Earth System Science Education as a System: Who is Responsible for Closing the Loop?

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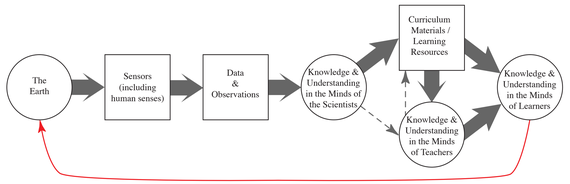
The Question:

Earth System Education as a System:

As systems thinkers engaged in Geoscience research, we are accustomed to think about Earth processes in terms of reservoirs, fluxes and feedbacks. We can also think of Earth research and education itself as a system of reservoirs linked by information flows.



There is loss and distortion of information at every single arrow in this diagram. Humanity pushes to reduce that loss and distortion. Engineers bend their ingenuity to reducing loss and distortion at the arrow from "The Earth" to "Sensors & Senses." Scientists struggle to extract more complete and less distorted understandings from their data and observations. Instructional materials developers and reviewers seek to minimize loss and distortion at the arrow from scientists' minds to curriculum materials. Educational researchers and evaluators seek to understand and ameliorate the losses and distortions that occur during the steps from curriculum material and teacher's mind to students' minds.

Beyond "Knowledge & Understanding in the Minds of Students":

The end goal of education is usually cast as the far right-hand reservoir of the flowchart: Knowledge and Understanding in the minds of learners. In geoscience education, though, one could envision an even deeper goal, indicated by the feedback arrow going leftward across the diagram from the learners to the Earth. We wish our students, as a consequence of their Geoscience education, to interact differently with the Earth than they would have otherwise. We wish them to make wiser decisions about society's interactions with natural systems and take wiser actions in their own interactions with natural systems than they would have without their Geoscience education.

Who is Responsible for Closing the Loop?

We identified professions that are taking responsibility for minimizing the loss of information at most of the arrows in the flowchart. But who does, or should, take responsibility for closing the feedback loop back to impact on the Earth? Who is responsible for ensuring that knowledge and understanding in the minds of students does, in fact, flow back to the Earth in the form better informed and more insightful actions upon the Earth?

To what extent does, or should, science education assume responsibility for shaping children's own interactions with natural systems, above and beyond helping them construct accurate knowledge and understanding? In other words, to what extent does, or should, science education contribute to closing the feedback loop?

The answer to this question is not self-evident, and it seems that thoughtful educators of good will could come to opposite conclusions.

The case for why science educators should NOT take responsibility for "closing the loop."	*The case for why science educators SHOULD take responsibility for "closing the loop."*
• We are *science* teachers. Our limited time with these students is completely full, more than full, just trying to help them build a reasonably accurate and complete understanding of Earth processes and phenomena. • Telling students that they or their families should change their behavior is environmental activism, not science. Once we start down the activist pathway, we undermine our credibility as a source of accurate, objective information. • Students' families have widely varying opinions about environmental issues as they impact lifestyle choices, local economic development, and politics. It's better to steer clear of topics that could cause conflict with parents or community leaders.	• If we don't do it, then who will? As Earth Science educators, we probably have a better understanding of Earth processes and phenomena than 99+ percent of the people that our students will come in contact with, both as young people and as adults. If we don't sieze this opportunity to help them learn to act and choose in ways that will have a minimum destructive impact on the Earth and environment, then when and where are they going to learn this?

What We Did:

Since we haven't been able to answer this question merely by reasoning from first principles, we take an empirical approach. Going out to the "laboratory of democracy," we ask what has been the outcome with respect to this question of the 49 separate deliberative processes in the 49 states that have state educational standards? What guidance or directives are the states giving to their K-12 science teachers on this topic?

