Explaining Phenomena and Solving Problems as a Central Shift in the Next Generation Science Standards Vision for Science Teaching and Learning

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Science Education
Who Am I?

- Secondary Science Educator/Science Education Researcher

- Prior work includes high school teaching in biology, physics, chemistry, earth and environmental science & middle school science teaching (8th grade)

- Current work/research (past 10 years) includes pre-service and in-service teacher professional development focused on inquiry and model-based inquiry. Additional research focused on technology as a resource for teaching science.
Presentation Overview

- Brief Overview/Introduction of Next Generation Science Standards (NGSS)
- Three-Dimensional Learning as Sensemaking
- Examples of Sensemaking—developing and using models to explain phenomena
- Models in science and NGSS
- New experiences in professional learning/Resources for NGSS
- Criteria for identifying effective professional learning targeting NGSS
I was not on the writing committees for the NRC Framework or the NGSS. Therefore, insights I share about NGSS have come from the following:

- Reading the science education literature and engaging in research over the past 10 years
- Work with teachers in schools
- Reading and engaging in discussion about the NGSS with NGSS writers, researchers, and teachers
- Engaging in Professional Learning focused on NGSS
- Working with pre-service teachers to develop instruction aligned with NGSS
Next Generation Science Standards

1996

2007-2008

2012-2013
Three Dimensions of Science Learning Outlined in NRC Framework/Used to Frame NGSS

THE THREE DIMENSIONS OF THE FRAMEWORK

1 Scientific and Engineering Practices
1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

2 Crosscutting Concepts
1. Patterns
2. Cause and effect: Mechanism and explanation
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

3 Disciplinary Core Ideas

Physical Sciences
PS1: Matter and its interactions
PS2: Motion and stability: Forces and interactions
PS3: Energy
PS4: Waves and their applications in technologies for information transfer

Life Sciences
LS1: From molecules to organisms: Structures and processes
LS2: Ecosystems: Interactions, energy, and dynamics
LS3: Heredity: Inheritance and variation of traits
LS4: Biological evolution: Unity and diversity

Earth and Space Sciences
ESS1: Earth’s place in the universe
ESS2: Earth’s systems
ESS3: Earth and human activity

Engineering, Technology, and Applications of Science
ETS1: Engineering design
ETS2: Links among engineering, technology, science, and society
Science & Engineering Practices (S & EPs)

Berland (2011) describes practices as the habits of mind and processes undertaken by communities of scientists as they work to develop explanations and arguments for explaining natural phenomena and/or leverage science for making informed decisions as citizens.
Crosscutting Concepts (CCs)

CCs provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas. — Framework p. 233
Disciplinary Core Ideas (DCIs)

The role of science education is not to teach “all the facts” but rather to prepare students with sufficient core knowledge so that they can later acquire additional information on their own.

DCIs are core ideas in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science.
### NGSS Matrix Organized by Core Ideas

