# Phenomenal Science Team

## Project Management Team
- **Darcy McMahon**
  - Phenomenal Science Project Director
  - Science Mathematics Technology Center

- **Matt Samocki**
  - Phenomenal Science Project Manager
  - Science Mathematics Technology Center

## Phenomenal Science Coaches
- **Jennifer VanDaele**
  - Kindergarten Coach, Science Editor
  - Lenawee ISD

- **Erin Davis**
  - First Grade Coach
  - Birch Run Public Schools

- **Jennel Martin-Powell**
  - Second Grade Coach
  - Science Mathematics Technology Center

- **Bo Winkler**
  - Third grade coach
  - Wink’s PLACE Consulting, LLC

- **Joe Austin**
  - Fourth Grade Coach
  - Waterford Schools

- **Elizabeth Christiansen**
  - K-5 Coach
  - Science Mathematics Technology Center

- **Jessica Ashley**
  - Fifth Grade Coach
  - Oakland Schools

- **Theresa Schroeder**
  - K-5 Coach
  - Bullock Creek School District

- **Sheila Bartle**
  - Editor
  - GivVoice

- **Rochelle Rubin**
  - 3-5 Reader
  - Oakland Schools

- **Megan Coonan**
  - K-5 District Coordinator
  - Bangor Township Schools

## Authors
### Kindergarten Authors
- **Cori Bierlein**
  - Bangor Township Schools

- **Patricia Clancy**
  - Midland Public Schools

- **Olivia Flores**
  - Perry Public Schools

- **Lisa Warren**
  - Trinity Lutheran School

### First Grade Authors
- **Alice Ernst**
  - Perry Public Schools

- **Sarah Fox**
  - Fulton Schools

- **Sarah Nevins**
  - Fulton Schools

- **Lori Taglauer**
  - Bangor Township Schools

### Second Grade Authors
- **Julia Adler**
  - Troy School District

- **Melissa Batts**
  - Troy School District

- **Kim Fluder**
  - Saginaw Township Community Schools

- **Jennifer Knoll**
  - Pinconning Area Schools

- **Julie Leach**
  - Frankenmuth School District

- **Tosha Miller**
  - Frankenmuth School District

- **Mary Kate O'Meara**
  - Groves Pointe Public Schools

- **Tracey Pitchford**
  - Ferris Area Schools

- **Clayton Spencer**
  - Ferris Area Schools

### Third Grade Authors
- **Jodi Bilacic**
  - Au Gres Schools

- **Nikki Broadstone**
  - Pinconning Area Schools

- **Ashly Ginderske**
  - Saginaw Township Community Schools

- **Holley Hart**
  - Pinconning Area Schools

- **Alexandria Hill**
  - Bangor Township Schools

- **Jacob Kaufman**
  - Arenac Eastern Schools

- **Arica Klopf**
  - Saginaw Township Community Schools

- **Emily Ramaya**
  - Pinconning Area Schools

### Fourth Grade Authors
- **Mary Burgess**
  - Roseville Community Schools

- **Sara Engelhardt**
  - Bangor Township Schools

- **Holly Fouchia**
  - Pinconning Area Schools

- **Deneal Johnson**
  - Pinconning Area Schools

- **Jeffrey Katt**
  - Standish-Sterling Community Schools

- **Steven Mankey**
  - Midland Public Schools

- **Heather Norman**
  - Jackson Public Schools

- **Lisa Rando**
  - Jackson Public Schools

### Fifth Grade Authors
- **Carrie Carncross**
  - Ferris Area Schools

- **Jodie Gould**
  - Harrison Community Schools

- **Amy Klopf**
  - Coleman Community Schools

- **Christy Macias**
  - Saginaw Township Community Schools

- **Jennifer Meyers**
  - Bangor Township Schools

- **Amy Mika**
  - Bangor Township Schools

- **Sonja Pohlsen**
  - Godfrey-Lee Public Schools

- **Hazel Thomas**
  - Saginaw Public Schools

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Special Thanks to our Field Testing Districts

Allegan Public Schools
Allen Park Public Schools
Alma Public Schools
Armada Area Schools
Auburn Area Catholic School
Bangor Township Schools
Bay-Arenac ISD
Berkley Schools
Birch Run Area Schools
Breckenridge Community Schools
Brighton Area Schools
Chippewa Valley Schools
Christian Schools International
Clare-Gladwin RESD
Comstock Park Public Schools
Crossroads Charter Academy
Dexter Community Schools
Essexville-Hampton Public Schools
Farwell Area Schools
Gladwin Community Schools
Godfrey Lee Public Schools
Grand Haven Area Public Schools
Grand Rapids Public Schools
Gratiot-Isabella RESD
Hamilton Community Schools
Harrison Community Schools
Hartland Consolidated Schools
Hudsonville Public Schools
Jackson Public Schools
Kent ISD
Lake Shore Public Schools
Lakewood Public Schools
L’Anse Creuse Public Schools
Lincoln Consolidated Schools
Macomb ISD
Manchester Community Schools
Mt. Pleasant Public Schools
Oakland Schools
Ottawa Area ISD
Perry Public Schools
Princeton Area Schools
Roseville Community Schools
Saginaw Chippewa Academy
Saginaw Township Community Schools
Shepherd Public Schools
St. Louis Public Schools
Standish-Sterling Community School District
Thornapple Kellogg School District
Utica Community Schools
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Vestaburg Community Schools
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Background

Phenomenal Science Units were developed as a result of collaboration between Michigan Virtual University and the Science, Mathematics, and Technology Center at Central Michigan University. In conversations with teachers, districts, and ISD’s in the Great Lakes Bay Region, it became apparent that, first, there was a great need for elementary science curriculum to meet the Next Generation Science Standards, and second, that educators in the region were eager to collaborate to develop such a curriculum. With generous support from Michigan Virtual University, the Science, Mathematics, Technology Center was enthusiastic about taking on the coordination of the project. The project gained momentum and interest from educators around the state, including Oakland Schools, creators of the Oakland Scope Units for science. A key collaborator, Oakland Schools has been working diligently in shaping the units. The result, after 3 years and countless hours on the part of grade level Teacher Leaders, are the units contained here. These units will continue to be a work in progress because every time we use them with students we learn more about how to better use them. For more information about teaching in a Phenomenal Science manner, please consult the Phenomenal Science Teacher's Guide, contact the SMTC for professional learning, or connect to MVU’s online learning course Introduction to Phenomenal Science. The Phenomenal Science website has further information about the Phenomenal Science project.

These units are aligned to the Michigan Science Standards (and the NGSS) and intentionally focus on all three dimensions of those standards including Disciplinary Core Ideas, Science and Engineering Practices, and the Cross-Cutting Concepts. All Phenomenal Science units include some integration of the reading and the writing strands of the Michigan English Language Arts Standards (CCSS-ELA) and the Mathematical Practices of the Michigan Mathematics Standards (CCSS – Mathematics). Phenomenal Science meets three critical needs lacking in elementary science: time, accessible quality resources, and comfort with teaching science and promotes science instruction as a process of student sense-making.

Science learning research is foundational to Phenomenal Science and includes constructivist approaches, social learning theories, neuroscience applications, higher order thinking, inquiry, and the crucial evidence of A Framework for K-12 Science Education.

Supported by research, the units were developed by teachers to address the lack of updated curricular materials and provide resources to shift instruction to meet all three dimensions of NGSS. These free phenomena-based units include assessments, lessons, handouts, and links to resources to engage students in sense-making around science phenomena. Currently the average access of units is 900 units/month.

To maximize time for science, the units include integration of Math and English Language Arts. Engineering is taught throughout and student use of technology is embedded. Our current rate of implementation by trained teachers is approximately 54% of each unit, many of whom were formerly teaching little to no science.

To build comfort with the NGSS instructional shifts, Phenomenal Science incorporates both face to face and online professional learning. Further online resources include a Teacher’s Guide, Website, and Blogs. Our initial results from professional learning show teachers’ substantial growth in NGSS comfort level and instructional strategy understanding.
Phenomenal Science Philosophy

The following theories form the research support base for Phenomenal Science Core Principles and Key Instructional Strategies. Thus everything we do in Phenomenal Science is founded on these. This section of the PS Teacher’s Guide is meant to be a brief introduction. For more in-depth information about the research foundations of Phenomenal Science please see Research Based Theories and Models.

- **Constructivism** - Based on research by Piaget, and many others, this theory about how students learn suggests that learning construct their own understanding of phenomena based on experiences and processing. Student driven and evidence-based investigations and experiences are key instructional moves as constructivist teachers. See the Constructivism Blog for more information.

- **Social Learning Theory** - Starting with Vygotsky’s research, this theory supports the idea that students learn within a community. The community includes peers, teachers, other adults, and home and family life as well. Discourse, talk moves, and whole-class processing strategies become critical learning strategies as a result. See the Social Learning Theory Blog for more information.

- **Inquiry Instructional Model** - As an outgrowth of Constructivist Learning and Social Learning Theory, Dewey’s Inquiry Based Learning in the form of Guided Inquiry becomes the backbone of Phenomenal Science units. Each instructional Cycle follows a modified “Five E Approach” as proposed by Bybee. This model helps us ensure that investigations happen prior to asking students to develop concepts and that student concepts have begun forming before we introduce vocabulary or expert voice. See the Inquiry Blog for more information.
- **Brain Compatible Teaching** - Building on research from Kolb, Gardner, Tomlinson and Jensen, and the field of neuroscience, we have termed this supporting research “Brain Compatible Teaching.” In a nutshell, this research supports engaging students with information in many multiple formats and approaches, as well as connecting meaning and emotion and understanding students’ background and needs. See the Brain Compatible Teaching Blog for more information.

- **Higher Order Thinking** - “A central goal of science education is to help students to develop higher order thinking skills, enabling them to think critically, ask significant questions, reason, and solve problems (Bybee and DeBoer 1994; Zohar and Dori 2003; Zoller 1993).” Research by Bloom and Webb show it is critical to have students build deep understanding through high level application of their learning. See the Higher Order Thinking Blog for more information.

- **Understanding by Design** - “The Understanding by Design framework is guided by research from cognitive psychology.” Developed by Wiggins & McTighe, “Understanding by Design (UbD) is a framework for improving student achievement through standards-driven curriculum development, instructional design, assessment” (McTighe & Seif, 2011) The UbD framework was applied during the curriculum development of all Phenomenal Science Units. For more information see the Understanding by Design Blog.

- **Place-Based Education** - PBE is an educational approach in which aspects of the community and environment help form the context for learning. Phenomena from the natural and built environment become a starting place for investigation and application to make a difference in local communities. (Montessori Saskatoon, 2015) As stated by Sobel, “place-based education has the potential to transform the very nature of schools.” (Sobel, 2002, p. 588) Research has shown that PBE boosts student achievement. (Place-based Education Evaluation Collaborative, 2010)
- Attending to Equity - There is a persistent achievement gap in STEM fields in America based on income-levels and cultural heritage. Attending to “Equity is ‘not about offering or producing sameness,’ but about ensuring that all young people can ‘live the richest life possible and reach their full academic potential.’” (Shea, 2015a, p. 1) As recommended in the Framework, Phenomenal Science strives to bridge the equity gaps by building on all learners’ experiences and developmental strengths in sense-making. It has been shown that “learning improves when varied student experiences are made relevant in informal and formal learning environments.” (Shea, 2015b, p. 1)

- Current Science Education Research - From Taking Science to School to the Framework for K-12 Science Education and many leading researchers in science education today, research shows that a balance of investigations with sense-making practices within a fully three-dimensional, phenomena focused, collaborative problem-solving culture allows for best student learning of science. For more information, see the Current Science Education Research Blog.
### Instructional Cycles

Each unit in the Phenomenal Science curriculum is divided into Instructional Cycles. The units range from 2-4 instructional cycles per unit with most units having 3 instructional cycles. The instructional cycles follow the Cycle of Inquiry as explained in the table below.

<table>
<thead>
<tr>
<th>The Focus Question for the Cycle</th>
<th>Each cycle has one open-ended driving question that relates to all the content and skills of the unit. The Key Question is presented at the opening of the cycle and revisited at the cycle’s conclusion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engage and Elicit</td>
<td>Each unit begins with an activity designed to elicit and reveal student understanding and skill prior to instruction. Teachers are to probe students for detailed and specific information while maintaining a non-evaluative stance. They also can record and manage student understanding which may change as instruction proceeds.</td>
</tr>
<tr>
<td>Explore</td>
<td>A sequence of activities provides opportunities to explore phenomena and relationships related to the Key Question of the unit. Students will <strong>develop</strong> their ideas about the topic of the unit and the Key Question as they proceed through the Explore stage of the learning cycle. Each of the activities may have its own Focus Question or central task that will be more focused than the unit question. The heart of these activities will be scientific investigations of various sorts. The results, data and patterns will be the topic of classroom discourse and/or student writing. A key goal of the teacher is to reference the Key Question of the cycle, the Engage and Elicit of the students and to build a consensus especially on the results of the investigations.</td>
</tr>
<tr>
<td>Explain</td>
<td>Each unit has at least one activity in the Explain portion of the unit when students reconcile ideas with the consensus ideas of science. Teachers ensure that students have had ample opportunity to fully express their ideas and then to make sure accurate and comprehensible representations of the scientific explanations are presented. A teacher lecture, reading of science text, or video would be appropriate ways to convey the consensus ideas of science. Relevant vocabulary, formal definitions and explanations are provided. It’s critical that the activity and supporting assessments develop a consensus around the Key Questions and concepts central to the unit.</td>
</tr>
<tr>
<td>Elaborate</td>
<td>Each unit cycle has at least one activity or project where students discover the power of scientific ideas. Knowledge and skill in science are put to use in a variety of types of applications. They can be used to understand other scientific concepts or in societal applications of technology, engineering or problem solving. Some units may have a modest Elaborate stage where students explore the application of ideas by studying a research project over the course of a day or two. Other units may have more robust projects that take a few weeks.</td>
</tr>
<tr>
<td>Evaluation</td>
<td>While assessment of student learning occurs throughout the unit as formative assessment, each unit will have a summative assessment. Summative assessments are posted in a separate document.</td>
</tr>
</tbody>
</table>
As teachers look for ways to have students use real-world data, apply interactive technology to real-world questions and foster meaningful tasks for reading, writing, argumentation and mathematics and framed by the Common Core Curriculum Standards, the issues here provide abundant opportunity. The main limitation is the class time available given other content demands.