Coding Scheme for Interactions between Humans and the Earth System

Label	E → H	H → E	I → E
Criteria	**Standard states or implies that Earth & environment influence or affect humanity OR standard states or implies that humanity is dependent on natural systems.** • The standard refers to "humans," "human beings," "humanity," "society" or "societal," "economy," "people," "community," or "family" and also mentions an object, phenomenon or process of the Earth or environment. • Other key words that connote humans being impacted by Earth processes include "damage" or "hazard." • Other key phrases that connote humans depending on the Earth include "natural resource," "renewable resource," "non renewable resource," "fossil fuel" • The standard mentions a specific natural resource (e.g. water) that humans use or depend on, in a context where use by humans is clearly implied. • The standard mentions a specific human or societal use of a resource, e.g. "drinking," "washing," "irrigating."	**Standard states or implies that human society influences/affects/changes the Earth or environment.** • The standard refers to "humans," "human beings," "humanity," "society" or "societal," "people," or "community," and also mentions an object, phenomenon or process of the Earth or environment. • Other words or phrases that imply humanity affecting the Earth and environment in a positive way include "preserve/protect/conserve [e.g. biological diversity, natural resources]," "reduction of energy consumption," "solve environmental problems," "management [of waste, of natural resources]." • Other phrases and concepts that imply humanity affecting the Earth and environment in a negative or possibly negative way include "pollute" or "pollution," "environmental impact [e.g. of a technology]," "environmental degradation," "consequences of exploration and/or development of natural resources," "depletion of ozone in the atmosphere," "global warming," "deforestation," • This category refers to actions or decisions of humanity acting collectively (organizations, institutions, governments, communities, corporations, society as a whole).	**Standard states or implies that the actions of individuals influence/affect/change the Earth or environment.** • This category differs from the previous in that it refers to actions or decisions made by individual adults or children in their private capacity in their daily lives (e.g. as they purchase, consume, conserve or waste, dispose of). • The individual actions/decisions can be good for environment (e.g. conserving water, conserving energy) or bad for environment (e.g. littering). • The focus of this category is on actions or decisions that could be achieved by all or most students, either now or when they become adults. • Actions or decisions taken by individuals in a professional capacity (e.g. farmer, scientist, government employee) are categorized as H→E rather than I→E, because these are not actions that will be accessible to all or most students, even after they become adults.

Examples of the Different Code Categories:

Yellow Code - E → H

Nebraska
(www.nde.state.ne.us/ndestandards/sciencedrft.htm)

Grades 2-4
4.4.3 By the end of fourth grade, students will develop and understanding of living things and environments.

Identify characteristics of soils, minerals, rocks, water, and the atmosphere. List earth materials that are used by humans (e.g., marble - buildings, clay - pottery, coal - heat).

New York (www.emsc.nysed.gov/ciai)

High School - The Living Environment

7.1b. Natural ecosystems provide an array of basic processes that affect humans. Those processes include, but are not limited to: maintenance of the quality of the atmosphere, generation of soils, control of the water cycle, removal of wastes, energy flow, and recycling of nutrients. Humans are changing many of these basic processes and the changes may be detrimental.

Blue Code - H → E

Delaware
(www.doe.state.de.us/Standards/Science/Standard1.html)

Standard 8 - Ecology

Grades K-3 - Changes in Environments

3. Pollution and human activities can change the environment and adversely _____ the health and survival of humans and other species. Careful planning and safe practices are required in waste disposal, recycling and waste management, pest control, and use of resources to ensure the well-being of humans and the environment.

Grades 9-12 - Changes in Ecosystems

1. All organisms are dependent upon the earth's finite supply of material resources to sustain life. Human decisions concerning the use of resources alters the stability and the biodiversity of ecosystems and adversely affect the natural recycling processes which maintain the quality of air, water, and land.
• Identify a commonly used resource. Research the methods used to obtain the resource, and the impact the removal of the resource has on the biogeochemical cycles of an ecosystem.
• Explore why biodiversity is considered a non-renewable resource and discuss the consequences that result from the reduction of biodiversity.

Purple Code - I → E

Delaware
(www.doe.state.de.us/Standards/Science/Standard1.html)

Standard 2 - Materials and their Properties

Grades 4-5 - Material Technology

Monitor the mount of waste generated in various activities at school and design a program for effective recycling of one of the major components of the trash.