<table>
<thead>
<tr>
<th>Elementary School</th>
<th>Life Science</th>
<th>Earth &amp; Space Science</th>
<th>Physical Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>K-LS1 From Molecules to Organisms: Structures and Processes</td>
<td>K-ESS2 Earth’s Systems</td>
<td>K-PS1 Matter and Its Interactions</td>
</tr>
<tr>
<td></td>
<td>K-LS3 Heredity: Inheritance and Variation of Traits</td>
<td>K-ESS3 Earth and Human Activity</td>
<td>K-PS3 Energy</td>
</tr>
<tr>
<td>1</td>
<td>1-LS1 From Molecules to Organisms: Structures and Processes</td>
<td>1-ESS1 Earth’s Place in the Universe</td>
<td>2-PS4 Waves and Their Applications in Technologies for Information Transfer</td>
</tr>
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<td></td>
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<td>1-ESS2 Earth’s Systems</td>
<td>2-PS1 Matter and Its Interactions</td>
</tr>
<tr>
<td>2</td>
<td>2-LS2 Ecosystems: Interactions, Energy, and Dynamics</td>
<td>2-ESS1 Earth’s Place in the Universe</td>
<td>2-PS2 Motion and Stability: Forces and Interactions</td>
</tr>
<tr>
<td></td>
<td>2-LS4 Biological Evolution: Unity and Diversity</td>
<td>2-ESS2 Earth’s Systems</td>
<td>2-PS3 Energy</td>
</tr>
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<td>3-ESS2 Earth’s Systems</td>
<td>3-PS2 Motion and Stability: Forces and Interactions</td>
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<thead>
<tr>
<th>Middle School</th>
<th>Life Science</th>
<th>Earth &amp; Space Science</th>
<th>Physical Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS-LS1 From Molecules to Organisms: Structures and Processes</td>
<td>MS-ESS1 Earth’s Place in the Universe</td>
<td>MS-PS1 Matter and Its Interactions</td>
<td></td>
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<td>MS-LS2 Ecosystems: Interactions, Energy, and Dynamics</td>
<td>MS-ESS2 Earth’s Systems</td>
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<td>MS-LS3 Heredity: Inheritance and Variation of Traits</td>
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<thead>
<tr>
<th>High School</th>
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<th>Physical Science</th>
</tr>
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<tbody>
<tr>
<td>HS-LS1 From Molecules to Organisms: Structures and Processes</td>
<td>HS-ESS1 Earth’s Place in the Universe</td>
<td>HS-PS1 Matter and Its Interactions</td>
<td></td>
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<td>HS-LS2 Ecosystems: Interactions, Energy, and Dynamics</td>
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**Note:** The core ideas for Engineering, Technology, and the Application of Science are integrated with the Life Science, Earth & Space Science, and Physical Science core ideas.
The framework (and NGSS) emphasizes developing students’ proficiency in science coherently across grades K-12 using learning progressions.

Learning Progressions are pathways for students to learn successively more sophisticated ways of thinking about core concepts of science (i.e., DCIs) from kindergarten through high school.
### Progressions Across K-12

#### Earth Space Science Progression

**Increasing Sophistication of Student Thinking**

<table>
<thead>
<tr>
<th>ESS1.A</th>
<th>The universe and its stars</th>
<th>K-2</th>
<th>3-5</th>
<th>6-8</th>
<th>9-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patterns of movement of the sun, moon, and stars as seen from Earth can be observed, described, and predicted.</td>
<td>Stars range greatly in size and distance from Earth and this can explain their relative brightness.</td>
<td>The solar system is part of the Milky Way, which is one of many billions of galaxies.</td>
<td>Light spectra from stars are used to determine their characteristics, processes, and lifecycles. Solar activity creates the elements through nuclear fusion. The development of technologies has provided the astronomical data that provide the empirical evidence for the Big Bang theory.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ESS1.B</th>
<th>Earth and the solar system</th>
<th>K-2</th>
<th>3-5</th>
<th>6-8</th>
<th>9-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Earth’s orbit and rotation, and the orbit of the moon around the Earth cause observable patterns.</td>
<td>The solar system contains many varied objects held together by gravity. Solar system models explain and predict eclipses, lunar phases, and seasons.</td>
<td>Kepler’s laws describe common features of the motions of orbiting objects. Observations from astronomy and space probes provide evidence for explanations of solar system formation. Changes in Earth’s tilt and orbit cause climate change.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ESS1.C</th>
<th>The history of planet Earth</th>
<th>K-2</th>
<th>3-5</th>
<th>6-8</th>
<th>9-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some events on Earth occur very quickly; others can occur very slowly.</td>
<td>Certain features on Earth can be used to order events that have occurred in a landscape.</td>
<td>Rock strata and the fossil record can be used as evidence to organize the relative occurrence of major historical events in Earth’s history.</td>
<td>The rock record resulting from tectonic and other geoscience processes as well as objects from the solar system can provide evidence of Earth’s early history and the relative ages of major geologic formations.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ESS2.A</th>
<th>Earth materials and systems</th>
<th>K-2</th>
<th>3-5</th>
<th>6-8</th>
<th>9-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind and water change the shape of the land.</td>
<td>Interactions between rainfall helps shape the land and affects the types of living things found in a region. Water, ice, wind, organisms, and gravity break rocks, soils, and sediments into smaller pieces and move them around.</td>
<td>Energy flows and matter cycles within and among Earth’s systems, including the sun and Earth’s interior as primary energy sources. Plate tectonics is one result of these processes.</td>
<td>Feedback effects exist within and among Earth’s systems.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ESS2.B</th>
<th>Plate tectonics and large-scale system interactions</th>
<th>K-2</th>
<th>3-5</th>
<th>6-8</th>
<th>9-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maps show where things are located. One can map the shapes and kinds of land and water in any area.</td>
<td>Earth’s physical features occur in patterns, as do earthquakes and volcanoes. Maps can be used to locate features and determine patterns in those events.</td>
<td>Plate tectonics is the unifying theory that explains movements of rocks at Earth’s surface and geological history. Maps are used to display evidence of plate movement.</td>
<td>Radioactive decay within Earth’s interior contributes to thermal convection in the mantle.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Integrating the Three Dimensions and Performance Expectations

2. Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:
2-LS2-1. Plan and conduct an investigation to determine if plants need sunlight and water to grow. [Assessment Boundary: Assessment is limited to testing one variable at a time.]
2-LS2-2. Develop a simple model that mimics the function of an animal in dispersing seeds or pollinating plants.*
2-LS4-1. Make observations of plants and animals to compare the diversity of life in different habitats. [Clarification Statement: Emphasis is on the diversity of living things in each of a variety of different habitats.] [Assessment Boundary: Assessment does not include specific animal and plant names in specific habitats.]

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 K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.
- Develop a simple model based on evidence to represent a proposed object or tool. (2-LS2-2)

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions.
- Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence to answer a question. (2-LS2-1)
- Make observations (firsthand or from media) to collect data which can be used to make comparisons. (2-LS4-1)

Disciplinary Core Ideas

LS2.A: Interdependent Relationships in Ecosystems
- Plants depend on water and light to grow. (2-LS2-1)
- Plants depend on animals for pollination or to move their seeds around. (2-LS2-2)

LS4.D: Biodiversity and Humans
- There are many different kinds of living things in any area, and they exist in different places on land and in water. (2-LS4-1)

ETS1.B: Developing Possible Solutions
- Designs can be conveyed through sketches, drawings, or physical models. These representations are useful in communicating ideas for a problem’s solutions to other people. (secondary to 2-LS2-2)

Crosscutting Concepts

Cause and Effect
- Events have causes that generate observable patterns. (2-LS2-1)

Structure and Function
- The shape and stability of structures of natural and designed objects are related to their function(s). (2-LS2-2)

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence
- Scientists look for patterns and order when making observations about the world. (2-LS4-1)
Three-Dimensional Science Learning

Engaging in science and engineering practices to use disciplinary core ideas and crosscutting concepts to explain phenomenon or solve problems
Biggest Shifts in NGSS

Three-dimensional learning for the purpose of sensemaking through explaining phenomena or solving problems

Shifting from ‘learning about’ to ‘figuring out’!
Examples of Sensemaking—Developing and Using Models to Explain Phenomena

Revised Model (Buoyancy)

F_N = Net Force
F_B = Buoyant Force
\( \downarrow \) = Forces
w = weight
P = pressure
C = Coke can
OC = Diet Coke can

Experiment #1

- Because the cans have the same volume, they displace the same amount of water (push on the water with the same force) and the water will push back (with the same force on each can, Newton’s 3rd law).

- The coke can sank because it had a greater weight and was able to overcome the \( F_B \) (force of the water pushing on the can).

- Depth does not affect the \( F_B \), because as the object goes deeper, the pressure increases on all sides and will have the same net force at all depths.

(Neutral forces highlighted in red’s)

Experiment #2

- The Ketchup packet has a big volume so it will press on the water and the water will press back with the same force, enough to overcome the weight of the object (Newton’s 3rd law).

- Once you squeeze the bottle the pressure will increase and the Ketchup packet will be “squeezed” decreasing its volume. This means the packet will be pressing on the water with a smaller force and the water will be pressing back with a smaller force (Newton’s 3rd law). The weight of the packet will overcome the force of the water and will sink.
A role for modeling in NGSS

Although we do not expect K-12 students to be able to develop new scientific theories, we do expect that they can develop theory-based models and argue using them . . . to develop explanations. (National Research Council, 2012, p. 48)
Why Models?