Inquiry

IN AN INQUIRY-BASED LEARNING ENVIRONMENT THE TEACHER'S JOB IS NOT TO PROVIDE KNOWLEDGE, BUT TO HELP STUDENTS ALONG THEIR PROCESS OF DISCOVERING KNOWLEDGE.
Phenomenal Science Core Principles

The Phenomenal Science Units are founded on research-backed beliefs about the process by which students construct their understanding of science. These beliefs and values underlie our instruction and curriculum development in the form of Core Principles. Here are the PS Core Principles in summary:

1. **Phenomena-Based Engagement:** In every instructional cycle, students encounter a puzzling event that really happens and are challenged to explain it. They develop their own explanation through intentional application of the Science and Engineering Practices, building understanding of core ideas, and consideration of the phenomena through the lens of a particular cross-cutting science concept. Through this active engagement, students must develop their own concept of the scientific phenomena under investigation
   a. **Evidence is the heart of the scientific enterprise.** Students generate evidence and analyze patterns in data that help to construct scientific explanations around key questions.
   b. **Science Driven Integration of content areas** allows for a synergy that leads to greater understanding in all content areas. Students who read and write about science phenomena after engaging in hands-on investigation of the phenomena, have much greater understanding about both the phenomena and what they read or write about it. The Michigan Department of Education has identified the new science standards as an opportunity for Supporting Early Literacy Development and that science is an ideal vehicle for this integration.

2. **Student Centered / Student Driven** – Instruction begins with the student’s ideas and understanding and follows the growth of the student throughout the instructional cycle.
   a. It’s critical to **elicit prior knowledge** as a unit or lesson begins.
   b. **Key questions** about Real World Phenomena should be student focused and drive student explorations and investigations.
   c. **Assessment** of knowledge, skill, and reasoning should involve students throughout the learning process and be well aligned to the main objectives and activities of the unit.

3. **Students discover and develop concepts through inquiry**
   a. **Activity Before Concept** – Student inquiry-based explorations which give personal experience with phenomena and ideas should precede a presentation of science ideas.
   b. **Concept Before Vocabulary** – Attaching science vocabulary to concepts developed by student investigations yields more success than beginning a unit or lesson with a list of science vocabulary.
   c. **Application** of the ideas to explain phenomena and / or engineer solutions provides review, extends understanding, and reveals relevance of important ideas.
      i. Inquiry Model of Instruction

4. **Understanding is Constructed Socially** through discourse and processing activities.
   a. **Talk, argument and writing** are central to scientific practice and are among the most important activities that develop understanding.
   b. Development of a healthy **Classroom Culture** by setting classroom norms and teaching students how to engage in productive discourse is vital to engaging students science discourse for deep science learning.
Phenomenal Science Key Instructional Strategies

The following Key Instructional Strategies are supported by the Core Principles of Phenomenal Science. They are powerful teaching strategies because they engage students in constructing their own understanding about science phenomena.

**Doing Science to Learn Science** While actively engaged in practicing science process to learn content and build conceptual understanding, students are developing understanding of science as a way to solve problems and make sense of the world.

*Anchoring Phenomena* Engaging learners in constructing their understanding of real puzzling phenomena causes them to build understanding in all three dimensions.

*Multiple Iterations* Students require more than one opportunity to construct understanding of a phenomena. Revising their thinking becomes a natural part of the process and is a necessary step to learning.

*Investigations* Hands on explorations of phenomena are critical for concrete elementary thinkers to develop their ideas. Investigations in Phenomenal Science are not intended to be “cookbook labs” in which students confirm understanding or get cookie-cutter results. Instead they strive to be more open-ended and enable students to gather evidence toward building understanding of the anchoring phenomenon.

*Modeling* Engaging students in developing, using, and revising their own models is critical to developing their understanding of science concepts.

*Summary Tables* Sometimes used in the form of “KLEWS Charts,” these tools allow a class to gather evidence over multiple investigations and iterations of the same phenomenon over the course of an Instructional Cycle. They will be posted in the class and may also be tracked in notebooks.

*Scientific Method vs Methods of Scientists* Because it is our intention to engage students in developing understanding of phenomena the way scientists do, Phenomenal Science does not incorporate a specific step-by-step version of the scientific method. Rather, particular skills are introduced and applied as needed.

*Science-Driven Integration of ELA / Math / Technology* What we find is that students understanding when developed in this synergistic way, is greater in ALL subjects than it would be in just spending more time on those subjects. As a result, Phenomenal Science has been very intentional about integrating speaking, listening, reading, writing, and math around real science, technology, and engineering experiences

*Exploration Stations* Also called Science Centers or Science Tables, these stations are employed in several Phenomenal Science units and can be incorporated into a regular rotation of learning centers. This is typically an opportunity for students to have more hands-on engagement with investigations, or more independent investigations of related phenomena.
Evidence-Based Thinking Making Thinking Visible / Audible Throughout each cycle, particularly while engaged in the Science and Engineering Practices, students will make their thinking visible to the teacher and especially for peers. Using these strategies, students are making their thinking visible / audible to build the teacher-student feedback loop.

**Science Notebooking** It is recommended that teachers require students to use an interactive science notebook to support learning in this unit. A major goal of a science notebook is for students to develop the ability to collect data, make sense of them and share with others.

**Class Question Maps** Also called “Driving Question Boards,” these are a tool for gathering students questions and co-developed answers to them. They are posted in the classroom and sometimes also captured in notebooks.

**Collaborative Groups** Because students generate their understanding through processing experiences and within social settings, collaborative groups are a key instructional strategy within Phenomenal Science.

**Evidence-Based Investigations / Talk / Writing** All discourse, visible thinking and student writing should be based on evidence that students have generated or gathered. Written evidence should be gathered in student notebooks when informal.

**Explanatory and Argumentative Speaking and Writing** Both explanatory and argument speaking and writing are critical to building deep understanding of concepts. They work together but are still distinctly different. Many informal opportunities are embedded in the units such as in discourse, spoken prompts for collaborative groups, and written notebook jots. More formal examples tend to occur toward the end of instructional cycles and units. These are also key areas for integration with language arts.

**Science Discourse / Talk Moves** Students build science understanding of concepts through processing of hands on investigations and activities. Their first mode of processing is talk.

**Concept Maps** Through use of concept maps as a processing tool, students can track their thinking and revise understanding in notebooks and together in collaborative groups.
## Scope and Sequence of Grade Level Units

The Phenomenal Science Scope and Sequence Overview (shown below) gives a glimpse of the expected order of all 21 units. The Unit Chart with Performance Expectations helps readers understand how this unit fits into the scope and sequence of the Phenomenal Science K-5 Science Curriculum. The Grade Level Sequence Maps show the order and approximate duration of the units for a grade level.

<table>
<thead>
<tr>
<th>Grade Level</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KINDERGARTEN</strong></td>
<td><strong>K.1: Barriers Up</strong></td>
<td><strong>K.2: Warm Up, Cool Down</strong></td>
<td><strong>K.3: Living it Up</strong></td>
</tr>
<tr>
<td></td>
<td>Force and Motion</td>
<td>Energy</td>
<td>Earth and Environment</td>
</tr>
<tr>
<td><strong>FIRST GRADE</strong></td>
<td><strong>1.1: Star Light, Star Bright</strong></td>
<td><strong>1.2: Feature Factor</strong></td>
<td><strong>1.3: Oh, Say Can You See?</strong></td>
</tr>
<tr>
<td></td>
<td>Space Systems</td>
<td>Structure, Function &amp; Info Processing</td>
<td>Sound and Light Waves</td>
</tr>
<tr>
<td><strong>SECOND GRADE</strong></td>
<td><strong>2.1: What Does It Matter?</strong></td>
<td><strong>2.2: Shifting Sands</strong></td>
<td><strong>2.3: Bloom Where You’re Planted</strong></td>
</tr>
<tr>
<td></td>
<td>Matter</td>
<td>Earth Events &amp; Diversity</td>
<td>Plants</td>
</tr>
<tr>
<td><strong>THIRD GRADE</strong></td>
<td><strong>3.1: Wild Wacky Weather</strong></td>
<td><strong>3.2: Let’s Move It</strong></td>
<td><strong>3.3: No Place Like Home</strong></td>
</tr>
<tr>
<td></td>
<td>Weather &amp; Climate</td>
<td>Force &amp; Motion</td>
<td>Plants and Animals</td>
</tr>
<tr>
<td><strong>FOURTH GRADE</strong></td>
<td><strong>4.1: Let it Rip!</strong></td>
<td><strong>4.2: Built for Survival</strong></td>
<td><strong>4.3: Surf’s Up</strong></td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>Plants &amp; Animals</td>
<td>Waves &amp; Info Transfer</td>
</tr>
<tr>
<td><strong>FIFTH GRADE</strong></td>
<td><strong>5.1: Go with the Flow</strong></td>
<td><strong>5.2: To Infinity and Beyond</strong></td>
<td><strong>5.3: Ch-ch-Changes</strong></td>
</tr>
<tr>
<td></td>
<td>Earth Systems</td>
<td>Earth &amp; the Universe</td>
<td>Matter &amp; Its Interactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>5.4: Round and Round It Goes</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Matter, Energy, and Ecosystems</td>
</tr>
</tbody>
</table>
Organization of the Units

To understand more about how the units are organized refer to Anatomy of a Phenomenal Science Unit. The Phenomenal Science Units have three main sections. The first section is the Goals Section. Here you will find unit level goals such as Performance Expectations (standards), Essential Questions, etc. The template below shows the type of information in the Goals Section. The second section is the Evidence Section. This contains the evidence of student learning or assessment for the unit. The third section contains the Learning Plan. The Learning Plan contains several parts: the Learning Plan Overview, Instructional Cycle Overviews, and Lesson Plans.
Helpful Resources

**Phenomenal Science Website** - one stop shop to access Phenomenal Science information and blogs

**PS: Addressing Needs in Science Education** - Research behind the development of the Phenomenal Science program

**Anatomy of a Phenomenal Science Unit** - Great walkthrough to help understand the organization of a unit, how to read it, and where to find what.

**Teacher Background Pages** - Here are the teacher background pages for each unit for both content and related phenomena. This is intended to be background understanding for the teacher only. Students typically do not need the depth of content explained here. (Note the grade-band progressions given)

**Materials Lists** - All Materials Lists for every unit

**Sample Parent Letter** - This is a sample parent letter about using Phenomenal Science Units. Make a copy and you can edit for your own needs.

**Phenomena List** - This is a complete list of all Phenomena used in all of the units.

**Focus and Investigation Questions** - These are graphic organizers showing all of the Focus Questions and Investigation Questions for the Units.

**Planning Guides** - these guides are useful in planning instruction. There are guides for planning Discourse, Models, Investigations, Summary Tables, Class Question Boards, Exploration Stations, and Assessment Tasks.

Book List - This is a complete list of books and other texts used in the units along with suggested supplemental and other leveled texts to support (coming soon)

Oakland Schools Lesson Packets for Phenomenal Science (coming soon)

Teacher Created Support Materials for Phenomenal Science Lessons (coming soon)

**Next Generation Science Standards**

**A Framework to K-12 Science Education**

**NRC Guide to Implementing the Next Generation Science Standards**

**Achieve Indicators of NGSS Implementation**
Beginning With the End in Mind
Unpacking Three Dimensional Standards

Alignment:
The Phenomenal Science Units were developed with a backwards design approach as described by Wiggins and McTighe. This means that the first step to understanding what must happen in a unit is to truly understand what is in the Michigan Science Standards / Next Generation Science Standards bundled in that unit. You can see the bundles of the standards in the Pacing and Alignment Guide (go to the Units page).

Phenomenal Science Units are aligned to the appropriate grade-level Michigan Science Standards (and the NGSS) and intentionally focuses on all three dimensions of those standards including Disciplinary Core Ideas, Science and Engineering Practices, and the Cross-Cutting Concepts. The following chart portrays these interrelations.

Also, all Phenomenal Science units include some integration of the reading and the writing strands of the Michigan English Language Arts Standards (CCSS-ELA) and the Mathematical Practices of the Michigan Mathematics Standards (CCSS – Mathematics). The Michigan Science Standards are a downloadable document, and Next Generation Science Standards are also available online. A graphic organizer has been developed which shows the topics, skills, concepts and phenomena of the units.

The following resources and information are helpful in understanding the three dimensions of the standards and how they work together.

- Next Generation Science Standards and Intro to the Standards
- Introduction to the standards for administrators
- Shifts caused by new standards and blog Traditional vs Next Gen Models of Instruction
- Consider also the blog Making More Effective Use of the 5E Model with NGSS
- Unpacking the new standards info - see slides day 1
● Evidence chart

● The standards have three dimensions which work together. Students need to develop understanding of **Disciplinary Core Ideas** through application of the **Science and Engineering Practices** and considering the **Crosscutting Concepts**.

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**The crux is this:** A student can demonstrate what they have learned in any related context. In this way, the NGSS performance expectation is like the seat of a stool with three legs (the three dimensions) holding it up. Those legs not only support the standard, they help form the context in which the students will be expected to demonstrate understanding.

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**Before NGSS, you may have used textbooks or taken a content approach centering on understanding and applying. What the new standards ask is that we go further in creating, evaluating and analyzing, so that students are not only consuming the content but are actually participating and interacting with it, working to develop it within the classroom.**

This is the key: The new classroom experience asks students to play the role of scientist and engineer, take ownership of their learning, and work with the content and engage in the practices. That is how the practices connect with that disciplinary core idea. The content background is the disciplinary core idea and the way content behaves in context is the crosscutting concept. These are big shifts—the idea that students not only need to develop STEM skills, but that they also need to engage them as they create, evaluate, and analyze within the STEM classroom.

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Some further helpful resources are:

- [STEM Teaching Tools Integrating Practices into Tasks](#)
- [STEM Teaching Tools Prompts for Crosscutting Concepts Integration](#)
- [Crosscutting Concepts Cards](#) and [Using the Crosscutting Concepts slides](#)
- [How were the NGSS developed?](#)
- [How to select 3D Materials](#)
Including Engineering

**WHAT IS ENGINEERING?**

Engineers solve problems using scientific knowledge. It’s worth noting, however, that a problem is not always something that’s electronic or physical, and engineering is not always about building a bridge, designing a wind turbine or constructing a wall—it’s broader. At its core, engineering is about solving a problem. The way you go about that is to identify and research the problem, survey the available materials, and then create prototypes to test. Engineers then use the data from those tests to determine whether a prototype does indeed create a solution to the problem.

Excerpts taken from *Mastering the Next Generation of Science Standards* accessed from knowatom.com

In the blog *Connecting Anchoring Phenomena with the Nature of Science and Engineering*, the author has a good description of how you could use the same phenomenon to tackle both an engineering problem and a science question.