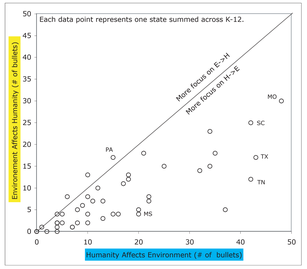
Standard 8 - Ecology

Grades K-3 - Changes in Environments

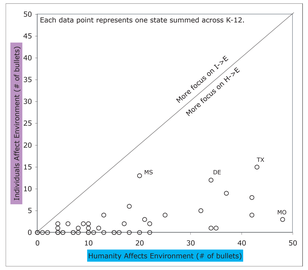
3. Design a simple brochure, poster, booklet, or video to increase public awareness about the impact of altered habitats or land development on various Delaware species (e.g., Piping Plover, Bluebird, Delmarva Fox Squirrel, Bald Eagle, Bog Turtle, frogs). Develop and implement a plan to address a classroom or school environmental issue (e.g., recycling, conserving electricity, maintaining and reducing cafeteria waste). Share with classmates the basis for the plan and make recommendations for its implementation.

What We Learned:

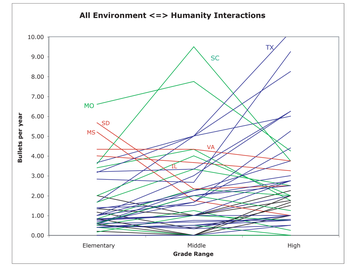
The overwhelming majority of state science standards place more emphasis on how humans effect the environment than on how the environment affects humans.



There is not much support in most state science standards for teaching the concept that individuals affect the environment.



Blue - heaviest human <=> environment emphasis in high school.
Green - heaviest human <=> environment emphasis in middle school.
Red - heaviest human <=> environment emphasis in elementary school.



An Example of Building Insight and Awareness Across the Grades: Florida.
(www.firn.edu/doe/curriculum/crscode/basic612/sci68.htm)

Strand D: Processes that Shape the Earth

Benchmark SC.D.2.1.1. The student understands that people influence the quality of life of those around them.

Kindergarten
1. Knows ways to care for the earth at home & in school (e.g. limit use of paper towels, turn off water while brushing teeth, turn off lights when no one will be in the room).

First
1. Extends and refines knowledge of ways to care for the earth at home and in school.

Second
1. Knows ways that human activities affects the environment (for example, land fills for disposal of wastes, land development for homes and industry, dams to control rivers or generate electricity.)

Benchmark SC.D.2.2.1. The student knows that reusing, recycling, and reducing the use of natural resources improves and protects the quality of life.

Third
1. Knows that using, recycling, and reducing the use of natural resources improve and protect the quality of life.

Fourth
1. Knows ways in which people can conserve natural resources.
2. Knows ways misuse of natural resources affects the quality of life for all species.

Fifth
1. Extends and refines knowledge of ways people can reuse, recycle and reduce use of resources to improve and protect the quality of life.

Benchmark SC.D.2.3.2. Knows the positive and negative consequences of human action on the Earth's systems.

Sixth
1. Knows positive and negative consequences of human actions on the Earth's systems (for example: farming, transportation, mining, manufacturing).

Eight
1. Knows that legislation can be adopted to protect Earth from detrimental human activities.

Benchmark SC.D.2.4. The student understands the need for protection of natural systems on earth.

Ninth through Twelfth
1. Understands the interconnectedness of the systems on earth and the quality of life.

Example of a Standard Linking All Three Elements of Human-Environment Interactions: Illinois.
(www.isb.state.il.us/ils/science/stage_A/descriptor.htm)

Elementary School – Grades 1&2
12E. Students who meet the standard know and apply concepts that describe the features and processes of earth and its resources.

3. Apply scientific inquires or technological designs to classify renewable and non-renewable natural resources, sorting different examples of simple natural resources, identifying the origin of these examples with their recyclable possibilities, or setting and working toward a possible recycling or reusing goal for classroom application efforts.

