Conceptual and Empirical Validation of Learning Progressions

Response to “Learning Progressions: Supporting Instruction and Formative Assessment”

Charles W. (Andy) Anderson
Michigan State University
What qualities are necessary in a good learning progression?

Summary from NRC: *coherence, comprehensiveness, and continuity.*
Additional Questions

1. Why is dialogue between researchers and developers so difficult?

2. What qualities should we be seeking in learning progressions in order to foster dialogue?

3. What do we gain from paying attention to those qualities?
1. Why is dialogue between researchers and developers so difficult?

Different design constraints

• Curricula and large-scale assessment programs
  – Need frameworks that describe learning in broad domains over long periods of time
  – Usually work on short timelines
  – Need stable frameworks

• Researchers
  – Need to develop knowledge claims that are theoretically coherent and empirically grounded
  – Often on longer timelines
  – Value innovation
The Learning Progression Hypothesis

- Guarded optimism that we may be ready to bridge the gap—to develop larger-scale frameworks that meet research-based standards for theoretical and empirical validation.

- Must be tested through the development and validation of specific learning progressions.
An Example: The Carbon Cycle

Key scientific practices

• **Tracing matter** (carbon) through chemical changes
  – Photosynthesis (generates organic carbon)
  – Growth, digestion, food webs (transform organic carbon)
  – Combustion, cellular respiration, decay (oxidize organic carbon)

• **Using transformation and dissipation of energy** to explain changes
## Learning Progression Framework

### Levels of Achievement

<table>
<thead>
<tr>
<th>Levels of Achievement</th>
<th>Progress Variables (Carbon-transforming processes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Photosynthesis</td>
</tr>
<tr>
<td></td>
<td>Transformation of organic carbon</td>
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<tr>
<td></td>
<td>Cellular Respiration</td>
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<tr>
<td></td>
<td>Combustion</td>
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<td></td>
<td>Large-scale processes</td>
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</tbody>
</table>

5: Qualitative model-based accounts

4: School science narratives

3: Events with hidden mechanisms

2: Event-based narratives

1: Human-based narratives

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**Learning performances** for specific processes and Levels of Achievement:
Accounts of processes in socio-ecological systems
Parts of Framework

- **Progress Variables** (columns of the table): Aspects of knowledge and practice that are present in some form at all Levels of Achievement, so that their development can be traced across Levels.

- **Levels of Achievement** (rows of the table): Patterns in learners’ knowledge and practice that extend across Progress Variables.

- **Learning Performances** (cells of the table): specific practices characteristic of students who are at a particular Level of Achievement and reasoning about a particular Progress Variable.
Coming Back to Questions 2 and 3

1. Why is dialogue between researchers and developers so difficult?

2. What qualities should we be seeking in learning progressions that foster dialogue?

3. What do we gain from paying attention to those qualities?
Qualities for Research-based for Validation

• **Conceptual coherence**: a learning progression should “make sense,” in that it tells a comprehensible and reasonable story of how initially naïve students can develop mastery in a domain. (Similar to qualities of coherence, comprehensiveness, continuity).

• **Compatibility with current research**: a learning progression should build on findings or frameworks of the best current research about student learning.

• **Empirical validation**: The assertions we make about student learning should be grounded in empirical data about real students.
Applying the Criteria to Specific Parts of the Framework

<table>
<thead>
<tr>
<th>Characteristic of Learning Progressions</th>
<th>Conceptual Coherence</th>
<th>Compatibility with Current Research</th>
<th>Empirical Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Individual cells: Learning performances</strong></td>
<td>• Learning performances are described in consistent ways, including (a) knowledge, (b) practice, and (c) contextN real-world systems and phenomena.</td>
<td>• Learning performances are compatible with those described in the research literature.</td>
<td>• Learning performances describe actual observed performances by real students. • Students are consistent across different questions or modes of assessment (e.g., written assessments and clinical interviews) that assess the same learning performance</td>
</tr>
<tr>
<td><strong>Rows: Levels of Achievement</strong></td>
<td>• Levels are conceptually coherent: Different Learning Performances reflect some underlying consistency in reasoning or outlook</td>
<td>• Levels reflect consideration (explicit or implicit) of strands of scientific literacy (see above).</td>
<td>• Levels have predictive power: Students should show similar Levels of Achievement for Learning Performances associated with different Progress Variable.</td>
</tr>
<tr>
<td><strong>Columns: Strands and Progress Variables</strong></td>
<td>• Definition of Progress Variable captures important aspects of Learning Performances at all Levels of Achievement</td>
<td>• Progress from one Level to the next is consistent with research on studentsÖ learning, considering all strands of scientific literacy</td>
<td>• Progress from one Level to the next can be achieved through teaching strategies that directly address the differences between Learning Performances</td>
</tr>
</tbody>
</table>
Development and Validation: An Iterative Process

- Develop initial framework
- Develop assessments (e.g. written tests, interviews) and/or teaching experiments based on the framework
- Use data from assessments and teaching experiments to revise framework
- Develop new assessments....
1. Why is dialogue between researchers and developers so difficult?

2. What qualities should we be seeking in learning progressions that foster dialogue?

3. What do we gain from paying attention to those qualities?
3. What do we gain from paying attention to those qualities?

   Better dialogue.
   More powerful models.
An Important Barrier

- Making standard-setting an iterative process
- How can we use what we learn rather than “locking in” our first drafts?
Thank You

Major Contributors

• Lindsey Mohan, Chris Wilson, Beth Covitt, Kristin Gunckel, Blakely Tsurusaki, Hui Jin, Jing Chen, Hasan Abdel-Kareem, Rebecca Dudek, Josephine Zesaguli, Hsin-Yuan Chen, Brook Wilke, Ed Smith, Jim Gallagher, and Edna Tan at Michigan State University

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Website: http://edr1.educ.msu.edu/EnvironmentalLit/index.htm
• Extra slides
Environmental Literacy “Loop” Diagram

Human, Social and Economic Systems

- Basic value: Access to basic environmental services for people of different social classes, nations, and generations.