Appendix I of the NGSS explains more about the inclusion of Engineering in the standards. It gives these progressions across Elementary grades:

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Three Dimensional Assessment

About the Evidence of Learning section:

Assessment Template

Summative could have both Item Cluster and Performance Task assessments

- What is an Item Cluster? (look at slides 6-15)
- What is a Performance Task? (look at slides 5 - 19)

How do we translate Checkbrics to points? How do we assign grades for report cards? This can be a challenge for teachers and we've found teachers who are first trying out PS often really struggle with them. Here is a resource from ASCD that gives some more background on using Performance Assessments which might help.

Pre Assessments - Formative Assessment Probes such as these and Science Formative Assessment are good resources for pre-assessment, but there are many other ways as well. Also, these section from Tools and Traits for Highly Effective Science Teaching called “Before and During the Science Lesson: Using Science Probes to Get at Student Thinking” (p. 41-44) and “Ok, I’m Teaching Science but How Do I Know They Are Learning?”

The second step of backwards designing units is to develop an assessment. This give the unit its "target," and ensures that it stays aligned to the standards. Because of the three-dimensional nature of the standards, most of the unit assessments are three dimensional Performance Assessment Tasks, and some are Item Clusters. You can investigate your unit's assessments in the Evidence of Learning Section (orange charts).

- What is an Item Cluster? (look at slides 6-15)
- What is a Performance Task? (look at slides 5 - 19)

Much of our development process followed the Three-Dimensional Science Performance Assessments (3dsciassessment.weebly.com) process which was co-developed with MDE's M-STEP and Item Cluster development process.

How do we translate Checkbrics to points? How do we assign grades for report cards? This could be a challenge for teachers, and we've found that sometimes teachers who are first trying out PS really struggle with this. Here is a resource from ASCD that gives some more background on using Performance Assessments which might help.

Several units incorporate pre-assessments. Formative Assessment Probes such as these and Science Formative Assessment are good resources for pre-assessment, but there are many other ways as well. Also, this section from Tools and Traits for Highly Effective Science Teaching called “Before and During the Science Lesson: Using Science Probes to Get at Student Thinking” (p. 41-44) can be a good resource.

In the Phenomenal Science Units we've embedded assessment in several places, since the learning, teaching, feedback cycle is continuous. There are also several different types of assessment. The summative assessments for the unit are typically performance assessment tasks like those linked above and can be found in the Evidence of Learning section as well as at the end of the instructional
cycles. Other assessment opportunities are highlighted in the Learning Plan Overview as well as in each lesson.
Formative Assessment

Formative Assessment is critical to teaching science using sense-making strategies. Formative assessment is a “process used by teachers and students during instruction that provides feedback to adjust ongoing teaching and learning to improve students’ achievement of intended instructional outcomes” (CCSSO, 2008, p. 3) As Furtak points out, “formative assessment is something that teachers and students can do together, every day, to monitor student learning and provide timely feedback (Shepard 2000; Trauth-Nare and Buck 2011).” (Furtak & Heredia, 2016) This makes formative assessment an invaluable tool for teachers engaging students in making sense of science phenomena. The text box details some specific differences that come with three-dimensional formative assessments.

- **Effective implementation of the NGSS can’t be done with summative assessment alone.** It requires different forms of ongoing classroom formative assessment.
- **3D assessments will require multiple components that work together** to provide a coherent picture of student understanding of DCIs, CCCs, and SEPs. Responses to these components will provide multiple sources of evidence to guide a teacher in making inferences about what students know and are able to do, and also point toward next steps in instruction.
- **3D formative assessments can be informal and embedded in teachers’ daily practice,** or formal written assessments that are specifically developed to surface student engagement in 3D learning. A formative assessment can be as simple as posing a question to a student or listening to a group working on an investigation.
- **Formative assessments should engage students in the full range of science and engineering practices.** This focuses assessment on making sense of phenomena and not factual recall. Assessments should focus on making sense of compelling phenomena. Some items should focus on multiple practices (from science, ELA, math).

(Furtak, Pasquale & Aazzerah, 2016)
It is important that the formative assessment used be both rigorous and responsive. Formative assessments help us answer three questions: Where are we going? Where are we now? How do we get there? Teaching science for understanding through sense-making is not a linear process, but formative assessments help us get there. (Gotwals, 2017). [Diagram from Furtak, 2017]

Using the process outlined by Furtak, et al, helps teachers make the best use of the formative assessment process.


Where are we going is answered in the PE’s, unit goals, and learning performance statements. Using a tool like the one shown below (from Furtak, 2017) can also help teachers take students current ideas, thinking and experiences into account when considering the formative assessment goal and tool to use.

How do we elicit student understanding? There are three main methods to gather evidence of student understanding: Discourse, Written work, Student Self assessment. (Gotwals, 2017). Choosing a rich task, especially during the Pre Assessment portion of the instructional cycles can be a very productive method for understanding student thinking. Rich tasks are ones that will show what naive conceptions and explanations
students are currently holding as well as give the teacher some potential leverage points about which to focus upcoming discourse and investigations. In this way, teachers can allow students to use student-generated evidence to build models, explanations and arguments toward more scientifically accepted explanations of phenomena.

The most challenging portion of formative assessment process is determining what can be learned from the results. Two main purposes for the formative assessment is to provide feedback to students and determine our next steps in instruction.

Another key challenge for teachers is determining what to be graded. Considering that the key purpose of formative assessment is to give feedback to teacher for planning and students for growth, they should be graded sparingly. Both students and teachers need to have trust in the process and be free and confident to share their thinking about their science ideas. (Gotwals, 2017. DeLeon & Allen, 2015)
Using evidence is the hardest piece of the puzzle. (Gotwals, 2017) According to Gotwals the main question teachers need to ask themselves with formative assessment data / evidence: What can you productively do with that idea? Some possibilities include, adding ideas to a Class Question Board or Competing Hypotheses Board; gather evidence as a class to support or refute the idea; use the idea to scaffold small group discourse or as questions in whole class discourse. Another great option for showing student growth and learning is to keep track of student models that change over time - can have a checklist for the model and pieces that you want to see in it. (Gotwals, 2017). Furtak recommends the following tools as helpful as teachers analyze student formative assessment data

Finally as can be seen from The Formative Cycle as a Teacher formative can help teachers attend to equity in the following ways:

- Formative assessment practices gives students chances to get meaningful feedback in a low-stakes environment, which supports their learning and helps them develop confidence in their ability to express their understanding.
- Give voice to all students in order to fully engage students in inquiry-based lessons and effectively implement informal formative assessment practices with them.
• Welcome and integrate students’ own experiences as part of the learning environment and development of knowledge. (DeLeon & Allen 2015)

So, with all this background, how do we use formative assessment within Phenomenal Science? There are several areas within the units to look for possible formative assessment tasks. First, in the Learning Plan Overview charts, the right-most column is dedicated to highlighting some of the formative assessment opportunities within each instructional cycle. All of the items in that column would be ones that could provide feedback to teachers and students about student understanding. Secondly, throughout the units there are embedded opportunities for Student Discourse and for Written Work. Discourse happens both in small groups and pairs and in whole class settings. Written work comes especially in the form of notebook entries, models, initial explanations and CER’s. Some instructional activities combine the two especially well such as, Summary Tables, Class Question Boards, Consensus Models or Explanations, and Investigations.

An example formative assessment task and some ideas about using this sort of task:
Don’t put the coat on the snowman. It will melt him.

It will keep him cold and stop him melting.

I don’t think the coat will make any difference.
What is Concept Cartoon?

“cartoon-style drawings presenting characters with different viewpoints around a particular situation”.

(Roesky & Krennepohl, 2008)

Concept Cartoon and Assessment

• Concept cartoons can be used as an alternative assessment
  (Youngjin Song, Misook Heo, Larry Krumenaker & Deborah Tippins)

• Concept cartoons can be used to get access to learners’ ideas, to probe their level of understanding and to highlight any confusion they may hold.

Concept Cartoon

• Feature cartoon-style drawings showing different characters arguing about an everyday situation.

• Designed to intrigue, promote discussion and to stimulate scientific thinking

• Puts forward a range of viewpoints about the science involved in everyday situation.

Concept Cartoon

Concept cartoons are extremely versatile as a teaching strategy (Brenda Keogh and Stuart Naylor, 1999),

They may be employed across subjects, such as in the development of reading skills in English, or the teaching of problem solving in Math.
For further ideas about formative assessments:

- [Michigan Math & Science Center Network Formative Assessment Webinars](#)
- Find sample Assessment Tasks with formative steps building to them at [Three Dimensional Science Performance Assessments](#)
- What We Call Misconceptions [May Be Necessary Stepping-Stones Toward Making Sense of the World](#)
- An excellent resource for using classroom discourse for formative assessment: [Talk Resource Tool: Classroom Talk as a Formative Assessment Opportunity](#)
- [Sources of Formative Assessment](#)
- Some of Page Keeley’s Formative Assessment Work: [Uncovering Student Ideas](#)
- [The Problem with Understanding](#)
- From Pre Assessments Section - [Formative Assessment Probes](#) such as these and [Science Formative Assessment](#) are good resources for pre-assessment, but there are many other ways as well. Also, these section from Tools and Traits for Highly Effective Science Teaching called “Before and During the Science Lesson: Using Science Probes to Get at Student Thinking” (p. 41-44) and “Ok, I’m Teaching Science but How Do I Know They Are Learning?”
- [What Happens Between Assessments](#) - see especially the section titled “Use Ongoing Assessments for Feedback and Adjustment”
- [Seven Keys to Effective Feedback](#) - note particularly the “Feedback Essentials” section
- [Rapid Survey of Student Thinking](#) Tool from Ambitious Science Teaching
Doing Science to Learn Science:

*Phenomena Based Engagement to Build Concepts*
Anchoring Phenomena

It is important to engage students at the beginning of a unit by presenting them with an observable and puzzling event, or a phenomenon. This will be the context for their learning while also serving to anchor the students around a shared experience that they can work to understand over the course of the unit. After the anchoring phenomenon is presented it should not be forgotten. It is essential that the students revisit the anchoring phenomenon several times throughout the unit as they work to understand the puzzling event via investigations, readings, and activities. When puzzling real observable events are presented to students, it is usually engaging for students. This presents the teacher with an excellent opportunity to elicit students’ current understanding which can be used for directing the inquiry cycle of instruction. For more ideas on eliciting students initial thinking read “Engagement through Elicitation is Key to Beginning Scientific Inquiry” from Tools and Traits for Highly Effective Science Teaching (p. 40) As a follow up check out “Helping Student Change ‘Why’ Questions Into ‘How’ Questions to Make Testable Questions” from p. 50-51 of the same text.

A case for using anchoring phenomena:

Using Anchoring Phenomenon with the 5E model
Tips for using Phenomena

- Focus questions should be linked to Phenomena
- Can explain phenomena at different points in the IC
- If explaining earlier then other related pieces need to still make relationship explicit
- If explaining later then can intro related ideas in the middle of IC
- Below is a graphic that helps show how the phenomena can be revisited during a instructional cycle (this should be done several times with an IC)
Excerpts taken from knowatom.com

Additional information can be found at:

Planning for Engagement (pages 3-7)

- Stem Teaching Tool #28
- Stem Teaching Tool #42
Science Concepts are Developed through Multiple Iterations

Phenomena Revisits
As stated in A Framework for K-12 Science Education (2011), “Building progressively more sophisticated explanations of natural phenomena is central throughout grades K-5.” (p. 26) Because students develop their concepts over time and after many varied interactions with the content and practices, it is critical that we provide students with as many opportunities to revisit the phenomenon and concepts through hands-on investigation, discourse, modeling, text, and collaborative work. Understand that it is valid within the instructional cycle to keep revisiting the phenomenon and to provide opportunities within the IC for:

- Explanation of the phenomenon at different points in the IC
- Building in some opportunities to explore related phenomena
- If reaching a final explanation of the phenomenon earlier than other related pieces in the IC, we need to still make relationship explicit
- If explaining later then can introduce related ideas in the middle of IC

More iterations are better than not enough. By taking the learning deeper, we can introduce related phenomena. As noted in this article, we can use the 5Es model of curriculum design in a nonlinear fashion to build in multiple iterations and deepen student learning opportunities.

Finally, it is important to note that PEs, can span more than one instructional cycle. Many times, phenomena do not allow a clear cut and dried instructional cycle to easily pair up with a PE, but do address a portion of it. It is ok and actually a good thing, to revisit the PE in another instructional cycle since this allows students more opportunities to consider their understanding and dig deeper thereby building better concepts.

- ASCD Article: STEM Teaches Failure as an Opportunity to Learn
- NSTA Article: What We Call Misconceptions May Be Necessary Stepping-Stones Toward Making Sense of the World
- Ambitious Science Teaching Video: Sound Unit Overview - shows how students develop concepts about a phenomena over the course of a unit through multiple iterations.

How is the development of Crosscutting Concepts developed over multiple iterations? How do multiple iterations impact student engagement with Science and Engineering practices? Click on the image to see all 3 dimensions.
Class Question Boards

Why use them?
According to Vale, “Science begins by asking questions and then seeking answers. Young children understand this intuitively as they explore and try to make sense of their surroundings. . . . Encouraging questioning helps to bring the true spirit of science into our educational system, and the art of asking good questions constitutes an important skill to foster for practicing scientists.” (Vale, 2013) As noted by Weizman, Shwartz & Fortus, there are four advantages to using Class Question Boards as an instructional tool to help students make sense of phenomena:

1. Helps students make connections between activities and anchoring phenomena / focus question
2. Helps organize learning into a “road map” for students
3. Scaffolds the student practice of asking questions
4. Develops student ownership of the content and builds class community (Weizman, Shwartz & Fortus, 2008)

Class Question Boards, also called Driving Question Boards are a powerful instructional strategy that engages students in processing investigations and other data to work through multiple iterations to build an explanation of a puzzling phenomenon. They, similar to Summary Tables, Competing Hypotheses, become a bridge between experiences and conceptual understanding. In order to complete them, students and classrooms must experience rich science discourse based on experiences and several of the Science and Engineering Practices, especially Asking Questions.