An Example Showing the Dominance of H → E (Blue): Delaware.
www.doe.state.de.us/Standards/Science/Standard1.html

Standard 8: Ecology
Grades 9-12
Interaction of Humans within Ecosystems

1. All organisms are dependent upon the earth's finite supply of material resources to sustain life. Human decisions concerning the use of resources alters the stability and the biodiversity of ecosystems and adversely affect the natural recycling processes which maintain the quality of air, water and land.
• Identify a commonly used resource. Research the methods used to obtain the resource, and the impact the removal of the resource has on the biogeochemical cycles of an ecosystem.
• Explore why biodiversity is considered a non-renewable resource and discuss the consequences that result from the reduction of biodiversity.

2. The availability of and access to natural resources shape the economic polices of society and form a basis for international trade agreements. Unequal distribution of resources and increased demand for natural resources require global cooperation and long-term planning to satisfy the resource needs of successive generations.
• Analyze socio-demographic data and compare the use of natural resources in developing countries to the more industrialized countries. Compare the amount of pollution generated in each.
• Identify how changes in consumer demands, marketing strategies, and technology have promoted a more efficient use of resources and have extended their availability.

3. People manage the earth and its resources by preservation, conservation, appropriate utilization, restoration. There is a wide variety of national laws (e.g., CLEAN AIR ACT, CLEAN WATER ACT, ENDANGERED SPECIES ACT) and state laws (e.g., COASTAL ZONE ACT) that exist to protect the environment.
• Select a local, pertinent environmental issue and participate in an activity which addresses this issue (e.g., beach clean-up, stream watch, adopt-a-highway, horseshoe crab census).

Human-Environment Interactions Outside the Science Standards:

• Free-standing Technology Standard outside of Science standard:
- e.g. environmental costs of technology such as automobile
- e.g. use of technology for predicting track of destructive storms

• Free-standing Environment & Ecology standard outside of Science standard
- e.g. impact of wetlands and watersheds on people
- e.g. impact of pesticides on ecosystems

• Geography Standard
- e.g. land use decisions and their environmental consequences
- e.g. characteristics of climates in different regions of the world and how they affect the lives of people who live there.

• Health Standard
- e.g. avoiding environmental toxins, such as lead and mercury
- e.g. healthy human life depend on healthy environment, clean water, clean air

• Family & Consumer Education Standard:
- e.g. making purchasing decisions that minimize environmental impact
- e.g. reduce, recycle, reuse

• Character Education Standard:
- "preservation of the environment"

An Example of a state standard putting an environmental focus where national standards had none: South Carolina.
(www.myschools.com/offices/eso/standards/science/default.cfm)

Grades 9-12
IV. Physical Science (physics)
B. Conservation of Energy and the Increase in Disorder

4. Everything tends to become less organized and less orderly over time. Thus, in all energy transfers, the overall effect is that the energy is spread out uniformly. Examples are the transfer of energy from hotter to cooler objects by conduction, radiation, or convection and the warming of our surroundings when we burn fuels.

a. Compare and contrast the environmental impact of power plants that use fossil fuels, water, or nuclear energy to produce electricity. (P, T)

Conclusions

- States vary widely in how much attention they think should be given, in science class, to interactions between humans and natural Earth systems.
- The lowest-emphasis states call for less than one mention per year of any human-environment interaction, averaged across the K-12 years.
- The overwhelming majority of state science standards place more emphasis on how humans affect the environment than on how the environment affects humans.
- Many states think that how individuals impact the environment should be taught in science class very little or not at all.
- Although research suggests that environmental education is most likely to result in "improved environmental behaviors" when participants are younger, many states load their coverage of human-environment interactions into the high school years.
- Coverage of human-environment interactions is scattered across the K-12 curriculum, not only in science class. Does scattered responsibility mean everyone is responsible? Or no one? Should science educators be collaborating more with geography, health, and consumer education teachers?