Research on Science Learning and Assessment for the Next Generation

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New Standards Reform Efforts

- *A Framework for K-12 Science Education* (July 2011)
- *Next Generation Science Standards* (April 2013)
  - 26 lead partner states, 7 state adoptations to date
  - http://www.nextgenscience.org

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The *Next Generation Science Standards* (NGSS)

- Current effort to not just update, but to reform science education across K-12
- Built upon a robust research base on science learning, teaching, and curriculum design
- Concerted effort to bridge theory and practice at a wide-scale policy level
Architecture of NGSS

5-PS1 Matter and Its Interactions

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Students who demonstrate understanding can:

5-PS1.1. Develop a model to describe that matter is made of particles too small to be seen. [Clarification Statement: Examples of evidence could include adding air to expand a basketball, compressing air in a syringe, dissolving sugar in water, and evaporating salt water.] [Assessment Boundary: Assessment does not include the atomic-scale mechanism of evaporation and condensation or defining the unseen particles.]

5-PS1.2. Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved. [Clarification Statement: Examples of reactions or changes could include phase changes, dissolving, and mixing that form new substances.] [Assessment Boundary: Assessment does not include distinguishing mass and weight.]

5-PS1.3. Make observations and measurements to identify materials based on their properties. [Clarification Statement: Examples of materials to be identified could include baking soda and other powders, metals, minerals, and liquids. Examples of properties could include color, hardness, reflectivity, electrical conductivity, thermal conductivity, response to magnetic forces, and solubility; density is not intended as an identifiable property.] [Assessment Boundary: Assessment does not include density or distinguishing mass and weight.]

5-PS1.4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

The performance expectations above were developed using the following elements from the NRC document A Framework for K-12 Science Education:

Science and Engineering Practices

Developing and Using Models
Modeling in 3-5 builds on K-2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.

Disciplinary Core Ideas

- Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that even air is made of particles that are too small to see.

Crosscutting Concepts

Cause and Effect
- Cause and effect relationships are routinely identified and used to explain change. (5-PS1.4)

Scale, Proportion, and Quantity
- Natural objects exist in drastically different sizes.
Overview: New Goals

- Focus on selected “big ideas” within and across disciplines
- Reflect an evolved vision of inquiry-based learning
  - Emphasis on science as a knowledge-building endeavor
  - Promote a practice-oriented approach
- Provide a progression for big ideas across grades
  - Research-based cognitive models of how learning scientific concepts and practices unfolds over time
  - Stresses coherence in the conceptual growth of scientific understanding across grades
‘Big Ideas’ in Science

Criteria for ‘Big Ideas’ within and across domains:

• Have broad importance across multiple disciplines, or be a key organizing principle of a single discipline;

• Provide a key tool for understanding or investigating more complex ideas and solving problems;

• Relate to the interests and life experiences of students or be connected to societal concerns that require scientific or technological knowledge;

• Be teachable and learnable over multiple grades at increasing levels of depth and sophistication
Disciplinary core idea: Inheritance and Variation of Traits

“Offspring acquire a mix of traits from their biological parents. Different organisms vary in how they look and function because they have different inherited information. In each kind of organism there is variation in the traits themselves, and different kinds of organisms may have different versions of the trait.”

<table>
<thead>
<tr>
<th>Former Standards</th>
<th>NGSS</th>
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<tbody>
<tr>
<td>K-4: Life Cycles of Organisms</td>
<td>3-LS3 Heredity: Inheritance and Variation of Traits</td>
</tr>
<tr>
<td>Plants and animals closely resemble their parents.</td>
<td>Analyze and interpret data to provide evidence that plants and animals have traits inherited from parents and that variation of these traits exists in a group of similar organisms.</td>
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- Notion of “variation” is an important stepping stone idea for building understandings in genetics and natural selection
Example of a Big Idea

Crosscutting concept: Systems and Systems Models

“Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.”

<table>
<thead>
<tr>
<th>Former Standards</th>
<th>NGSS</th>
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<tbody>
<tr>
<td>5-8: Structure And Function In Living Systems</td>
<td>MS-LS1 From Molecules to Organisms:</td>
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<tr>
<td></td>
<td>Structures and Processes</td>
</tr>
<tr>
<td>The human organism has systems for</td>
<td>Use argument supported by evidence</td>
</tr>
<tr>
<td>digestion, respiration, reproduction,</td>
<td>for how the <strong>body is a system of</strong></td>
</tr>
<tr>
<td>circulation, excretion, movement, control,</td>
<td><strong>interacting subsystems</strong> composed of</td>
</tr>
<tr>
<td>and coordination, and for protection from</td>
<td>groups of cells.</td>
</tr>
<tr>
<td>disease. These systems interact with one</td>
<td></td>
</tr>
<tr>
<td>another.</td>
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- New framing of specific concepts foregrounds and build connections with the crosscutting concepts
Science Practices: New Vision of Science Inquiry

Key feature in *Framework*: Core disciplinary concepts (‘Big Ideas’) are built and refined through engagement with practices of scientific inquiry

• Science is a **knowledge-building enterprise** that employs a systematic and **evidence-based** approach to building models that explain the world around us (Giere, 2004; Godfrey-Smith, 2006; Nersessian, 2002)
  • Models developed iteratively through a process of testing and revision