NGSS focus on sensemaking or explaining phenomena/solving problems

Models requires/mobilizes other SE & Ps, DCIs, CCs
Our work (6-7 yrs)

• Identifying design strategies supportive of engaging students in modeling

• Sequencing design strategies effectively in modules

• Considering how modules can be strategically located within year long curriculum

• Researching teaching pedagogies and teacher and students discourse as teachers engage students in developing and using models
Design Strategies

• Complex Anchoring Phenomena
• Unpacking Explanations
• Gotta-Have-Lists
• Partitioned Modeling Templates
• Investigations
• Summary Tables
A complex anchoring phenomenon is an occurrence or event that happen(ed) in our world.

- Rocket Launching
- Tanker Car Imploding
Complex Anchoring Phenomena Affordances

- Elicits students’ prior knowledge

- Explained by the coordination of multiple science principles

- Can lead to different students investigations that are useful in refining an explanatory model of the anchoring phenomenon

- Connect science learning to daily lives (Campbell, Neilson Oh, 2013).
Complex Anchoring Phenomena in Exemplar Unit

Explaining Ramps with Models
The two balls will roll the same distance, so the ball with the highest average speed will reach the end first. Both balls begin accelerating at the same rate. This means that they increase their speed (in this case our goal was not to make a distinction between speed and velocity and accepted either term) the same amount each second. Speed is a measure of how far an object moves in a certain amount of time. If an object’s speed is increasing, the distance it travels each second must increase as well. So in section B (see Figure 2), since the steepness is identical, the balls will each increase their speed the same amount each second. Connecting this with speed, we can say that the balls will both move the same distance each second and they will move a greater distance than the second before. When the balls reach the beginning of section C, they will still be tied and in the same position as each other.

During section C, ball 2 accelerates while ball 1 remains moving at a constant speed. During section D, Ball 2 will begin to move ahead of ball 1 because it is going a larger distance each second than is ball 1 (ball 2 has a higher speed). At the end of section D, ball 2 is ahead of ball 1.

During section D, both balls move at a constant speed, the distance covered each second for each ball does not change, but the speed of ball 1 is less than ball 2. Every second, ball 1 will roll a smaller distance than will ball 2. The result is that ball 2 continues to increase its lead.

At section E, ball 2 will begin slowing down since it is going up the incline. Since its speed is decreasing, the amount of distance it covers each second will decrease as well. It is interesting to note that ball 2 will still cover more distance each second than will ball 1 until the speeds match. This occurs at the end of section E. At this time, both balls have the same speed and will travel the same distance each second. Since ball 2 is ahead of ball 1 and both are covering the same distance each second, ball 2 reaches F first.
Unpacking Explanations
Affordances

- Explanation used to identify the important science principles critical for providing a scientifically acceptable explanation of the phenomenon.

<table>
<thead>
<tr>
<th>Important science principle derived from the <em>Unpacking Explanation</em></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principle Identified</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Speed is a measure of how far something travels in a certain amount of time.</td>
</tr>
<tr>
<td>B</td>
<td>Acceleration is a measure of how much change there is in velocity (the use of the term speed is ok for this demo) in a certain amount of time. Acceleration to a physicist can also be used for an object whose speed is decreasing.</td>
</tr>
<tr>
<td>C</td>
<td>An object that has a higher speed than another travels farther each second than the slower moving object.</td>
</tr>
<tr>
<td>D</td>
<td>When there is no acceleration, there will be no change in speed.</td>
</tr>
</tbody>
</table>
Unpacking Explanations

Affordances

• The identified principles can then be introduced or highlighted in various ways throughout the unit to help students consider how the principles can contribute to their evolving explanatory models of the anchoring phenomenon
The ‘Gotta-Have-List’ is a “set of ideas [or tools for thinking (e.g., DCIs, CCs)] students think must be included in the final explanatory model” (Windschitl & Thompson, 2013, p. 66).

