Developing a K-12 Learning Progression for Carbon Cycling in Coupled Human and Natural Systems

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ENVIRONMENTAL LITERACY

Framework for Carbon Cycling in Socio-ecological Systems

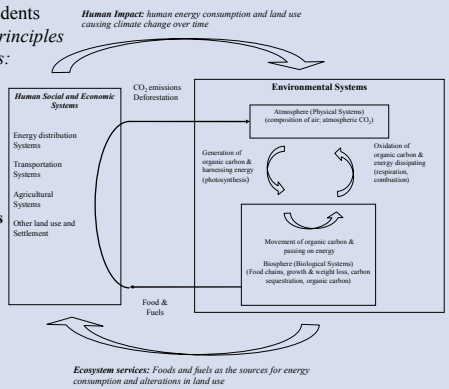
- Carbon-transforming processes are uniquely important in socio-ecological systems and understanding those processes is essential for citizens' participation in environmental decision-making.

- Environmental science literate students should be able to use *fundamental principles* to explain *biogeochemical processes:*

- Processes:
  - **Generation** of organic carbon
  - **Transformation** of organic carbon
  - **Oxidation** of organic carbon

- Principles:
  - **Tracing matter through processes**
  - Tracing energy through processes
  - Change over time

- Our study examines students' accounts of tracing matter (or "stuff") through processes.



Methods and Goals of Analysis

- Participants included students in grades 4-10 from 10 classrooms serving primarily suburban and rural public schools.

- Assessments were paper-pencil tests developed over a three year period focused on the three carbon-transforming processes. We selected 14 items from our item pool that specifically asked students about matter in systems and processes.

- Learning progressions are descriptive sequences of student's thinking about a topic:
  - Upper Anchors- target performances or goals for science education
  - Lower Anchors- what students bring to science classrooms
  - Intermediate transitions- levels describing transitions between upper and lower anchors

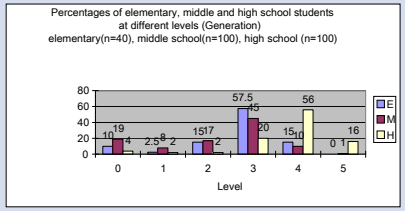
- Goals of analysis were to develop three products:
  1. Tracing matter levels to describe students tracing of "stuff" through processes.
  2. Exemplar response to represent characteristic explanations for a given level on each assessment item.
  3. Analysis of 14 assessment items to further refine levels and identify trends across processes.

Tracing matter levels

Level 7: Quantitative Reasoning about Uncertainty	Can explain sources and quantitative estimates of uncertainty associated with carbon fluxes and their influence on global warming.
Level 6: Quantitative Model-based Reasoning	Quantitatively traces matter within and between organisms and between living and non-living systems.
Level 5: Qualitative Model-based Reasoning	**Qualitatively describes matter transformations during processes and conserves chemical substances.**
Level 4: "School Science" Narratives	**Recognizes matter transformations at the cellular and atomic-molecular level and attempts to conserve chemical substances.**
Level 3: Events Driven by Hidden Mechanisms	**Recognizes mechanisms for events at a hidden scale; conserves matter for visible physical changes.**
Level 2: Sequences of Events	**Describes observable changes in systems, but not attempt to conserve matter during those changes.**
Level 1: Egocentric Reasoning about Events	**Explains why events involving changes in matter happen in terms of human needs and intentions.**

Generation of organic carbon

Is wood a mixture? When an acorn grows into a large tree, where did the increases in weight come from? What is food for the acorn (plant)? What gases do plants take in and how are they used? How could cutting down trees influence climate?



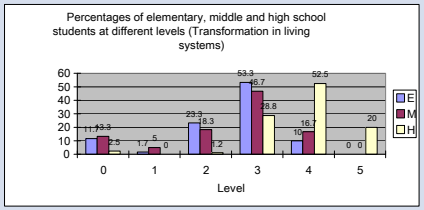
Elementary & middle school students cluster around level 3, explaining photosynthesis in terms of materials going into the plant.

High school students cluster around level 4 and focus on a cellular accounts of photosynthesis.

Transformation of organic carbon

Is wood a mixture? When an acorn grows into a large tree, where did the increases in weight come from? What happens to an apple after you eat it? How could glucose from a grape give you energy to move your finger?

Elementary and middle school students give level 3 explanations of digestion and biosynthesis, being able to trace materials through the body, but not to the cells.



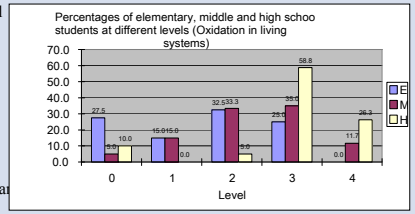
High school students range between level 3 and 5, showing they have cellular accounts of digestion & biosynthesis, but they cannot trace matter completely through these processes.

Oxidation of organic carbon in living systems

What happens to an apple/dead tree when it rots? What gases do plants take in and how are they used? When Jared lost weight, where did the mass of his fat go?

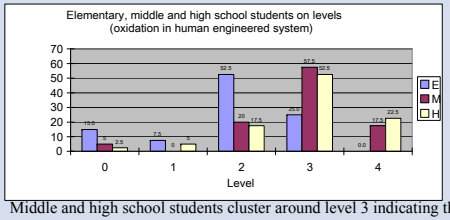
Elementary and middle school students are split between level 2 reasoning (matter disappears) and level 3 where matter is changed, but not at the cellular level.

High school students are decidedly level 3, although some have an atomic-molecular account of cellular respiration.



Oxidation in human-engineered systems

What happens to a match when it burns? What happened to the gasoline when a car is empty? How could using gasoline affect global warming? What make materials energy-rich?



Elementary students cluster around level 2, focusing on observable changes in match/gas and allowing matter to disappear.

Middle and high school students cluster around level 3 indicating they do not understand combustion at an atomic-molecular level (e.g., matches turn to ash; gasoline evaporates).

Trends in our learning progression

- ***Invisible to Visible***
  - Hierarchy of Systems- scale at which students trace matter expands
  - Connections between systems- students make connections between systems using matter
- ***Events to Process***
  - Causality- student learn to use matter (and energy) to explain why things happen
  - Conservation- students learn that matter cannot disappear
  - Connections- students learn to make connections between seemingly separate processes
- ***Objects to Materials***
  - Mixtures- students learn that carbon-containing molecules form many important mixtures
  - Gases are matter- students learn to trace gases into and out of processes

Center for Curriculum Materials in Science (CCMS)

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