• **A community of research**, with continually negotiated **norms** regarding what counts as good evidence, arguments, and models (Kitchner, 1993; Kuhn, 1977; Latour, 1987)
  • Scientists develop **particular perspectives** about what is knowable, how to best come to know it, and what counts as knowing (epistemology)
  • These epistemological norms guide the development of valid and reliable knowledge
Problematizing the ‘Science Method’

Hypotheses are not grounded in model of phenomenon

Experimental strategies are used in an epistemological vacuum

No evidence given to support arguments, rarely entertain more than one plausible explanation

Observations and experiments are considered end goals, not a means to testing models and theories
Practices in the NGSS

- Science practices: Ways of participating in science that lead the community towards new understandings
  - Not just what, but how science is understood that matters

- Eight practices identified in NGSS:
  1. Asking questions and defining problems
  2. Developing and using models
  3. Planning and carrying out investigations
  4. Analyzing and interpreting data
  5. Using mathematics, information and computer technology, and computational thinking
  6. Constructing explanations and designing solutions
  7. Engaging in argument from evidence
  8. Obtaining, evaluating, and communicating information
Practice: Discuss the limitations and precision of a **model** as the representation of a system

- “The light from the Sun affects the changing of the seasons. It’s all-around light, so it [the flashlight] is not accurate. Like, you can’t really see it because it’s so faint. I mean, it’s hard to see it. Plus, a light bulb gives off heat, so that gives you the idea that the Sun gives off heat.”

- ID non-correspondences (flashlight and Sun)
- Suggest alternative (a light bulb) to have stronger correspondences with the real Earth system, improving the model’s precision.
Practices With Content

- Practice: Construct a **scientific argument** showing how data support a claim

  S1: *It [Earth] does spin on its axis.* . .

  S2: *Yeah, but which way? [pauses . . . S1 does not answer] Well, you know New York gets light before San Francisco?*

  S3: *Why do we know that?*

  S2: *San Francisco is three hours behind New York [grabs globe and locates United States]*

  S1: *Okay, okay.*

  S3: *Yes, I know that.*

  S2: *So that means that the Sun will hit there first [gestures with hand towards New York on the globe – spins globe slowly in a counterclockwise motion] and then it hits there [San Francisco]*

  S3: *Yeah, three hours later.*

  S1: *[still spinning globe counterclockwise] So then you know that it spins this way.*

  (Miller, et al, 2013)
Learning Progressions

- Descriptions of successively more sophisticated ways of thinking about a topic developed as children learn about and investigate a topic over a broad span of time (NRC, 2007)

- Not a simple accumulation of knowledge
  - Developmental approach to learning
  - Goal is understanding that is robust and applicable to broader phenomena

- Concepts are not repeated, but revisited with increasing complexity and epistemological rigor
LPs vs. Traditional Sequences

Vary from current scope and sequences in two important ways:

1. LPs are grounded in research about how students actually come to understand core ideas in the domain
   - Prior standards primarily rooted in normative paradigms
   - Intermediate steps may include variations from canonical knowledge

2. Focus on deepening understanding and adding increased complexity, applicability, and epistemological rigor through successive learning opportunities
   - Much more than adding information or details
Example: Forces and Motion

Idea about forces

Forces & Motion

Net forces act to move objects; no net force = stationary

Net force is proportional to acceleration

Force = push or pull to move something

Motion caused by force in that direction

(Alonzo & Steedle, 2008)
Stepping Stone Ideas

- Productive ‘misconceptions’
  - Stepping stones to deep understandings (Wiser et al, 2009)
  - Can be substantially different from accepted science concepts

- Middle school: Genetic information as specifying the structure, and consequently function, of proteins
  - Incomplete, but can explain how genes result in observable effects (Duncan et al, 2009)

- Elementary: Establish weight as a property of matter
  - Inaccurate, but supports idea that even invisible things (gas, atoms) have weight
  - Using “mass” at this level is meaningless and not helpful (Wiser et al, 2009)
Two distinct kinds of incorrect ideas:

1. Scientifically inaccurate ideas that are conceptually unproductive
   • Simply wrong

2. Inaccurate yet productive ideas that can foster learning of more sophisticated understandings
   • Incomplete, overly simplistic, or tied to only a few limited contexts

Productive yet inaccurate understanding are important building blocks in the learning process.
   • Curricula and standards should not shy away from these ideas as learning goals
Assessment Challenges

- Reciprocal relationship between LPs and assessments
- Assessment design challenges for intermediate levels
  - Responses not consistent across different item contexts and formats (Steedle & Shavelson, 2009)
- Challenge to assess content, practices, and epistemology
  - Often content is privileged over practice
  - Unclear how to interleave assessment of scientific reasoning
Assessing Learning Progressions
Wright Map

- Relation of student proficiencies to item difficulties
- Increasing difficulty across levels
- "Messy middle"
Comparison of Gain
### Implications for Science Instruction

- **New content expectations**
  - More robustness at younger grades
  - Expected understandings are more interrelated and contextualized

- **New pedagogical expectations**
  - Support for integrating content, practices, and ways of knowing
    - Make practices visible
    - Active engagement to build practices

- **New vision of science PCK**
  - Teachers’ integrated knowledge of content, practices, and epistemology with ways to support wide range of students
Future Directions

• Research on assessment of LPs: we need more sophisticated instruments and measurement models

• Stitching of LPs across grade bands and domains is a challenge the field has yet to explicitly tackle

• Need to better understand how the learning of concepts and practices bootstrap each other in different domains

• What does this look like across different learning settings?
Thank you!

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