- Must address speed/velocity
- Must address acceleration
- Distance traveled has to be discussed
- Energy? (Maybe)
- Forces? (Maybe)
Gotta-Have-Lists

- Iteratively developed across the unit
- Students generally develop the ‘Gotta-Have-Lists’ with assistance and guidance from the teacher.

**Affordance**
- Helps hold students accountable for making sense of ideas and how they can be used in explaining the anchoring phenomenon.
Partitioned Modeling Templates

A representational template given to students that is partitioned to amplify changes in the complex anchoring phenomenon over time.
Partitioned Modeling Templates

• Important, since representing models on paper often leads students to focus on static aspects of the phenomenon. However, the most important features of most phenomena are a result of changes in the phenomena over time.

Affordance
• Presses students to consider important dynamic features of the model.
Investigations

Formal and informal experiences students have collecting evidences to support or refute their emerging explanatory models

- Students created position vs. time graphs to support their idea that objects with higher speeds travel farther than objects going slower.
- Students created position vs. time graphs to show that objects that are not accelerating cover the same amount of distance each second.
- Students developed conjectures about how they would modify the ramps so a tie resulted or how Ball 1 might get to the end of Ramp 1 before Ball 2 gets to the end of Ramp 2. Students used flexible plastic track to make modifications and to gather evidence (un)supportive of their conjectures.
Investigations

- Identified to help understand a component of the developing model that seems most tentative or that would benefit from additional supporting evidence (Campbell et al., 2012a, 2012b).

Affordance

- Afford students the opportunity to engage in a range of science practices to better understand how these practices can contribute to a developing explanatory model and to develop a deeper understanding of the nature of science connected to science practices (Duschl, 2012).
Summary Tables

A public record in the classroom for recording new evidences and arguments as they occur across a unit.

Three columns: (a) the activity or investigation completed, (b) patterns or observations, (c) what we think caused patterns or observations (Windschitl & Thompson, 2013).
Summary Tables

• Serves as a public forum and record for making sense of activities within the unit

Affordance
• Useful for helping students make sense of activities in the unit with classmates and the teacher
• Useful in helping frame revisions and final versions of small group or class explanatory models
Design Strategies Sequenced

Complex Anchoring Phenomenon

- Unpacking Explanations
- Students Introduction to Phenomenon
- Gotta-Have-Lists
- Partitioned Modeling Templates/Students Initial Models
- Investigations
- Summary Tables
- Final Models
New experiences in professional learning/Resources for NGSS

Welcome to the Next Generation Science Exemplar System for Professional Development, or NGSS. NGSS is a web-based PD environment designed to engage teachers in the major ideas of the National Research Council’s Framework for K-12 Science Education and the student performance expectations found in the Next Generation Science Standards.

For more information about our project, please see the About NGSS page.

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Password
Sign In »

Registration Now Open for New Virtual Conference: NGSS Practices In Action

Are you looking for practical strategies for integrating the Next Generation Science Standards (NGSS) into your classroom? Join NSTA for an intensive one-day virtual conference to learn how to apply the NGSS practices with K-12 students. During this web-based professional learning opportunity participants will:

• Explore the practices modeling, explanation and argumentation, and engineering
• Learn about specific strategies by grade level and discipline
• Ask questions of NGSS experts
• Engage in dialogue with science educators from across the country

Hone your understanding of NGSS and discover methods to use in your classroom right away during this can’t-miss opportunity. Explore the agenda and register today!

Date: Saturday, November 16, 2014
Time: 10 a.m. – 8 p.m. ET
9 a.m. – 5 p.m. CT
8 a.m. – 4 p.m. MT
7 a.m. – 3 p.m. PT

Member price: $79 | Nonmember price: $99

#NGSSchat
Every other Thursday 9-10 EST

NGSS@NSTA
STEM STARTS HERE
Criteria for identifying effective professional learning targeting NGSS

**PD Involves**
- Teacher sensemaking around rich images of classroom
- Teachers working collaborative to apply NGSS to their own classroom enactment
- Capitalize on cyber-enabled environments
Thank you!

For references or any other resources/questions:

[Email Address] todd.campbell@uconn.edu