Learning Progressions for Environmental Science Literacy

Community Workshop on Climate Change Education: Defining Needs & Key Issues
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Websites: http://edr1.educ.msu.edu/EnvironmentalLit/index.htm, http://lter.mspnet.org/index.cfm/[1]

Research Framework

- *Environmental science literacy* is the capacity to understand and participate in evidence-based discussions of socio-ecological systems and to make informed decisions about appropriate actions and policies
- *Learning progressions* are descriptions of increasingly sophisticated ways of thinking about or understanding a topic (Committee on Science Learning, 2007). Learning progressions leading to environmental science literacy involve changes in *knowledge, practice,* and *discourse.* We distinguish four levels of achievement, from:
    - *Level 1:* Reasoning characteristic of students in upper elementary school, to
    - *Level 4:* Reasoning comparable to high school national standards (achieved by less than 10% of high school students in our samples: Mohan, Chen, & Anderson, in press)

1. Knowledge of Processes in Socio-ecological Systems

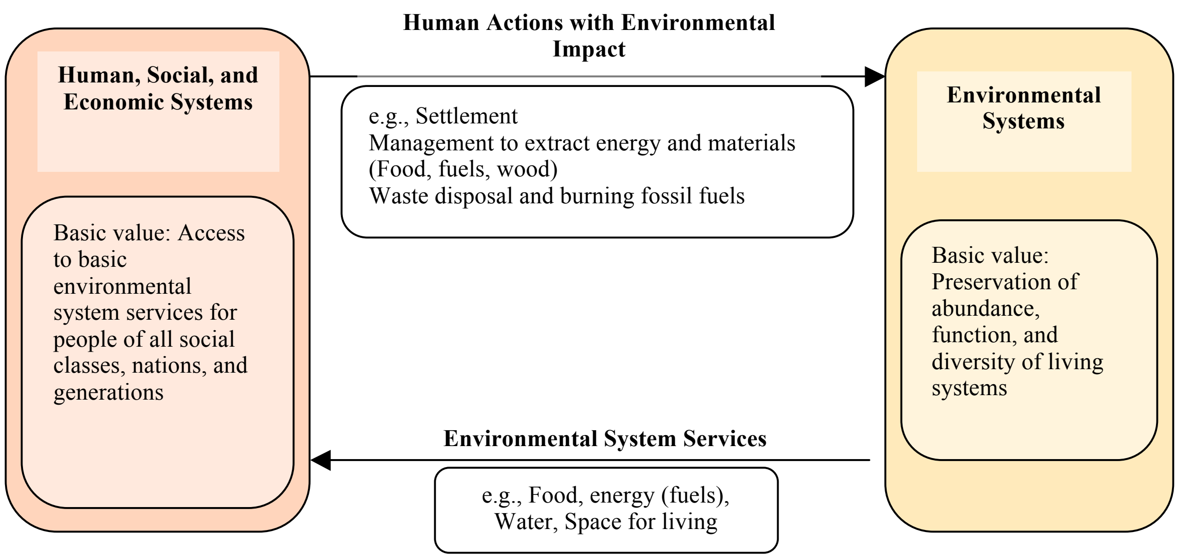

Figure 1: Structures and Processes of Socio-ecological Systems (Modified Loop Diagram, based on LTER Decadal Plan)

Table 1: Linking processes for carbon strand learning progression

Level 4 general processes	Generating organic carbon	Transforming organic carbon			Oxidizing organic carbon		
Level 4 accounts	Photosynthesis	Biosynthesis	Digestion	Biosynthesis	Cellular respiration		Combustion
Linking processes	Plant growth		Animal growth		Breathing, exercise	Decay	Burning
Level 1 accounts	Plants and animals as actors, accomplishing their purposes in life, using their abilities, if their needs (food, water, sunlight, and/or air) are met					Natural process in dead things	Flame as actor consuming fuel

Linking processes (in red) are familiar to students at all levels of achievement, but they are understood and grouped differently by students at different levels (see discussion of discourse below).