How Do We Use Class Question Boards?
Initial set up: When first introducing the CQB at the beginning of an instructional cycle (often shortly after presenting the anchoring phenomenon), students are invited to brainstorm as many questions as they can about the phenomenon. Encourage students to ask questions that they feel will help them explain the phenomenon. With older students this initial brainstorm may be done in notebooks or on sticky notes followed by a small group discussion of their questions. With younger students, these may be shared first in small groups (without recording). Then in a whole class discourse each team can share one question at a time which is then recorded by the teacher on chart paper or white board. During this recording, all responses are accepted and other groups are invited to concur with nominated questions if they had a similar question in their group. This could be recorded as check marks or pluses next to the questions, or if written on stickies, they may add the question to that area of the board. Once all questions have been shared and recorded, often students can be invited to look for
patterns and decide if some questions are related and should be “put together” or grouped in some fashion. One great teacher tip from Nordine and Torres, suggests that teachers make a “draft" CQB before this initial set up with students, to refer to during this discussion and sharing so that any redirecting might occur as necessary. ([Nordine and Torres](#), 2013) This could be crafted by looking at the “Investigation Questions" for each lesson in the cycle. Finally, it is not critical that all questions are included at this phase since students typically will discover in the midst of exploring that there are other questions they need to find answers to. ([Nordine and Torres](#), 2013)

During the Instructional Cycle: After investigations, usually during the Explain phases of an IC, you will want to revisit the CQB with your students. This prompts discussions about “What questions have we been able to answer?” “How do we know?” and “What questions do we still need to know?” Often times this will also lead to revisions of the CQB in which some questions are removed, some are answered, some evidence may be included, and/or some new questions are added. As noted by Nordine and Torres, “During sense-making discussions at the end of activities, the DQB is helpful for ensuring focus and fostering deeper thinking about the most central ideas in the unit. If a student asks an “off-the-wall” question, we can honor the student’s curiosity without derailing the discussion by asking him or her to write the question on a sticky note and put it in a “parking lot” section of the DQB, which holds questions that are interesting but not related.” ([Nordine and Torres](#), 2013)
Finally, at the end of an IC, we can finalize the CQB by ensuring that the critical questions for explaining the phenomenon are answered and that there is also supporting evidence for our answers. If there are further questions arising, suggest some other resources or upcoming opportunities there might be to answer them. Relate this process to how scientists ask and answer questions and note, “there is always more questions to be answered in science!” At this point, the CQB is an excellent tool and resource for students to use in crafting a final explanation, argument, or model to explain the Anchoring Phenomenon.

Class Question Boards cause students to employ scientific practices to consider big ideas and develop concepts in a highly engaging way. After all the questions come from the students! As Wiggins and McTighe note,

> “From a pedagogical point of view, we seek questions that are likely to make students want to do two things: (1) actively pursue an inquiry and not be satisfied with glib, superficial answers, and (2) willingly learn content along the way in the service of the inquiry. That's why the best questions, used properly, make learning more active and enjoyable. When such questions are employed effectively, students experience far less sense of pointless drudgery because they are acquiring knowledge and skill for more obvious and worthy reasons. The learning is thus more intrinsically than extrinsically motivated, making it far more likely that students will persist with the work required for understanding and continuous improvement.” (2013)

Some Resources for further investigation:
- [Enhancing Science Kits With the Driving Question Board](http://example.com)
- [The Driving Question Board](http://example.com)
- Some good tips for brainstorming questions at [For Students, Why the Question is More Important Than the Answer](http://example.com)
- [The Right Questions](http://example.com) article from ASCD has more details about process for formulating questions
- [The Right Question Institute](http://example.com) by the authors of Make Just One Change has great practical resources such as [Experiencing the Question Formulation Technique](http://example.com)

**Competing Hypotheses Strategy**
The competing Hypotheses Strategy is another organizing strategy similar to the Class Question Board. This strategy builds student scientific thinking and argument skills. Take a few minutes to read Competing Hypotheses.

Which Science and Engineering Practices do students engage in while using a CQB? Which Crosscutting Concepts seem to lend themselves to CQB thinking? Click on the image to see the 3 dimensions.
Modeling

How to do Modeling with Elementary Students:

1. Use a Model to explain a phenomenon or investigation: Modeling is one of the best ways to make student thinking visible which allows for group discourse, revising of ideas, and group collaboration. A model needs to be explanatory in nature and therefore attempt to explain a particular event or process that has specific conditions that matter to the explanation. Modeling is a critical science practice that allows students to make sense of their learning.

2. Steps of Modeling:
   a. Initial Model: The initial model allows teachers to formatively assess the current understanding or misconceptions held by students. It is important to foster a growth mindset so students are comfortable with their current understanding and then able to revise when necessary.
   b. Model based on more evidence: Evidence from continued activities need to be used to revise the initial model.
   c. Feedback from others: A gallery walk is a great way to expose students to their peers work and give structured feedback that will lead to revisions in the model.
   d. Revise models based on feedback and more evidence: Constructive feedback will allow yet another revision to the model.
   e. Consensus Model: A whole class model in which small groups work together to create one consensus model.

3. All of the above steps can be done individually, in small groups, or whole group. The initial model should be completed individually to allow each student to grapple with their current understanding. It is most beneficial for students to complete the majority of this practice working in small groups and use the consensus model occasionally.

4. Collaboration and discourse are key parts to the modeling process so the whole process should not be an independent endeavor. Resources from AST and the Inquiry Project will further address science discourse and talk moves.

5. Here are some examples of modeling k-5.

6. The “gotta have” checklist is a student centered way to give criteria for the final model.

According to Ambitious Science Teaching, there are five qualities of scientific modeling used to build student understanding through sense-making:

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1. The first quality of “models for modeling” is that they should represent an event or process (we often use the term “phenomenon” for this), rather than “things.”

2. The phenomenon should be context-rich, meaning that it is about a specific event that happens in a specific place and time under specific conditions.

3. It helps if students’ models are pictorial, meaning that there is some visual resemblance between the representations on paper and the process or event being modeled.

4. The fourth characteristic of models for classroom modeling is that the representations include both observable and unobservable features.

5. The final quality of models for modeling is that they are revisable. Because models show how events, things, properties and ideas are related to one another, students need to test these relationships out. As a result of readings, activities, discussions, and experiments, students make changes to their models over time. (Ambitious Science Teaching, 2015)

Here is a Resource: AST’s Magnetic Storyboard Tool describes how to use for student modeling.
How is the development of Crosscutting Concepts cultivated with student modeling? How does modeling impact student engagement with Science and Engineering practices? Click on the image to see all 3 dimensions.

<table>
<thead>
<tr>
<th>Crosscutting Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patterns</strong></td>
</tr>
<tr>
<td>Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.</td>
</tr>
<tr>
<td><strong>Scale, Proportion, and Quantity</strong></td>
</tr>
<tr>
<td>In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system’s structure or performance.</td>
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<tr>
<td><strong>Cause and Effect: Mechanism and Explanation</strong></td>
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<tr>
<td>Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.</td>
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<tr>
<td><strong>Systems and System Models</strong></td>
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<tr>
<td>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.</td>
</tr>
<tr>
<td><strong>Energy and Matter: Flows, Cycles, and Conservation</strong></td>
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<tr>
<td>Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems’ possibilities and limitations.</td>
</tr>
<tr>
<td><strong>Structure and Function</strong></td>
</tr>
<tr>
<td>The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.</td>
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<tr>
<td><strong>Stability and Change</strong></td>
</tr>
<tr>
<td>For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.</td>
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</tbody>
</table>
Summary Tables

1. In science it is important that ideas/conclusions be able to change over time as new evidence is found. As in real science, our science classroom needs to allow for thinking to change/be revised as students collect new data. One of the best ways that teachers can assist students in organizing their thinking is by making use of a summary table or KLEWS Chart- a way to record activities and ideas.

2. The process:
   a. Present phenomenon → A puzzling event that will get them engaged in the upcoming learning.
   b. Ask Focus Question → This is posed to the students at the beginning of each instructional cycle. It is the question that students are working to understand/answer.
   c. Begin investigating → This will typically be the first explore of the instructional cycle.
   d. Record the first investigation/activity in the summary table.
   e. Continue to fill in with subsequent investigations and activities
   f. Use evidence gathered at end to develop a claim / explanation of phenomenon

3. A summary table can be easily adapted to meet the needs of your classroom. For example column headings can be tweaked to best fit the CCC for the instructional cycle. Other adaptations could include a column for evidence, noticings, questions, etc. Below are examples of some of the possibilities:
   a. Summary table:

   | Phenomenon: | Present the phenomena to the class |
   | Focus Question: | Write the focus question. This is what students are working to understand/answer. |
   | Activity/Investigation | Observations (patterns, what happened?) | Why? (what do you think caused this?) | Clues (how does this help us understand the focus question/phenomenon) |
   | | | |

   Answer Focus Question: Use evidence gathered in table to develop a claim / explanation of phenomenon.
b. **KLEWS Chart**

<table>
<thead>
<tr>
<th>What do we think we <strong>KNOW</strong>?</th>
<th>What are we <strong>LEARNING</strong>?</th>
<th>What is our <strong>EVIDENCE</strong>?</th>
<th>What are we <strong>WONDERING</strong>?</th>
<th>What <strong>SCIENCE</strong> words and principles help us explain?</th>
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4. **Tips and Tricks:**
   - This works best as a whole class product
   - Limit number of columns to 4-5
   - Try not to exceed more than 5 rows
   - Written information
     - Elementary level → teacher can aide in crafting wording
   - Complete each row as it happens in class
How is the development of Crosscutting Concepts cultivated with student summary tables or KLEWS charts? How does these strategies impact student engagement with Science and Engineering practices? Click on the image to see all 3 dimensions.

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<td>against contexts and used to predict and explain events in</td>
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<td>new contexts.</td>
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<tr>
<td><strong>Systems and System Models</strong></td>
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<tr>
<td>Defining the system under study—specifying its boundaries</td>
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<tr>
<td>and making explicit a model of that system—provides tools</td>
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<tr>
<td>for understanding and testing ideas that are applicable</td>
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<tr>
<td>throughout science and engineering.</td>
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<tr>
<td><strong>Structure and Function</strong></td>
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<td>The way in which an object or living thing is shaped and</td>
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<tr>
<td>its substructure determine many of its properties and</td>
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<td>functions.</td>
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<tr>
<td><strong>Stability and Change</strong></td>
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<td>For natural and built systems alike, conditions of</td>
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<tr>
<td>stability and determinants of rates of change or the</td>
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<tr>
<td>evolution of a system are critical elements of study.</td>
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</table>
Investigations

Why Use Investigations?

Do students need to do investigations? Developmentally, elementary students are still in an area of “concrete” thinking. As teachers it is our task to help them translate some of their ideas from concrete to more abstract thinking - developing some conceptual understanding of the world around them. It is very difficult to engage students with more abstract concepts if they don’t have concrete, hands-on experiences to which they can “hook” the new ideas. By starting with concrete experiences, we meet them where they are currently thinking and reasoning and can take them further in their thinking. From the concrete experiences we are building from a solid foundation of experience.

We also know that students benefit from multiple modalities of learning. Investigations and hands-on activities allow for students to learn in all 4 modalities at once: visually, auditorily, kinesthetically, and socially. This allows for a whole lot of neurons firing in the brain - building pathways and connections and strengthening them all at once.

Finally, investigations mirror the way science works in the real world. This allows students to build a deep understanding of the Science and Engineering Practices and to become masters at learning through engaging in them. It also allows them to “see” themselves as scientists or at the very least, scientific learners. It also makes real the process of collecting first hand evidence and using it to develop understanding and make shared meaning. There is no other better process than beginning with an investigation to develop that understanding. This first hand evidence is also the best (only?) way to really get students to shift their thinking from stubborn naive conceptions. When confronting this evidence in light of misconceptions, cognitive disequilibrium ensues, and students are forced to reconcile the two ideas and build meaning.

How Do We Use Investigations With Students?

Taking on investigations with your students can be very daunting. However, it doesn’t have to be! The first thing to know is that there isn’t a set right way to “do” investigations. The main goal is to have students gather data (evidence) that will allow them to build understanding of a phenomenon.
When first starting investigations with your students you may want to follow a more “gradual release” sort of model. So, to start with you might do several investigations together as a whole class. In later cycles, you might do parts of the investigation whole-class and allow groups to conduct parts together. Eventually, student groups and possibly even individuals will be empowered to conduct their own investigations from start to finish. Of course, this will also vary by grade-level and will need to be adjusted according to the amounts of materials you have available. Ideally, we work to have students engaging with the Science and Engineering Practices to conduct their own investigations as often as possible.

Here is a general process to follow in guiding your students to do investigations:

- Lead with a question
  - This can be the focus question or investigation question from your lesson or one that students develop from Summary Table or a Driving Question Board
- Investigate to find the answer
  - Use think alouds to develop procedures together
  - Be flexible in student choice of methods to investigate when possible
- Allow students to develop their procedure as often as can be
  - Will need to give plenty of guidance and scaffolding to get students adept at this.
  - May start with thinking through a procedure that is given, then allow them to develop whole class short procedures, and so on.
- Guide students to develop methods for recording and tracking data
  - Will need to give plenty of guidance and scaffolding to get students adept at this.
  - May start with thinking through a procedure that is given, then allow them to develop whole class short procedures, and so on.
- Follow up with plenty of processing opportunities to make meaning of the investigation

In summary, some key components of a quality investigation include: students enabled to get hands on materials that help them make meaning; investigations should be student led as much as possible; engage students in Practices to make meaning and keeps students wondering and making meaning.
Which Science and Engineering Practices do students tend to engage in while doing investigations? Which Crosscutting Concepts seem to lend themselves to investigating? Click on the image to see the 3 dimensions.
Scientific Method vs. Methods of Scientists
AKA how science gets done

Try this Formative Assessment Probe by Page Keely (Doing Science). . .
Does it surprise you that “Tamara?” is the most accurate view of how scientists “do” science? In spite what we all learned in school as the scientific method, there is no one beginning to end process that scientists follow. As teachers we need to be cautious about presenting the scientific method as a step-by-step linear process.

Try another Formative Assessment Probe by Page Keely (Hypothesis). . .

The best choices are A, B, G, K, L and M. Why are these options surprising to you? They tend to go against how we learned about hypotheses in our own school experiences. However, research scientists rarely even use hypotheses. The main reason for this is because it tends to skew their view of the data they gather. Just like our students, it is human nature to want to be “right” and so to state an hypothesis puts them in danger of not being objective any longer.

Watch this video about How Science Works. . . As you can see, the scientists definitely do not follow a linear process! What implications do you think this might have for how we might present the “scientific method” to students?

As one can see from the video, scientists must be adept at using many different skills, practices, processes and methods. They also need to be able to choose which one to employ in any given juncture in the process. We need to build this same sort of skill set in our students. Engaging students in the eight Science and Engineering Practices builds toward this. Also, we need to help student think through the steps they might follow for an investigation or experiment. Working through the process as a whole class we can model the thinking process of choosing a next step to continue to build our understanding of a phenomenon. Check out “I Taught My Students How to Do the Scientific Method”
and They Are Good at Using It!” from Tools and Traits for Highly Effective Science Teaching (p. 13-14) for some further ideas about what this looks like.

If students have this sort of thinking and metacognition modeled for them through think-alouds and whole-class investigation, eventually we can shift their ability to enable them to choose appropriate next steps for their own investigations as well. This might look like posting the following chart on the wall and using it to help guide our choice of strategies as we endeavor to build understanding.

