbon, Water, and Biodiversity

Part of Loop	*Carbon*	*Water*	*Biodiversity*
Environmental System Service (Bottom Arrow)	Fossil fuels, Food	Fresh water	Food, Land for living
Human Economic System (Left Box)	Fossil fuel distribution and consumption: energy and transportation systems	Water distribution and use for homes, industry, agriculture	Food distribution and consumption Land ownership and use
Environmental Impact (Top Arrow)	Carbon emissions and deforestation	Management of watersheds and ground water systems	Land use: Management for agriculture Settlement in cities, suburbs, exurbs
Large-scale Structures (Environmental Systems Box) (Note that each large-scale structure is associated with macroscopic and cellular/atomic-molecular structures.)	Trophic levels in ecosystems Fossil fuel production systems	Watersheds (surface water systems) Ground water systems Human engineered water systems	Natural and agricultural populations (more and less diverse in genetics, age, environmental effects on individuals) Natural and agricultural communities (more and less diverse in species, size of populations
Large-scale Processes (Environmental Systems Box) (These are usually fairly well balanced between creation and destruction in natural ecosystems) (Note that each large-scale process is associated with macroscopic and cellular/atomic molecular processes.)	**Processes that generate organic carbon:** photosynthesis **Processes that transform and move organic carbon:** food webs, digestion, biosynthesis, (human organic chemistry: plastics, etc.); carbon sequestration **Processes the oxidize organic carbon:** cellular respiration in producers, consumers, decomposers; combustion of biomass and fossil fuels	**Processes that move & re-distribute water** run-off, infiltration, transpiration evaporation, condensation, precipitation, groundwater pumping, water diversions, etc. **Processes that alter water composition** Adding materials: erosion, dissolution, point & non-point source pollution Removing materials filtration, wetlands chemistry, water treatment processes	**Processes that create biodiversity:** Population: Mutation, sexual recombination, (genetic engineering) Community: Colonization by new species (e.g., weeds, succession) **Processes that sustain biodiversity:** Population: life cycles, reproduction, relationships among individuals Community: relationships among populations with different niches, habitats, survival strategies **Processes that reduce biodiversity:** Populations: natural selection, human selection (deliberate and unintended) Communities: reduction of niches and habitats by human management, invasive species
Changes over Time (Environmental Systems Box) (due to imbalanced processes*)*	Global climate change	Reduction in quantity and/or quality of available fresh water	Reduction of genetic diversity in populations and species Reduction of species diversity in communities (including extinction)
Personal (Consumer/Owner) Citizenship Scenarios[1]	Personal carbon footprint Carbon footprint of consumer products	Personal water use Water use of consumer products	Personal food consumption (e.g., strawberry interview) Personal land use (e.g., home ownership)
Social (Voter/Advocate) Citizenship Scenarios	Wedge game: options for reducing imbalance between generation and oxidation of organic carbon	Water use scenarios (e.g., Ice Mountain interview) Land use policies affecting water quality & quantity	Food supply systems and policies Land use policies

[1] Citizenship scenarios involve asking students to "complete the loop" when they are playing public or private citizen roles. That is, they need to connect personal and social decisions they make to our dependence on environmental system services and to the effects of our actions on environmental systems.

Table 2: Comparing Levels of Student Achievement for Carbon, Water, and Biodiversity Strands

Level	*Carbon*	*Water*	*Biodiversity*
Framing Questions	*What happens to "stuff?" (matter)* *What makes it happen? (energy)*	*Where does water come from and go to?(water)* *What is in water and how can that change? (materials in water)*	*How are individuals and eco-systems alike and different?* *How did they get that way?*
Level 7: Quantitative Reasoning about Uncertainty	Can explain sources and quantitative estimates of uncertainty associated with carbon fluxes and their influence on global warming. Can quantify uncertainty in projections of energy consumption's impact on global warming.	Can explain sources and quantitative estimates of uncertainty in projections of water supply or water quality associated with climate change or human management of watersheds and groundwater.	Can apply models of change that include quantification of probabilities (uncertainty) of events such as mutation rates, drift, birth and death rates and natural or human-caused disturbances.
Level 6: Quantitative Model-based Reasoning	Quantitatively traces matter within and between organisms and between living and non-living systems. Quantitatively traces energy in terms of bond energy (ΔH) and traces energy and matter through large-scale systems.	Quantitatively traces water and materials in water through systems at multiple scales. Relates quantitative measures of concentration of materials in water to measures of mass and effects of purification processes.	Quantitatively traces information across multiple scales. Quantifies the relative contribution of multiple sources of variation; rates of change; and variables associated with diversity at the ecosystem and population levels.
Level 5: Qualitative Model-based Reasoning	Qualitatively describes matter transformations during biogeochemical processes and conserves chemical substances. Qualitatively describes energy transformations, including tracing sources back to resources and degradation.	Uses models to trace water and materials in water along multiple pathways through systems at multiple scales. Relates atomic-molecular models of solutions and suspensions to water quality and macroscopic and large-scale processes.	Traces information through short and long term processes at both the population and ecosystem level. Considers multiple sources of variation, processes than maintain variation, and processes that reduce variation in natural and human-controlled systems.
Level 4: "School Science" Narratives	Recognizes matter transformations at the cellular and atomic-molecular level and attempts to conserve chemical substances. Identifies energy sources and recognizes energy transformations, but rarely gets transformations right.	Uses spatial visualization to trace matter through systems and explain mechanisms of flow. Associates water quality with dissolved or suspended materials, but not specific about chemical identity or atomic-molecular models.	Recognizes many of the appropriate systems and processes that explain change over time in natural and human-controlled systems, but fails to connect the systems and/or processes in a manner constrained by scientific principles.
Level 3: Events Driven by Hidden Mechanisms	Recognizes mechanisms for events at a hidden scale; conserves matter for visible physical changes. Recognizes energy sources such as foods, fuels, and sunlight, but does not distinguish between energy and other needed conditions or materials.	Recognizes that a mechanism is required to move or change water, but mechanisms provided do not account for limitations of processes or systems. Associates water quality with conditions or non-specific materials (e.g., "chemicals").	Recognizes connections between micro and macro, and macro and large scale systems, but the mechanisms connecting those systems are explained by cultural narratives or embodied experience. Diversity in systems not considered in explanations of processes or change.
Level 2: Sequences of Events	Describes observable changes in systems, but not attempt to conserve matter during those changes. Uses triggering events, conditions, and needs to explain why things happen.	Uses iconic visualizations and representations, usually about visible parts of systems, but does not recognize hidden mechanisms for events. Characterizes water quality in broad terms—good or bad.	Recognizes variation in systems where it is visible at the macroscopic scale. No connections made between small scale systems such as genes and large scale phenomena such as phenotypic variation.
Level 1: Egocentric Reasoning about Events	Explains why events involving changes in matter happen in terms of human needs and intentions.	Explains what happens to water and water quality in terms of human needs and agency.	Explain what happens to organisms, species or ecosystems in terms of humans needs or natural tendency.