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2. Practices: Citizenship and Principled Reasoning

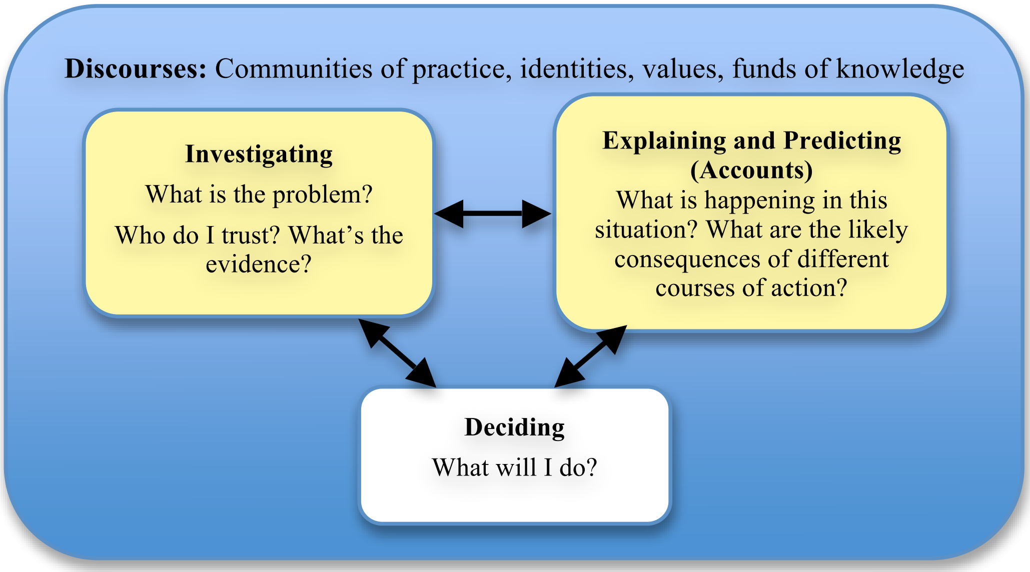


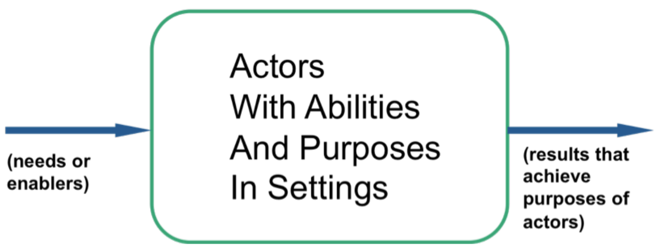
Figure 2: Practices for informed decisions about socio-ecological issues

Key Principles for Carbon Water, and Biodiversity Strands

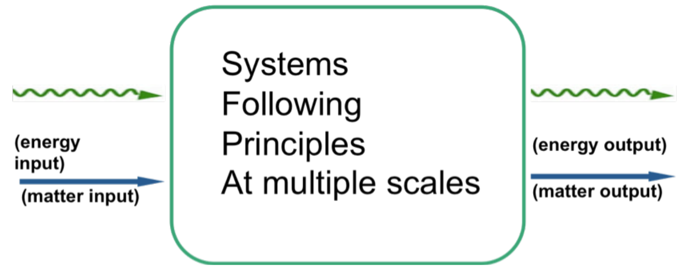
		Carbon Strand	***Water Strand***	***Biodiversity Strand***
Types of Accounts				
Types of processes		Processes that create, transform, oxidize organic carbon	Processes that move water across landscapes and processes that affect water quality	Processes leading to continuity and/or change in biological communities
Characteristics of Each Account				
Characteristics of systems	***Structure and function***	Inorganic substances: CO_2, H_2O, O_2 Organic substances: Monomers and polymers of biomolecules	Freshwater systems: watersheds, ground water, atmospheric water Human water systems: pipes, treatment plants, etc.	Genetic characteristics: individual genotypes, population genetic variability, community species diversity Phenotypic structure, function, relationships Non-living environment
	Hierarchy of scales	Atomic-molecular, microscopic, macroscopic, large scales	Atomic-molecular, microscopic, macroscopic, watershed scales	Individual, population, community/ecosystem, landscape (multiple ecosystems) scales
Principles constraining processes	***Principle 1***	Conservation of matter: -conservation of atoms -conservation of mass -fluxes and reservoirs of carbon-containing materials	Conservation of matter: -conservation and movement of water through changes of state and landscapes -conservation and movement of materials carried by water	Principles governing reproduction (following Darwin): --excess reproductive capacity --descent with modification
	Principle 2	Conservation and degradation of energy	Gravity and pressure: water runs downhill, constrained by impermeable materials	Population dynamics: Population size and variability are determined by environmental constraints, dispersal constraints, relationships among populations