1. Scientific Method is not a linear process.  
2. Need to teach students that Scientists need to be adept at using many methods  
3. Need to give students opportunities to choose which methods they need to employ to investigate a phenomenon or question often  
4. Resources: (CAS “How does science work” stuff)

Another interesting resource is Inviting Uncertainty into the Classroom from Ed Leadership.

How is the development of Crosscutting Concepts cultivated with more open-ended investigations? How does doing science like scientists help or hinder students’ use of Science and Engineering practices? Click on the image to see all 3 dimensions.
Science-Driven Integration of ELA / Math / Technology

Every elementary educator knows that classroom time is at a premium and in recent years there has been an overwhelming emphasis on Reading and Math. As a result it is imperative that our science curriculum and instruction are mindfully integrated with ELA, Math, and even Social Studies. According to the Michigan Department of Education, SCIENCE is actually the perfect vehicle to drive this integration and that the Michigan ELA Standards “cannot be fully addressed outside of the context of science education. . . . Young children who participate in learning science are more likely to interpret and learn with challenging text, acquire rich vocabulary and language, write for a broader range of purposes, and build evidence-based argument to communicate with others.” from Supporting Early Literacy Development and Science Instruction. As can be seen in the MSS/NGSS standards themselves, connections are made to Michigan Mathematics Standards as well. Connections among the three are especially prevalent in the Practices of each as can be seen in this venn diagram.

Research also supports the idea that students need content experiences to fully understand what they read as can be seen in the video Teaching Content is Teaching Reading.

English Language Arts
Many of the Key Instructional Strategies embedded in the Phenomenal Science Units, such as Science Discourse, Collaborative Groups, Modeling, Summary Tables, Notebooking, Argument and Explanations, naturally integrate many key aspects of literacy and language arts. As these come up throughout the units, look for the standards connections noted there in the Why column. The units also strive to integrate a great deal of informational text such as those found in MeL ebooks, book flix, Britannica encyclopedia, World Book encyclopedia and articles. Other text sources include: NewsELA, YoungZine, ReadWorks, Article of the Week and Archive AoW. Some other good ideas about integration between Science and ELA can be found in Exploring the Science Framework which digs
into the practice of Obtaining, Evaluating and Communicating Information. The Michigan English Language Arts Standards are helpful for comparison. MeL List is also a helpful resource. For practical suggestions around developing literacy through science instruction, read Linking Literacy Development and Science chapter from Tools and Traits for Highly Effective Science Teaching (p. 27 - 35)

Mathematics
There is a great connection between the Mathematical Practice and the Science and Engineering Practices. Exploring the Science Framework: Making Connections in Math gives some great examples about how we can be more intentional about making this integration obvious and explicit. As noted by Edutopia author Ben Johnson in How to Creatively Integrate Science and Math, “Ultimately, as another study reported, the students’ increased conceptual understanding of math and science is the greatest benefit of math and science teacher collaboration. Conceptual understanding means the students know the bigger picture of why things work in math and science, not just how to make them work.” Further, cited on the site Integrating Science and Math, Research indicates that an integrated approach to learning aligns with the way the brain naturally processes and internalizes new information. Since mathematics and science are integrated in the world outside the classroom, and technology has become a natural extension of this integration, it seems only logical that these areas are studied together inside the classroom.” This same site is a great resource for more information and strategies. Refer to the Michigan Mathematics Standards for further connections.

Social Studies
It has also been noted that within the units there are many connections to the Michigan Social Studies standards. With classroom time so short, we must take advantage of all the connections we can make.

Technology
Students need to be proficient at using and evaluating technology resources. Consider this article, Five Reasons Why Tech Matters, to further understand the need for students to experience technology. There are many ways to engage students in the use of technology within the Phenomenal Science units.
Refer to the [ISTE Technology Standards](#) and the [Michigan Integrated Competency Standards](#) for connections.

Some further resources:

- ASCD Article: [Writing and STEM a Crucial Combination](#)
- ASCD Article: Help students ask questions while reading: [Storytelling with Questioning](#)
- Ambitious Science Teaching Video: [Interactive Read Alouds](#)
- AST’s [Three Roles for Reading Science Text Tool](#)
- [Using MyNASA Data](#) to Analyze and Interpret Data
- Teacher Vision’s [Analyzing Data - Tips and Tricks](#)

Which Science and Engineering Practices do students engage in during integration of ELA or Math? Which Crosscutting Concepts seem to lend themselves to Math or ELA thinking? Click on the image to see the 3 dimensions.
Exploration Stations

Exploration Stations are also sometimes called Science Tables and are like centers or stations, that students can visit during an appropriate time to learn and do science activities and/or process them through such methods as discourse, drawing, writing or reading. They help increase opportunities for students to build and extend understanding by engaging in the practices and considering crosscutting concepts. They become another iteration of the content in a different mode and method.

- Example of 1st grade Science Table
- Other Science Table Ideas

Exploration Stations are a great way for students to build independence and exercise more of their own choice and voice. Because constructivist, inquiry-based classrooms invite some cognitive disequilibrium, Exploration Stations are one way for helping students own this uncertainty and take charge of working toward deeper understanding as can be seen in this Education Leadership article, *Inviting Uncertainty into the Classroom*, which states that allowing students to grapple with open-ended problems helps students respond well to uncertainty. Exploration Stations can be both an invitation to wrestle with those problems and a resource for finding ideas when students might be stuck. *Using Learning Centers* suggests that well managed centers can actually lead to easier classroom management and fewer discipline issues. The Scholastic article *Learning Centers, Part 1: Why They're Important* makes the case that centers are very developmentally appropriate especially in early elementary. *Science in Early Childhood Classrooms: Content and Process* presents a research-based case for using centers and some good examples of their use.
Several resources for setting up Exploration Stations include:

- How to Set Up Your Preschool Nature and Science Learning Center
- Keys to Planning Successful Learning Centers
- Learning Centers, Part 2: How to Manage Them
- Tinkering in STEM Education
- Using Elementary with links

Podcasts in the Classroom - How-to and resources
Which Science and Engineering Practices do students engage in while at an Exploration Station? Which Crosscutting Concepts seem to lend themselves to use in an Exploration Station? Click on the image to see the 3 dimensions.
Evidence-Based Thinking:  
Making Thinking Visible / Audible to Build the Teacher-Student Feedback Loop
Basing Science Learning in Evidence

A Framework for K-12 Science Education emphasizes the need for students to support the development of their ideas with evidence, in accordance with how the scientific community practices science. It states, “all sciences share certain common features at the core of their inquiry-based and problem-solving approaches. Chief among these features is a commitment to data and evidence as the foundation for developing claims. . . . In short, scientists constitute a community whose members work together to build a body of evidence and devise and test theories.” (NAP, 2011, p. 27)

Taking Science to School (NAP, 2008) suggests four areas of science proficiency. One of the four is “2. Generating and evaluating scientific evidence and explanations.” (NAP, 2011, p. 252) In line with this nature of science and science understanding, Phenomenal Science emphasizes that students develop their understanding of science concepts based on scientific evidence. This means that students need to be engaged in collecting evidence, analyzing evidence, comparing evidence, discussing evidence and using evidence to construct arguments and explanations.

There are several powerful strategies that teachers can use to engage students in making their thinking audible and visible and support students’ use of evidence. For example:

- Engaging students in giving feedback on models, explanations, or arguments is a valuable way to allow them to compare evidence and discuss it. In this AST Video of a fourth grade classroom, students provide feedback to peers’ evidence-based models using sticky notes. The Feedback Toolkit is an excellent resource for teachers planning to use this strategy with students.
- Gathering evidence from investigations and using it in a class discussion is something that should happen in every learning cycle. The AST video, Scaffolding Debate, gives a good view of the strategy and how students engage in argument from evidence.
- Another excellent instructional strategy is to allow students to have “Competing Hypotheses” throughout the iterations of an Instructional Cycle. This AST Video, details the process.
- The Gotta Have Checklist is a great way for students to compare evidence and reflect on the importance of it in student generated explanations and arguments. This video resource, Gotta Have Checklist, also from Ambitious Science, shows how it is done.
- Another more generic guide: Ambitious Science Teaching’s Helping students talk about evidence: A guide for science teachers

All of the Instructional Strategies described in this section describe strategies to engage students in using evidence:

- Summary Tables / KLEWS Charts are a great tool for students to gather evidence toward building an explanation of a phenomena throughout an instructional cycle.

Class Question Boards engage students in asking and answering questions about the phenomena, through gathering and processing evidence.
• Concept Maps and Other Graphic Organizers are great tools for making thinking visible which helps guide evidence driven discussions and group work
• Models which are developed and revised based on evidence and enable students to make their thinking visible and bridge the gap between evidence and explanation.

  • Notebooking is an excellent student tool for gathering and reflecting on evidence
  • Science Discourse which helps make concepts and ideas audible and should also be grounded in evidence.
  • All Argument and Explanation that students develop should be based in evidence
Science Discourse

Students build science understanding of concepts through processing of hands on investigations and activities. Students first mode of processing is talk. As a result the most critical factor of teaching science in a sense-making fashion is engaging students in discourse. Discourse can transpire as whole-class discussions, partner sharing, or small group work, but a key factor for each mode is teacher guidance and facilitation of powerful discourse questions. Often teachers will plan for these key questions in light of feedback from formative assessment opportunities and observations of class processing tools such as Class Question Boards, Summary Tables, Competing Hypothoses, or class consensus models - all of which also generate whole-class discourse.

Another important aspect of science discourse is the opportunity it presents to uncover student ideas, thinking, and naive conceptions which is vital to building student understanding. (NAP, 2011) These can become stepping stones if skillfully built upon with key discourse questions, further investigations, and examining other sources of evidence. As stated in What We Call Misconceptions May Be Necessary Stepping-Stones Toward Making Sense of the World

“If students have the guidance and space to reason aloud with one another, they can fill the classroom with ideas about how to solve problems and why the ideas make sense in the particular context being examined (Cohen and Ball 1990). As students identify the strengths and weakness of their ideas, they position themselves to better understand the problems at hand, the extent to which the ideas may offer solutions (Bransford and Schwartz 1999), and how these ideas might help in similar contexts later. It’s helpful for us as teachers to think less about correcting misconceptions and more about helping students engage in science reasoning to try out, evaluate, and refine their resources (ideas, ways of thinking about the world) to explain real-world phenomena or solve problems.” (Campbell, Schwartz & Windschitl, 2016)

The type of talk used in classrooms is a result of different things. First it is indicative of a teacher's beliefs about students and learning. (Bevan, 2011) Secondly, it is affected by the teacher's own history as a student and years of modeling of classroom talk. So, often what happens is that teachers may hope to conduct classroom discourse in such a way that supports student sense-making, but still find themselves slipping into a more traditional or IRE (Inquiry, Response, Evaluation as explained here and also by BACOLOR, COOK-ENDRES, LEE & ALLEN, 2014) mode. The mode Phenomenal Science teachers strive to work in with students is dubbed “Exploratory” by Atwood, Turnbull and Carpendale (2010) and is characterised by “characterized by reciprocal interactions in which students justify their statements, are open to questioning or expansion of assumptions and assertions, and work with each other's ideas, including the particulars of ideas, to co-construct and refine a shared understanding. Studies have shown that exploratory conversation is linked to enhanced learning outcomes at the elementary and secondary level.” (Bevan, 2011) One great recommendation for teachers working toward making this shift in their classrooms is to videotape your lessons and reflect on the performance. This is seconded by Oliviria suggesting “opportunities for structured reflection on teaching practice can allow educators to improve their questioning strategies, leading to deeper scientific thinking for their audiences.” (Stromholt, 2011)

Having collaborative norms in place and using sentence frames to help guide the discussions are critical. Planning for the key questions a teacher will need to guide the meaning-making discussions is also critical. An excellent collection of resources for science talk can be found here. Also this section
from Tools and Traits for Highly Effective Science Teaching is valuable, “Ok, I’m Teaching Science, but How Do I Know They are Learning?” (p. 44-46)

- **Further Resources**
  - **Why:**
    - excerpts from *Taking Science to School*
    - The Teacher Channel Blog
    - *Why are Academic Discussions So Important for our ELLs?*
    - *Why Talk is Important in Classrooms*
    - Video: *How Discourse Enhances Learning*
  - **How:**
    - read *Implementing norms and routines for classroom discourse central to the subject-matter domain*
    - *How Can I Get My Students to Learn Science by Productively Talking with Each Other?*
    - *How can I foster curiosity and learning in my classroom? Through talk!*
    - *How can teachers guide classroom conversations to support students’ science learning?*
    - The difference between *Output and Interaction* in student talk
    - Scaffolds for Talk from Ambitious Science Teaching
    - Preparing Classroom Culture for Deeper Learning
    - Talk Resource Cards
    - Partner Conversational Supports
    - Pre- and Post-Talk Writing Supports
    - Critical Thinking: The Art of Socratic Questioning
    - Excellent Toolkit from AST contains both Why support and How Tips and Tools: *Structured Talk for How and Why Reasoning*
    - Great metacognitive tools for young learners: AST’s *Discourse Traffic Light*
    - AST’s *Discussion Diamond* with protocol
  - **Examples:**
    - look at Discourse Primer
    - *Talk Moves in Academic Discussions Video* - examples of ways to teach productive talk moves to students.
    - *The Inquiry Project* - video series on productive talk in science with classroom examples. Videos also touch on “why” and “how”.
    - From *A Framework for K-12 Science Education*
    - Ambitious Science Teaching Video: Student Share-Outs
    - Ambitious Science Teaching Video: Scaffolds to Make Student Ideas Public
How is the development of Crosscutting Concepts cultivated with student discourse? How does student discourse help or hinder student engagement with Science and Engineering practices? Click on the image to see all 3 dimensions.
FIGURE 3 Discourse prompts that teacher or students can use for supporting sense-making talk in small-group and whole-class discussions

When trying to make sense of phenomena

When trying to (initially) understand an event or process (whole class)
- What do you/we see going on here?
- What did you/we notice when ___ happened?
- When or where does ___ occur?
- Do we see any patterns in what happened?

When trying to elicit ideas (whole class or small groups)
- What do you/we think is causing this?
- What has happened here? (at level of inference)
- What would happen if ___?

When pressing for possible explanations (whole class or small groups)
- What might be going on here that we can’t see?
- Why do you/we think this happens this way? (emphasize cause)
- What do you/we think causes ___?

When working on summarizing ideas and selecting those to work on throughout a unit (whole class)
- What are some things we are not sure about here?
- How could we test our ideas?
- What kinds of information or experiences do we need to learn more?