Human Actions with Environmental Impact

- Settlement, Management to extract energy and materials (food, fuels, wood)
- Burning fossil fuels (climate change)

Environmental System Services

- Food, Energy (fuels), Water, Space for living

Environmental Systems

- Basic value: Preservation of abundance and diversity of living systems.
Environmental Literacy Topics

- **Biodiversity**: foods and land for living, settlement and management for production, processes that create, sustain, and reduce biodiversity
- **Carbon**: foods and fuels, global climate change, processes that produce, transform, and oxidize organic carbon
- **Water**: fresh water, water management, processes that move and distribute water, processes that alter water composition (data not included in presentation)
- **Citizenship**: Practices of making decisions about human actions that use environmental system services or have environmental impact. (Investigating with interviews.)
A tree falls in the forest. After many years, the tree will appear as a long, soft lump barely distinguishable from the surrounding forest floor.

The mass of the lump on the floor is less than the mass of the original tree. Where do you think that the mass that is no longer in the lump has gone? In what form?
The Carbon Cycle

Answer that makes scientific connections

• Decay mostly reduces tree to carbon dioxide and water, with a few minerals that go into the soil

Middle school students answers?
**Human Impact:** human energy consumption and land use causing climate change over time

**Ecosystem services:** Foods and fuels as the sources for energy consumption and alterations in land use
Unit of Analysis: Processes in Environmental Systems
Events We Have Asked About (Macroscopic Scale)

- Plant growth, plants’ need for sunlight, plant gas exchange (generation of organic carbon)
- Plant and animal growth, digestion, food webs (transformation of organic carbon)
- Exercise by animals, weight loss, decay (oxidation by cellular respiration)
- Burning wood and candles, moving cars, appliances (oxidation by combustion)
- Grandma Johnson, Amazon tree growth (multiple processes)
Levels of Achievement in Carbon Learning Progression

We use seven levels of achievement to map out students’ progress (See Handout Tables 2, 4, 5):

**Levels 1-3: Stories about events.** Students make sense of the world by telling stories about events that they see and hear, with little awareness of systems or hidden mechanisms.

**Level 4: School science narratives.** Students include atoms, molecules, and large-scale systems in their stories, but they cannot use scientific models and principles to “complete the socio-ecological loop”.

**Levels 5-7: Model-based reasoning about socio-ecological systems.** Students use scientific models and principles to complete the loop, connecting human social and economic systems and issues with environmental systems and issues.
Carbon

Level 5 Reasoning about the Carbon Cycle

- **Matter: CO₂ & H₂O**
- **Matter: Organic matter & O₂**
- **Energy: Sunlight**
- **Movement of CO₂, H₂O, and minerals**
- **Photosynthesis**
- **Biosynthesis, digestion, food webs, fossil fuel formation**
- **Energy: Chemical potential energy**
- **Combustion, cellular respiration**
- **Energy: Work & heat**
Percentage of high school students giving Level 5 responses:

Approximately 2-5%
What Makes Level 5 Reasoning Hard?

- **Connecting scales**
  - Different macroscopic events are explained by common atomic-molecular processes
  - Different macroscopic events are connected in large-scale systems

- **Basic chemistry**
  - Atoms of gases can be rearranged into solid and liquid molecules
  - Chemical identities of substances and classes of substances

- **Understanding the power of models**
  - One model can generate stories of many different events
Carbon

Level 3 Reasoning about the Carbon Cycle

![Diagram showing the carbon cycle with Sunlight, Plants, Nutrients, Food chains, Decay, Carbon dioxide, Oxygen, Animals, and Decomposers.]

**Energy sources for plants:** sunlight, nutrients, water

**Energy sources for animals:** food, water

**Decomposers don’t need energy**
Some Characteristics of Level 3 Reasoning

- Focus on macroscopic events and systems
- Separate stories about different events
- Stories of gases are separate from stories of solids and liquids
- Energy as conditions or materials needed to make something happen
## Trends From Younger to Older Students: Characteristics of Accounts of Phenomena

<table>
<thead>
<tr>
<th>Account Element</th>
<th>Lower Anchor (Elementary Items)</th>
<th>Upper Anchor (High School Items)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials (Tracing matter)</td>
<td>Objects, plants, animals, “ephemera” (gases, conditions) as separate entities</td>
<td>Substances with chemical identities, mixtures. Matter, energy, conditions clearly separated.</td>
</tr>
<tr>
<td>Agents (Tracing energy)</td>
<td>Needs, actors, conditions, causes</td>
<td>Transformation and degradation of energy</td>
</tr>
</tbody>
</table>
| Mechanisms (Reductionist models in time or scale) | **Time:** Stories with few steps. “Things happen.”  
**Scale:** Essentialistic or vitalistic views: Things do what they do because that’s their nature.  
**Models:** Mechanical or representational models | **Time:** multi-step processes  
**Scale:** Processes in subsystems organized by scientific hierarchy (See Table 1 on handout)  
**Models:** Hierarchy of systems |
| Contexts or settings (Contextual models) | **Time:** Some ideas about necessary conditions or preceding/succeeding events.  
**Scale:** Few comments about larger systems or connected events in other places.  
**Models:** Qualities of stories (see Egan) | **Time:** Change over time due to imbalances among processes, feedback loops  
**Scale:** Large-scale systems and processes that include macroscopic systems and processes.  
**Models:** Large-scale systems, reservoirs and fluxes |