2. Discourse: Informal vs. Scientific Discourse

Discourse is a term used by sociolinguists such as James Gee (1991) to denote general ways of thinking and manner of talking about the world. Gee defines a discourse as "a socially accepted association among ways of using language, of thinking, and of acting that can be used to identify oneself as a member of a socially meaningful group" (Gee, 1991, p. 3). Discourses are also called "social languages."



Level 1: informal or force-dynamic accounts focus on needs and abilities of actors (animals, plants, flames, machines) and how they achieve their purposes. Note that enablers are not transformed into results and matter and energy are not distinguished.



Level 4: scientific accounts (for carbon) focus on transformations of matter and energy in systems at multiple scales. Note that all processes transform matter and energy, with conservation laws as basic constraints.

- K-12 students and college non-science majors are basically "monolingual:" They rely on informal or force-dynamic discourse to make sense of the world.
- College science majors are like "second language learners," they can sometimes use scientific discourse, but in awkward and incomplete ways.
- Post-graduate scientific training helps people become truly "bilingual." They can choose informal or scientific discourse according to their reading of the situation.

Example from pretest given to science majors in cell biology course. College chemistry was a prerequisite.

Gasoline is mostly a mixture of hydrocarbons such as octane: C_8H_{18}. Decide whether each of the following statements is true (T) or false (F) about what happens to the atoms in a molecule of octane when it burns.
T (20/23) Some of the atoms in the octane are incorporated into carbon dioxide in the air.
F (7/23) Some of the atoms in the octane are incorporated into air pollutants such as ozone or nitric oxide.
F (8/23) Some of the atoms in the octane are converted into energy that moves the car.
F (16/23) Some of the atoms in the octane are burned up and disappear.
F (10/23) Some of the atoms in the octane are converted into heat.
T (17/23) Some of the atoms in the octane are incorporated into water vapor in the atmosphere.

Choices for scientists seeking to communicate with audiences who have not mastered scientific discourse:
- Outreach: *translation* of scientific research into terms people understand
- Education: *preparation of citizens* who can understand scientific accounts and arguments from evidence

Examples of Texts Related to Climate Change

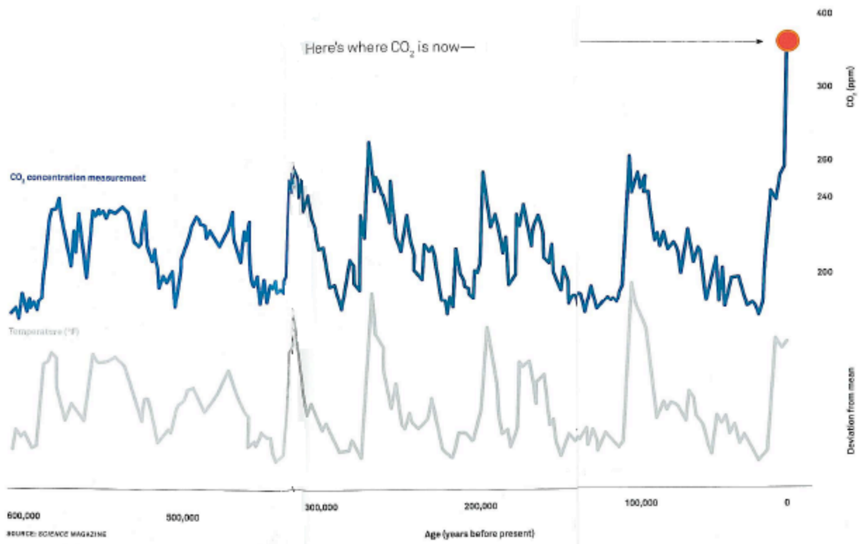
Below is the complete text of all standards addressing change in ecosystems and earth systems in the ***National Science Education Standards*** (262 pages)[2]
- The students' studies develop the concept of the earth system existing in a state of dynamic equilibrium. They will discover that while certain properties of the earth system may fluctuate on short or long time scales, the earth system will generally stay within a certain narrow range for millions of years. This long-term stability can be understood through the working of planetary geochemical cycles and the feedback processes that help to maintain or modify those cycles. (NSES, page 188)
- Human beings live within the world's ecosystems. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption. Human destruction of habitats through direct harvesting, pollution, atmospheric changes, and other factors is threatening current global stability, and if not addressed, ecosystems will be irreversibly affected. (NSES, page 186)