When pressing students to construct or revise evidence-based explanations and explanatory models

When working to get students to reason about gaps or contradictions in explanations/models (small groups)
- Can you tell me/us what role [idea X, or aspect Y] has in your explanation/model?
- How does this part of your explanation/model fit with the rest?
- Does your explanation or model provide an account for how and why the phenomenon happens?

When preparing students to persuade others with evidence and scientific theory (small groups)
- Let’s focus on just one part of your explanation (such as before, during, or after an event) or model (e.g., the cause and effect or mechanism), and then an activity we’ve done that helps you/us understand that part of the explanation/model.
- Why did that activity convince you that [part of the explanation/model] is true?
- Is there a ‘fit’ between your evidence and your explanation/model?
- How does your model fit with other ideas that we have learned about in science?

When facilitating public comparison of evidence-based explanations or explanatory models (whole class)
- Compare this group’s explanation/model with yours? Is it similar? Different? How?
- Does their use of evidence or reasoning make you re-think any part of your own explanation/model?
- Can more than one explanation/model be supported by evidence or theory?

When considering final adaptations to final evidence-based explanations/explanatory model (whole class)
- Should we go back and revise our models/explanations?
- What puzzles do we still have?

Note: These strategies were taken from the AmbitiousScienceTeaching.Org discourse tools: Eliciting Students’ Ideas and Adapting Instruction and Pressing for Evidence-Based Explanations. An additional tool is also available for Supporting Ongoing Changes in Thinking as students are at work throughout the unit of instruction.
Explanatory and Argumentative Speaking and Writing

While a C-E-R Strategy is often used interchangeably in science for both Explanatory and Argumentative Speaking and Writing, in order to align with the Michigan elementary ELA Standards as well we should be cognizant of how the terms are used within ELA. Consider this article, *In Elementary School Science, What’s at Stake When We Call an ‘Argument’ an ‘Opinion’?* as an example of how important it can be to be clear about this alignment for both teachers and students. In this portion we have included information about both that will hopefully clarify the differences and how they work together.

**Explanatory Speaking and Writing**

When we work with students to develop Explanatory speaking and writing for science, we always work to explain a phenomenon or investigation. Research from secondary sources can also be included. Our explanation, whether written or spoken, should describe events or results and should answer either “how” or “why” and perhaps both. Examples of explanatory writing might include: How-to Guide, Cause and Effect, Magazine or Newspaper Article, Brochure, Infographic, Public Service Announcements, and Documentaries. Here are some examples to consider. Explanatory writing works especially well when having students dig into the Crosscutting Concepts of Cause and Effect, Patterns, Structure and Function or Stability and Change.

In getting students to develop this type of thinking, speaking and writing, a gradual release model is helpful. Teachers may want to begin by conducting “Think-alouds” in which the teacher begins by thinking through what the class has observed and beginning to develop an explanation for an investigation or phenomena. Developing sentences and even paragraphs together as a whole class is a good way to practice. Having students begin to practice by speaking their explanatory thinking in pairs or small groups is also a critical step. Pairs or groups may then be ready to write explanatory thinking together. Finally, students might be expected to craft their own explanatory sentences or paragraphs which would...
happen after the different levels of practice. Of course, this will look different and take different lengths of time depending on the grade level. (see chart below) When we are scoring explanatory writing we should keep in mind both science and ELA. In Appendix F of the NGSS, there is a progression (shown in box at right) for the practice of Explanation to consider on p. 11. This can be compared and used in conjunction with these rubrics that are aligned to Common Core State Standards for ELA and this rubric from Read, Write, Think within this example lesson on scientific explanation for K-2.

**Argumentative Speaking and Writing**

In Argument writing and speaking, on the other hand, students should make a claim about a phenomena, investigation, or current situation. Using a Claims-Evidence-Reasoning structure is especially helpful in developing Argument structured thinking with students. When using this structure in science, students should gather data (potential evidence) first. After analysis, students can determine what case the evidence seems to make for them. Crafting a statement that answers the focus question and is supported by their evidence becomes a Claim. Finally, older students can add some Reasoning statements which explain how the Evidence supports their Claim statement. So in writing an Argument, the structure follows the order of 1) Claim, 2) Evidence, 3) Reasoning, but in developing the Argument the order is 1) Evidence, 2) Reasoning, 3) Claim. When students are engaging in the practices of Investigation and Data Analysis, Argument speaking and writing is a natural fit.

There are many strategies which help students engage in Argument thinking, writing and speaking. This site, Argument Driven Inquiry outlines an 8-Step Process and The Core of Science Relating Ideas and Evidence, outlines how both students and scientists craft arguments from investigations. Some further strategies can be found in this resource called Scientific Argumentation and these examples. This resource is aimed at high school students and teachers but helps understand the ideas of Claim, Evidence and Reasoning. One important skill includes helping students craft arguments from texts they read, and
this article is a good resource to consider for this process. Generally, a gradual release process similar to that outlined for Explanatory writing should be followed. When students are ready for a more formal written Explanation or Argument, working with them to develop an “indicator list” or “gotta-have-it checklist” is a helpful strategy. This can become very helpful in scoring the writing. Just as with Explanation, we need to keep in mind what we know about the Argument practice from Appendix F, p. 12 and at left. This rubric is a good resource for more ideas on scoring Argument writing as aligned with ELA.

Here are some great resources to dig deeper into the practices of Explanation and Argument:

- A good summary comparison of Explanatory and Argument speaking and writing is in an article from NSTA which does a good job of describing each.
- How can formative assessment support culturally responsive argumentation in a classroom community?
- Ambitious Science Teaching’s Helping students talk about evidence: A guide for science teachers

- Ambitious Science Teaching (AST) Video Series called Integrating Scientific Argumentation for K-2 Learners.
- AST Writing Springboard Tool - scaffolding for reluctant writers
- AST Scaffolding Written Explanation Tool
- AST’s Claim and Evidence Sentence Starters
- Good tips about CER but linked to Explanation: Claims & Evidence (using Interactive Word Walls)
Which Science and Engineering Practices do students engage in while using a Explanatory or Argument speaking or writing? Which Crosscutting Concepts seem to lend themselves to explanatory or argument thinking? Click on the image to see the 3 dimensions.

<table>
<thead>
<tr>
<th>Science and Engineering Practices</th>
<th>Crosscutting Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking Questions and Defining Problems</td>
<td>Scientific Knowing and Explanation</td>
</tr>
<tr>
<td>Planning and Carrying out Investigations</td>
<td>The World of Matter</td>
</tr>
<tr>
<td>Developing and Using Models</td>
<td>Patterns</td>
</tr>
<tr>
<td>Using Mathematics and Computational Thinking</td>
<td>Space andtime</td>
</tr>
<tr>
<td>Obtaining, Evaluating, and Communicating Information</td>
<td>Systems</td>
</tr>
</tbody>
</table>

Developed by NRC based on content from the Framework for K-12 Science Education and supporting documents for the Next Generation Science Standards.
Notebooking

Notebooking is a powerful strategy that enables students to develop a deep understanding of science content while also supporting and reinforcing language skills. Notebooks also provide a mechanism for teachers to tailor instruction based on formatively assess student learning. Feedback is a critical component of growth and notebooks allow both the teacher and peers to give individualized comments that push the learner to dig deeper, clarify, and/or add on to their learning. For a brief introduction to notebooking, check out this section “Science Notebooks: a Growing Strategy for Linking Science and Writing” from Tools and Traits for Highly Effective Science Teaching (p. 51-58)

As explained in Sensemaking Notebooks: Making Thinking Visible for Both Students and Teachers, there are four key ways to use notebooks. 1) Gathering Prior Knowledge, 2) Collecting Data, 3) Making Sense of the Data, 4) Metacognition. The article is a great resource for learning more about using notebooks to help students make sense of science.

There are many ways to effectively implement the use of a science notebook into your classroom. Some options include a spiral notebook, a journal, a digital notebook, a journal folder, or lined/computer paper stapled together. When considering how to best utilize this strategy in your classroom it is best think about the grade level, writing and reading abilities, and organizational skills that the students already possess. Additional information for implementation of a science notebook can be found here.

Notebooks can be used daily as students work through processing information. Entry types should be chosen carefully to meet the requirements of the lessons outcomes. This document includes several ideas for potential notebook entries.
Still have questions? That is understandable! Use the following resource to uncover even more information about the tips and tricks of science notebooks.

Examples of notebooks can be found within this google slide presentation. Some good tips, tricks and examples are in this article titled Five Good Reasons for Using Notebooks.
How is the development of Crosscutting Concepts cultivated with student notebooking? How does notebooking impact student engagement with Science and Engineering practices? Click on the image to see all 3 dimensions.

<table>
<thead>
<tr>
<th>Crosscutting Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patterns</strong></td>
</tr>
<tr>
<td>Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.</td>
</tr>
<tr>
<td><strong>Cause and Effect: Mechanism and Explanation</strong></td>
</tr>
<tr>
<td>Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.</td>
</tr>
<tr>
<td><strong>Scale, Proportion, and Quantity</strong></td>
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<tr>
<td>In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system’s structure or performance.</td>
</tr>
<tr>
<td><strong>Systems and System Models</strong></td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td><strong>Energy and Matter: Flows, Cycles, and Conservation</strong></td>
</tr>
<tr>
<td>Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems’ possibilities and limitations.</td>
</tr>
<tr>
<td><strong>Structure and Function</strong></td>
</tr>
<tr>
<td>The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.</td>
</tr>
<tr>
<td><strong>Stability and Change</strong></td>
</tr>
<tr>
<td>For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.</td>
</tr>
</tbody>
</table>
Concept Maps

Concept maps provide students an opportunity to make their thinking visible in a conceptual format. Allowing students to make sense of their current understanding via concept maps increases the awareness for both student and teacher of what is actually being learned. This is a great way for teachers to formatively assess students and provide feedback and it is also a great way for students to be reflective on their own learning and understanding of the topic creating individual ownership. Concept maps can be easily used as a notebook entry. They can be very specific or creative depending on the teachers desired outcome. In this link, and in illustrations below you will find examples of concept maps.

- A schematic representation of meaningful relationships among concepts.
- Good for starting a topic.
- Good for finding any misconceptions.
- Gives an insight into the structures the students has built up about world.
- Encourages students to clarify their ideas using a visual representation.
- Assesses current understanding and assists in further learning.
How is the development of Crosscutting Concepts cultivated with concept maps or graphic organizers? How does using concept maps or graphic organizers impact student engagement with Science and Engineering practices? Click on the image to see all 3 dimensions.
Collaborative Groups

Engaging students in collaborative discourse is critical to sense-making activities. In fact, most of the eight Science and Engineering Practices require students to act in a social context to fully engage in the practice. As noted by Adams, “the idea of co-construction should not be confined to teacher – pupil interaction alone. Behaviourist learning and teaching interactions often led to a culture of pupil dependence on teachers; pupils did as they were told and had good surface understanding, but little sense of purpose (Weeden & Winter, 1999). To avoid such dependency, social constructivist approaches acknowledge the need for pupil – pupil interaction. The exploitation of peer approaches to learning provides possible answers to the problems of encouraging and enabling primary-age pupils to take gradually more control over their own learning.” (Adams, 2006) However, using collaborative groups effectively can be daunting and is not necessarily a simple task. This guide will help develop our Collaborative Groups Toolbox with some critical strategies for success.

One key understanding for successful groups is knowing the Five Key Aspects (see also below). Having this tool, teachers can plan for each of those aspects whenever they structure collaborative groups and ensure groups are interdependent, have a group goal, individuals are also accountable, and students have been taught the social skills necessary. For more details peruse the article from ASCD titled “Making Cooperative Learning Powerful,” and “Not Just Group Work - Productive Group Work!”
Five essential components must be present for small-group learning to be truly cooperative:

**Positive Interdependence** (sink or swim together)
- Each group member’s efforts are required and indispensable for group success
- Each group member has a unique contribution to make to the joint effort because of his or her resources or role and task responsibilities

**Face-to-Face Interaction** (promote each other’s success)
- Orally explaining how to solve problems
- Teaching one’s knowledge to others
- Checking for understanding
- Discussing concepts being learned
- Connecting present with past learning

**Individual and Group Accountability** (everybody does his part)
- Keep the size of the group small. The smaller the size of the group, the greater the individual accountability may be
- Assess individual learning
- Randomly examine students by calling on one student to present his or her group’s work to the teacher (in the presence of the group) or to the entire class
- Observe each group and record the frequency with which each member contributes to the group’s work
- Have students teach what they learned to someone else

**Interpersonal and Small-Group Skills** (social skills building)
- Social skills, such as leadership, decision-making, trust-building, communication, and conflict-management skills, must be taught

**Group Processing** (reflection)
- Group members discuss how well they are achieving their goals and maintaining effective working relationships
- Group members describe what member actions are helpful or not helpful
- Group members make decisions about what behaviors to continue or change
Another set of key foundational tools when planning for collaborative groups are setting classroom routines and norms. Ensuring students understand the parameters around things like voice level and how to get materials and supplies starts students off on the right foot. Developing classroom norms works together with teaching social skills. In the beginning of the year, the teacher will want to work together with students to develop a set of classroom norms. Here are some examples:

- **Classroom Management Tips**
- **Structuring Collaboration for Student Success** (video)
- **Establishing Classroom Norms**

This will go hand in hand with teaching social skills such as these examples show. Some teachers also find it very helpful to assign student roles within groups as well. When teaching the social skills, and in assigning grades to group
work, a good rubric will come in handy, such as these for grade K-2 and 3-5 and also this student friendly rubric. And finally having some good techniques to keep students on track with things such as noise level are very helpful such as described in “Productive Group Work: The First 20 Days”

With the classroom structured for success, and all 5 aspects of collaborative groups accounted for in the lesson, teachers are ready to consider some different structures. There are many ways to engage students in group work and often some go-to structures can be helpful. Here are some illustrations some helpful structures:

- **Types of Cooperative Learning**
- **Common Techniques**

Some other Collaboration Resources:

- AST A/B Partner Talk Protocol
- AST Discourse Diamond with Protocol

Finally, consider assigning "scientific" type roles to your group members as suggested by Ambitious Science Teaching.
Sure that the whole group takes a moment to hear and entertain questions from everyone. This is not a role that students find easy, so it helps to provide them with question stems such as:

- Asks: “What does it mean that _____?”
- Asks: “How do we know that _____?”
- Paraphrases what other have said: “So, what I think you are saying is... Is that right?”
- Asks: “What would happen if we changed _____?”
- Asks: “What’s your evidence?”

**Skeptic.** This person tries to strengthen the group’s work by probing for weaknesses in the developing explanation or model.

- Asks: “Here’s an alternative explanation—is this just as good as the one we have now?”
- Asks: “Does it always work this way (the explanation)?”
- Asks: “How does our idea match up with what we’ve just learned?”

**Progress Monitor.** This person asks others to periodically take the measure of the group’s progress.

- Asks: “What can we say we’ve accomplished so far?”
- Asks: “What do we still need to know/do to accomplish this task?”
- Asks: “What can we now add to our explanation that we didn’t have before?”
- When you stop by a table to listen in on a group, you should expect this person to be able to communicate the ideas of the group members AND attribute ideas to particular people (giving credit where it is due).

You can sometimes incorporate the “peacekeeper” role into one of the other roles described above.

**Peacekeeper.** This person monitors time of people in the group—this person is allowed to control who has “the floor” with the goal of ensuring that everyone gets a chance to talk and that everyone takes time to listen.

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**Which Science and Engineering Practices do students engage in while in collaborative groups? Which Crosscutting Concepts seem to lend themselves to collaborative group work?** Click on the image to see the 3 dimensions.
A Word About Vocabulary

Two of the Core Principles of Phenomenal Science are “Activity before Concept” and then “Concept before Vocabulary”. These two principles sum up the core of what needs to happen with science instruction in regards to vocabulary and imply a sequence for developing understanding prior to introducing vocabulary. In shifting our science instruction to be more three dimensional as required by the new Michigan Science Standards, students need to learn science by doing science practices. As a result, students should be introduced to vocabulary that they need after they have begun to develop a concept of it through real experiences. During reading of the text, fine for teachers to highlight the vocabulary that students discovered in the investigation experience.

For science vocabulary, it has been shown to not be helpful to pre-introduce or front-load the terms in our instruction. Vocabulary should be introduced as students experience a need for that term - often during an experience, investigation, or sense-making activity. We often use the phrasing "Scientists call that __________." As informational text usually follows this sequence, it makes sense to highlight the terms within it that students might have experienced, seen or heard earlier and help students connect them to the students’ real experiences. Since the hands on experiences should happen prior to most reading of informational text in a Phenomenal Science instructional cycle, this is a great reinforcement of both the concept and the term to note them when encountered in the text.

Many teachers have found that having students keep a “Glossary” section in their notebooks is a great way to have students track and define the vocabulary after they have built a concept of it. In this way, students might first write the word on the notebook entry they are keeping for investigation or sense-making when they first are introduced to it, highlight it there. Later, students add all highlighted words to the glossary when it is time for a more formal definition. This more formal definition is often introduced or co-constructed during an Explain portion of an instructional cycle sometimes in conjunction with an informational text or video.

As can be seen this model fits nicely with the Michigan K-3 Literacy essentials which state:
The teacher
- selects Tier 2 and Tier 3 vocabulary words to teach from read alouds of literature and informational texts and from content area curricula
- introduces word meanings to children during reading and content area instruction using child-friendly explanations and by providing opportunities for children to pronounce the new words and to see the spelling of the new words

Within PS Units the authors have identified lists of vocab (not exhaustive) that students will probably need for each instructional cycle. These vocabulary lists can be found in the in the Learning Plan Overview for each unit. You can see an example of this on p. 19-20 of Unit 1.3 Learning Plan Overview. The introduction of vocabulary has been described by the process outlined above and can certainly be embedded in the many various read-alouds suggested in the units. Words will also be used on class consensus models, explanations, arguments, and / or other anchor charts such as CQBs, Summary Tables / KLEWs Charts. Planning out child friendly definitions is a wonderful way to anticipate how to introduce the words to students as the students find they need them. Students will have additional opportunities to use the vocabulary in the various experiments, investigations, and books and highlighting these is a good practice for teachers prepare to teach PS units. Students will also have
further opportunities to work with the words during use of exploration station, which can be embedded into all instructional cycles.

<table>
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<tr>
<th>Instructional Cycle</th>
<th>Focus Question</th>
<th>Anchoring Phenomenon</th>
<th>Vocabulary Introduced</th>
<th>Formative Assessment Opportunities</th>
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It is important to note why vocabulary is found in this portion of the Unit Plan. Students will best remember and understand vocabulary when it is introduced in the process of discovering that concept. So as students are investigating the liquid found on the outside of a cold glass of water and drawing their models of this idea, but struggling with what to call it, it is a good time to say something like “scientists call that ‘condensation’.” To introduce terms earlier or front load them takes the discovery out of the power of the students. A great example of this can be seen in the video, “Responsive Talk: How Students Use Vocabulary” from Ambitious Science Teaching.

When students are ready for some more explicit vocabulary work, what are some tools and tasks that can help them further build understanding? Watch “Everyday Language and Science Language” and consider the article “Interactive Word Walls” for some ideas about connecting students everyday experiences with the new vocabulary. Another vocabulary tool example can be found in Phenomenal Science Unit 2.1, see Lesson?? Finally, use the Vocabulary Planning Guide to help you plan your vocabulary instruction for your next unit.

Some other helpful resources:

- [Oakland Schools Literacy Webinars](#)
- [A Winning Combination](#) - article from Science and Children (NSTA) with word wall games
- [Science Achievement for All](#) - supporting research article
- [Interactive Conceptual Word Walls](#) - supporting research article

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Research Based Theories and Models
Constructivism

Constructivism is a theory -- based on observation and scientific study -- about how people learn. It suggests that people construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences. When we encounter something new, we have to reconcile it with our previous ideas and experience, maybe changing what we believe, or maybe discarding the new information as irrelevant. In any case, we are active creators of our own knowledge. To do this, we must ask questions, explore, and assess what we know.

As the basis for progressive pedagogy, constructivism is heavily grounded in psychology and social science research (National Research Council, 2000), both of which have intellectualized the perception of learning (Ayers, 1991) (Windschitl M., 2002) Much research has been found to support Constructivism aspects such as “learners’ alternative conceptions (Andersson, 1991; Carey, 1985; Vosniadou & Brewer, 1989), thinking and problem solving in the various disciplinary domains (Bransford & Stein, 1984; Hiebert et al., 1996), the use of representations in learning and teaching (Latour, 1990; Suchman, 1990), and metacognition (Brown, 1980; Flavell, 1991; White & Frederiksen, 1998). . . . (and) the social and cultural influences on knowledge construction. In line with (these) findings, . . . theorists have proposed new ways of framing the act of teaching, for example, as co-constructing knowledge with students, acting as conceptual change agent, mentoring apprentices through the zone of proximal development, and supporting a community of learners.” (Windschitl M., 2002)

Grennon, Brooks & Brooks have identified 5 tenets of Constructivist Teaching:
“First, constructivist teachers seek and value students’ points of view. Knowing what students think about concepts helps teachers formulate classroom lessons and differentiate instruction on the basis of students’ needs and interests.

Second, constructivist teachers structure lessons to challenge students’ suppositions. All students, whether they are 6 or 16 or 60, come to the classroom with life experiences that shape their views about how their worlds work. When educators permit students to construct knowledge that challenges their current suppositions, learning
occurs. Only through asking students what they think they know and why they think they know it are we and they able to confront their suppositions.

Third, constructivist teachers recognize that students must attach relevance to the curriculum. As students see relevance in their daily activities, their interest in learning grows.

Fourth, constructivist teachers structure lessons around big ideas, not small bits of information. Exposing students to wholes first helps them determine the relevant parts as they refine their understandings of the wholes.

Finally, constructivist teachers assess student learning in the context of daily classroom investigations, not as separate events. Students demonstrate their knowledge every day in a variety of ways. Defining understanding as only that which is capable of being measured by paper-and-pencil assessments administered under strict security perpetuates false and counterproductive myths about academia, intelligence, creativity, accountability, and knowledge. (Grennon Brooks & Brooks, 1993).” (Brooks & Brooks, 1999)

Additional Links and Resources:
- Concept2class: Constructivism
- Learning theories: Constructivism
- Constructivist Views of Learning in Science and Mathematics
- Constructivist Teaching Science
- Teaching and learning in science: A new perspective

In the classroom, the constructivist view of learning can point towards a number of different teaching practices. In the most general sense, it usually means encouraging students to use active techniques (experiments, real-world problem solving) to create more knowledge and then to reflect on and talk about what they are doing and how their understanding is changing. The teacher makes sure she understands the students’ preexisting conceptions, and guides the activity to address them and then build on them.

In a constructivist classroom, learning is . . .

- Constructed: Students are not blank slates upon which knowledge is etched. They come to learning situations with already formulated knowledge, ideas, and understandings. This previous knowledge is the raw material for the new knowledge they will create.
- Active: The student is the person who creates new understanding for him/herself.
- Reflective: Students . . . lead the way by reflecting on their experiences. . . . The teacher helps create situations where the students feel safe questioning and reflecting on their own processes,
- Collaborative: Students reflect upon activities and build understanding in collaborative groups
- Inquiry-Based: The main activity in a constructivist classroom is solving problems.
- Evolving: Students have ideas that they may later see were invalid, incorrect, or insufficient to explain new experiences. These ideas are temporary steps in the integration of knowledge.
Constructivism videos:
Use a Learning Theory: Constructivism Video
Constructivist Learning Video

What happens when a student gets a new piece of information? The constructivist model says that the student compares the information to the knowledge and understanding he/she already has, and one of three things can occur:

- The new information matches up with his previous knowledge pretty well (it's **consonant** with the previous knowledge), so the student adds it to his understanding. It may take some work, but it's just a matter of finding the right fit, as with a puzzle piece.

- The information doesn't match previous knowledge (it's **dissonant**). The student has to change her previous understanding to find a fit for the information. This can be harder work.

- The information doesn't match previous knowledge, and it is **ignored**. Rejected bits of information may just not be absorbed by the student. Or they may float around, waiting for the day when the student's understanding has developed and permits a fit.

Additional Links and Resources:
Piagets stage theory of cognitive development
Discovery learning
Current trends: Constructivism
Constructivism and Social Constructivism in the Classroom
Constructivism and the 5Es
10 Basic Learning Principles in Constructivism:

1. Learning is a way of structuring meaning in an active way. It includes conceptual change.

2. Learning is a reconstruction of developing students' apprehension into a more complex and effective mode.

3. Learning is subjective. It is internalization of ideas with different symbols, graphics, metaphors and models.

4. Learning is shaped with situations and the condition of the environment.

5. Learning is a social process. It develops through communications, sharing perspectives, exchanging information and solving real problems collaboratively.

6. Learning is an emotional process because mind and emotion are closely linked.
7. The appropriateness of learning to student's development, its association with need or students' real life is important in the learning process.

8. Learning is developmental and is affected by students social, emotional, physical and logical development.

9. Learning is student-centered and focuses on student's needs.

10. Learning doesn't start at a definite time or end at a definite time. In contrast, it continues in a permanent way.

From: Constructivism, Presentation by Michelle G. Hatid-Guadamor
Social Learning Theory

Social Constructivism is theory about how students learn posed by Vygotsky. It is related to the theory of constructivism and has many aspects in common such as:

- “What the student currently believes, whether correct or incorrect, is important.
- Despite having the same learning experience, each individual will base their learning on the understanding and meaning personal to them.
- Understanding or constructing a meaning is an active and continuous process.
- Learning may involve some conceptual changes.
- When students construct a new meaning, they may not believe it but may give it provisional acceptance or even rejection.
- Learning is an active, not a passive, process and depends on the students taking responsibility to learn.” (Constructivism and Social Constructivism in the Classroom)

Going further, however, social constructivism emphasizes the necessity of collaboration for learning to occur. According to Vygotsky, language and culture are critical to cognitive development. (GSI Teaching & Resource Center, 2018) In fact he “posits that learner construction of knowledge is the product of social interaction, interpretation and understanding (Vygotsky, 1962). As the creation of knowledge cannot be separated from the social environment in which it is formed, learning is viewed as a process of active knowledge construction (Woolfolk, 1993)” (Adams, 2006) Furthermore, because of the nature of language, “knowledge constructs are formed first on an inter-psychological level (between people) before becoming internalized or existing intra-psychologically (Daniels, 2001).” (Adams, 2006)

This theory recognizes three major components of social learning: (David, 2014)

- Social Interaction - social interaction is a necessary part of learning structures because learners first learn something together before it becomes internalized
- More Knowledgeable Other - The More Knowledgeable Other “refers to anyone who has a better understanding or a higher ability level than the learner, with respect to a particular task, process, or concept. The MKO is normally thought of as being a teacher, coach, or older adult, but the MKO could also be peers, a younger person, or even computers.” (David, 2014) This MKO provides guidance or modeling in situations where there are new ideas or skills to be assimilated. (Adams, 2006)
- Zone of Proximal Development - The ZPD is the distance between a student’s ability to perform a task under adult guidance and/or with peer collaboration and the student’s ability solving the problem independently. According to Vygotsky, learning occurred in this zone. (David, 2014)

Social Constructivism also strongly advocates that experience is crucial to the student construction of true understanding. Vygotsky distinguished “between the genuine or ‘scientific’ concepts learned as a result of schooling and the ‘everyday’ or ‘spontaneous’ concepts learned by the child elsewhere.” (Wertsch, 1985, p. 102). The link between formal and informal concepts, according to Vygotsky, takes place through the use of the psychological tool of language.” (Jones & Brader-Araje, 2002) Language is the mitigator between the known and the unknown and the main powerful tool wielded by learners to construct understanding together about experiences. Without language students would not be able to move from thinking of concrete experiences to higher order abstract thinking. (Jones & Brader-Araje, 2002) “According to Vygotsky, language serves as a psychological tool that causes a fundamental change in mental functions.” (Jones & Brader-Araje, 2002)
Adams suggests a number of principles of Social Constructivism:

- “Focus on learning not performance.
- View learners as active co-constructors of meaning and knowledge.
- Establish a teacher–pupil relationship built upon the idea of guidance not instruction.
- Seek to engage learners in tasks seen as ends in themselves and consequently as having implicit worth.
- Promote assessment as an active process of uncovering and acknowledging shared understanding.” (Adams, 2006)

He summarizes that “the most obvious reform required then is the devising of more open-ended tasks that require students to think critically, solve complex problems and apply their knowledge in and to their own world (Shepard, 2000). “ (Adams, 2006) Which mirrors what is recommend by the NRC:

An important stage of inquiry and of student science learning is the oral and written discourse that focuses the attention of students on how they know what they know and how their knowledge connects to larger ideas, other domains, and the word beyond the classroom. . . . Using a collaborative group structure, teachers encourage interdependence among group members, assisting students to work together in small groups so that all participate in sharing data and in developing group reports. (National Research Council, 1996, p.36) (Jones & Brader-Araje, 2002)

Some practical classroom suggestions can be found in the Social Constructivism section of University College Dublin’s Constructivism and Social Constructivism in the Classroom.
Inquiry Instruction

As an outgrowth of Constructivist Learning and Social Learning Theory, Dewey's Inquiry Based Learning in the form of Guided Inquiry becomes the backbone of Phenomenal Science units. Each instructional Cycle follows a modified “Five E Approach” as proposed by Bybee. This model helps us ensure that investigations happen prior to asking students to develop concepts and that student concepts have begun forming before we introduce vocabulary or expert voice.