[2] Coverage in the original *Benchmarks for Science Literacy* was similar, but Project 2061's *Atlas of Science Literacy, Volume 2* includes new benchmarks explicitly addressing climate change and its effects.

From the **Intergovernmental Panel on Climate Change** ***Summary for Policymakers*** (IPCC, 2007): designed to be convincing to experts, carefully sourced, explicitly based on evidence and scientific models (requires education).

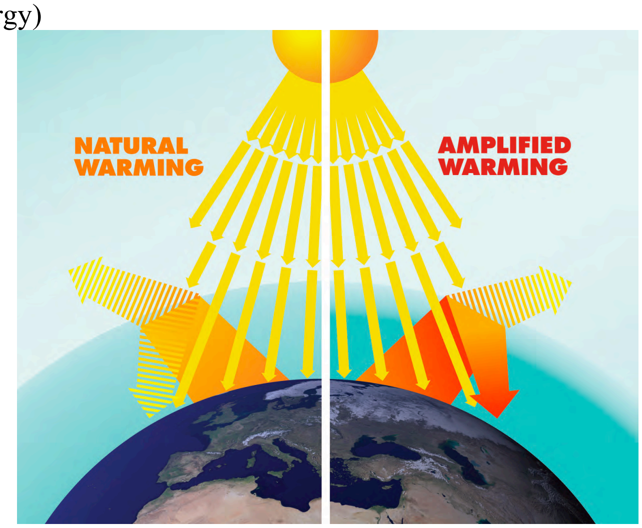
> For the next two decades a warming of about 0.2°C per decade is projected for a range of emission scenarios. Even if the concentrations of all GHGs [greenhouse gases] and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emission scenarios. {3.2} (IPCC, 2007, p. 6)

Al Gore's book, ***An Inconvenient Truth,*** presents evidence for a link between atmospheric carbon dioxide concentration and global average temperature in the form of a commentary on a simplified graph (intended as translation).



> In Antarctica, measurements of CO_2 concentrations and temperatures go back 650,000 years.
> The blue line below charts CO_2 concentrations over this period….
> The gray line shows the world average temperature over the same 650,000 years.
> Here is an important point. If my classmate from the sixth grade were to see this—you remember, the guy who asked about South America and Africa—he would ask, "Did they ever fit together?"
> The answer from scientists would be, "Yes, they do fit together."
> It's a complicated relationship, but the most important part of it is this: When there is more CO_2 in the atmosphere, the temperature increases because more heat from the Sun is trapped inside. (Gore, 2006, pp. 66-7)

From ***Climate Literacy: The Essential Principles of Climate Sciences.*** www.climatescience.gov (note implicit reliance on conservation of energy)



> The amount of solar energy absorbed or radiated by Earth is modulated by the atmosphere and depends on its composition. Greenhouse gases— such as water vapor, carbon dioxide, and methane— occur naturally in small amounts and absorb and release heat energy more efficiently than abundant atmospheric gases like nitrogen and oxygen. Small increases in carbon dioxide concentration have a large effect on the climate system.