As has been noted in How People Learn, " Simply telling students what scientists have discovered, for example, is not sufficient to support change in their existing preconceptions about important scientific phenomena. Similarly, simply asking students to follow the steps of “the scientific method” is not sufficient to help them develop the knowledge, skills, and attitudes that will enable them to understand what it means to “do science” and participate in a larger scientific community. And the general absence of metacognitive instruction in most of the science curricula we experienced meant that we were not helped in learning how to learn, or made capable of inquiry on our own and in groups. Often, moreover, we were not supported in adopting as our own the questioning stance and search for both supporting and conflicting evidence that are the hallmarks of the scientific enterprise." (How People Learn, page 398)

The key factor being that students should EXPERIENCE a phenomenon or concept before they try to describe it or read about it. So in each iteration within the instructional cycle in PS units we strive to ensure students have as real and concrete an experience as possible. This is followed most naturally by student talk as a way to make meaning of the experience (perhaps whole-class, partners, or collaborative groups or some mix). The next step to build upon the experience and layer in meaning would be drawing followed by writing and reading. Whether reading or writing most naturally follows drawing is dependent on the level of text or writing task. Of course, once the concrete experience occurs, often times the next steps happen simultaneously or at least with student talk layered throughout the process. This is the sort of “Gradual Release of Responsibility” that works most naturally.
in developing student explanations of phenomena. As one can see the Guided Inquiry Model allows students to build from more concrete experiences to abstract experiences.

START with a puzzling Phenomenon

Concrete Experience

Hands-on Investigation

Discourse About Experience

Drawing own Ideas from Investigation

Writing about own Ideas from Investigation

Reading about others’ Ideas from Investigation

Abstract Ideas / Concepts

Closer to Scientific Concept / Ready to begin next Iteration

Within each iteration throughout the instructional cycle, students get closer in their own explanation, model, or argument about the phenomenon to a “scientific” one. The following shows a description of the types of activities that occur in each of the phases of the Five E Inquiry Model followed in Phenomenal Science units.

| The Focus Question for Each cycle | Each cycle has one open-ended driving question that relates to all the content and skills of the unit. The Key Question is presented at the opening of the cycle and revisited at the cycle’s conclusion. |

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<thead>
<tr>
<th>the Cycle</th>
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<tbody>
<tr>
<td>Engage and Elicit</td>
<td>Each unit begins with an activity designed to elicit and reveal student understanding and skill prior to instruction. Teachers are to probe students for detailed and specific information while maintaining a non-evaluative stance. They also can record and manage student understanding which may change as instruction proceeds.</td>
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<tr>
<td>Explore</td>
<td>A sequence of activities provides opportunities to explore phenomena and relationships related to the Key Question of the unit. Students will develop their ideas about the topic of the unit and the Key Question as they proceed through the Explore stage of the learning cycle. Each of the activities may have its own Focus Question or central task that will be more focused than the unit question. The heart of these activities will be scientific investigations of various sorts. The results, data and patterns will be the topic of classroom discourse and/or student writing. A key goal of the teacher is to reference the Key Question of the cycle, the Engage and Elicit of the students and to build a consensus especially on the results of the investigations.</td>
</tr>
<tr>
<td>Explain</td>
<td>Each unit has at least one activity in the Explain portion of the unit when students reconcile ideas with the consensus ideas of science. Teachers ensure that students have had ample opportunity to fully express their ideas and then to make sure accurate and comprehensible representations of the scientific explanations are presented. A teacher lecture, reading of science text, or video would be appropriate ways to convey the consensus ideas of science. Relevant vocabulary, formal definitions and explanations are provided. It’s critical that the activity and supporting assessments develop a consensus around the Key Questions and concepts central to the unit.</td>
</tr>
<tr>
<td>Elaborate</td>
<td>Each unit cycle has at least one activity or project where students discover the power of scientific ideas. Knowledge and skill in science are put to use in a variety of types of applications. They can be used to understand other scientific concepts or in societal applications of technology, engineering or problem solving. Some units may have a modest Elaborate stage where students explore the application of ideas by studying a research project over the course of a day or two. Other units may have more robust projects that take a few weeks.</td>
</tr>
<tr>
<td>Evaluation</td>
<td>While assessment of student learning occurs throughout the unit as formative assessment, each unit will have a summative assessment. Summative assessments are posted in a separate document.</td>
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For an even deeper dive into understanding inquiry-based teaching visit [Concept to Classroom’s Inquiry Based Learning Workshop](#). For a synopsis of the research supporting the use of Inquiry-Based instruction, visit [Inspired Issue Brief: Inquiry Based Teaching](#) and [Teach Thought’s 10 Benefits of Using Inquiry-Based Teaching](#).
Another key aspect of the Guided Inquiry model followed in PS units, is the challenge of following this model at the same time as encouraging students own questions and ideas. Through the discourse, drawing, and students questions, the artful teacher will fine tune the craft of using what students bring to the experience as the springboard for the next experience, discourse, reading or writing. One guide for encouraging this sort of interaction between teacher and curriculum goals and student-driven ideas can be found in the suggestions given in [Playful Inquiry for Elementary Students](#). For some more ideas, check out TeachThought’s [60 Ways to Help Students Think for Themselves](#).

Further, as students and teachers move through each instructional cycle from beginning to end, they become more adept at managing the skills of inquiry and the Science and Engineering Practices. Another layer of gradual release of responsibility occurs in this way as well. This article from Edutopia is an excellent resource for helping students take charge of the inquiry process: [Inquiry-based Learning from Teacher-Guided to Student-Driven](#). This same article also shows how helpful Classroom Question Boards and Exploration Stations can be used as does the article: [Inquiry-Based Learning: Developing Student-Driven Questions](#). Finally, teachers often wonder if there is a time and place for direct instruction within Inquiry-Based teaching: [Just-in-Time Instruction](#) details how and when teachers might include this within their Explain phase of instruction. Hopefully, these resources put Phenomenal Science teachers and students well on the way to learning together through inquiry.
Student Centered Learning

TeachThought defines Student Centered Learning as “a process of learning that puts the needs of the students over the conveniences of planning, policy, and procedure.” (4 Principles Of Student-Centered Learning, TeachThought) Student Centered Learning within Phenomenal Science also integrates some factors meta-analyses of research, neuroscience research, even some theories such as Gardner’s Multiple Intelligences, Glasser’s Choice Theory and Kolb’s Learning Styles. As Dewey states “The belief that all genuine education comes about through experience does not mean that all experiences are genuinely or equally educative.” (Dewey, 1938)

This “'learning orientation' (Watkins, 2001) keeps the locus of control squarely with the pupil.” When this happens, students recognize that learning comes through effort are are rewarded with an increase in achievement and personal power and growth. (Adams, 2006; Dweck, 1999; Glasser, 1998) “In this orientation, learners . . . derive satisfaction from perseverance and success in difficult tasks (Dweck, 1999; Watkins, 2001).” (Adams, 2006) Historically, there have been several champions of this sort “progressive” education, as noted by Windschitl:

“Early progressive movements championed “child-centered” approaches and advocated much the same instructional philosophy as constructivism does today. In the late 1800s, Francis Parker led reforms in Quincy, Mass., and at Chicago’s Cook County Normal School based, in part, on the child-centered theories of Rousseau, Froebel, and Pestallozi (Farnham Diggory, 1990). He emphasized learning in context, for example, by taking his students on trips across the local countryside during geography classes rather than having them recite countries and capitals. His students created their own stories for “Reading Leaflets,” which replaced both the primers in his grammar schools and the rote learning that went with them (Stone, 1999). In 1919, Helen Parkhurst founded the Dalton School on the principles (among others) that school programs should be adapted to the needs and interests of the students and that students should work to become autonomous learners (Semel, 1999). Similarly, John Dewey routinely used the common experiences of childhood as starting points for drawing his students into the more sophisticated forms of knowledge represented in the disciplines (Dewey, 1902/1956). He intended that educative experiences be social, connected to previous experiences, embedded in meaningful contexts, and related to students’ developing understanding of content (Dewey, 1938). (Windschitl M., 2002)

Some of the most commonly touted research work done in this area was conducted by Kolb in the 1960s. He identified three “learning styles:” Auditory, Visual, and Kinesthetic. More recently, Gardner identified between seven to ning various areas of intelligence. Kolb’s and further research eventually showed that while students may have preferences, at one period in their life or another, that we all take and process information through all modes and all areas of intelligence can be grown and strengthened.”There is no strong evidence that teachers should tailor their instruction to their students' particular learning styles . . . 'Matching is not a particularly good idea,' Mr. Kolb says. . . . (There are) 'practical and ethical problems of sorting people into groups and labeling them. Tracking in education has a bad history.'” (Finley, 2015) According to Finley, Moore states “that ‘the best way to honor people’s individuality isn't to shove them into simplistic categories.’ But it isn't to treat them as identical robots either, and this requires beginning with the person, and not with the content.” (Finley, 2015) The take away for teachers today, supported by brain-based research, is that the more students are active in all three modes while learning, helps brains build connections and meaning. (Jensen, 2010)
key instructional strategies that are supported by this include investigations, collaborative work, and sense-making activities such as summary tables and CQBs.

In the realm of psychology in the latter portion of the 20th century, Glasser’s research determined that people have five psychological needs: survival, freedom, power, belonging, and fun (Glasser, 1998). According to Glasser’s Choice Theory, every action people take is motivated to meet one or more of these needs (Glasser, 1998). A key implication for classrooms is to ensure that students are able to use classroom activities to meet their needs, and that teachers help students recognize how these activities can do that. This theory further implies that classroom instruction allows for student choice, encourages belonging by building in social interactions and ensure emotional safety, that activities appeal to students, and finally that they are a level appropriate to gain understanding and thus gain power. There is a strong link here with Vygotsky’s Social Learning Theory also. As noted by Irving, “to meet Glasser’s five needs, social interaction is paramount. (2015). Further, he states also, “emotion is a major component of needs satisfaction (Louis, 2009), and thus emotion is a major component of learning (Sullo, 2007).” (Irvine, 2015)

Some cognitive research suggests that students learn best under certain brain-friendly conditions. Sprenger notes the following (corresponding image derived from teachthought.com):

- **“No clear and present dangers.”** Keeping threat and stress low is imperative for the brain to function at high levels.
- **Many procedures and rituals.** Procedures and rituals calm the brain and free up working memory.
- **Flexible grouping that encourages a sense of community.** Brains work better when they are with other brains.
- **Adequate wait time and time on task.** Some students are slow processors and require more time to access information.
- **Choice.** Choice is the key to brain-compatible classrooms and to differentiation. The brain loves choice because it allows it to problem-solve.
- **Curriculum is meaningful.** Meaningful curriculum that relates to students lives will be memorable. That is not an easy task, but its well worth it.
- **Formative assessment with timely feedback is used.** Ongoing assessment and feedback let the brain know what is expected of it, and provide a framework for learning.
- **Attractive and peaceful surroundings.** An attractive environment might include plants, stuffed animals, colorful posters, student work, and natural lighting. It would also provide some
climate control, because the brain works best in temperatures between 68 and 72 degrees” (Sprenger, accessed 2018)

However, current neuroscience research takes this even further with fMRI studies. An analysis by Zadina notes several key distinctions:

“While learning styles theory drew a distinction between learning visually, auditorially, or kinesthetically, neuroscience research revealed the importance of vision in learning (Nelson, Reed, & Walling, 1976). Thus, we can guide educators to make lessons more visual while reminding them that all components of a lesson use brain resources and increase cognitive load, so the images must be meaningful and make a contribution”

“An understanding of the biology of threat, of how anxiety and stress impact learning, and the nature of our traumatized students can help educators understand why a method that appears to work can actually inhibit learning and they can learn strategies that create the right amount of positive stress while eliminating the negative stress that can impact cognitive function (Goswami, 2004; McEwen & Sapolsky, 1995)"

“Evidence suggests the value of classroom strategies aimed at improving attention.”

“Research using functional magnetic resonance imaging (fMRI) shows more demand on working memory when students are initially learning, when the cognitive load is higher, than later in the learning process (Chein & Schneider, 2005). Teachers understanding cognitive load theory can teach differently, allocating more time early in the process than later and designing lessons in ways that address the effects of cognitive load and working memory limitations” (Zadina 2015)
In recent decades, there have been several meta-studies conducted which analyzed classroom practices that have proved to be effective at helping students learn in both cognitive realm and psychological areas. Much of this work has consistently shown many instructional strategies embedded within the Phenomenal Science units to be highly effective for students. The two graphics shown here show the correlation between several of these meta-studies as well as recommended instructional strategies for high impact.
Finally, some key ideas from the realm of Student Centered Learning for teachers to keep in mind: “When children engage in activities they view as pleasurable, and when the projects are ones they have chosen, . . . dopamine is released in the brain. This neurotransmitter increases attention and helps information to be stored in long-term memory. 1 . . . . When children choose to engage in academic work, there is joy. Let's not lose track of one important goal of learning: making sense of the world for the pure joy of it”. (Kennedy, 2012) Further, as we try to ensure in Phenomenal Science Units, “A time-honored way to make learning more lively and proactive is to frame schoolwork around enchanting and thought-provoking questions and to weave the content in as "answers" or "tools" in helping learners address those questions.” (McTighe and Wiggins, 2013)
Higher Order Thinking and Depth of Knowledge

“Were all instructors to realize that the quality of mental process, not the production of correct answers, is the measure of educative growth something hardly less than a revolution in teaching would be worked.” (Dewey, 1916) According to Barak and Dori there is much agreement that “A central goal of science education is to help students to develop higher order thinking skills, enabling them to think critically, ask significant questions, reason, and solve problems (Bybee and DeBoer 1994; Zohar and Dori 2003; Zoller 1993).” (2009) In fact, a decade prior to the NGSS, “To comply with science education reform (National Research Council (NRC) 1996, 2000; National Science Teachers Association (NSTA) 2003) and the Standards for Professional Development in Schools (NCATE 2001), science teachers are expected to apply constructivist learning and higher order thinking among their students (Barak et al. 2007; Dori and Herscovitz 2005; Tobin et al. 1990).” (Barak and Dori, 2009)

As described by King and colleagues, “Higher order thinking skills include critical, logical, reflective, metacognitive, and creative thinking. They are activated when individuals encounter unfamiliar problems, uncertainties, questions, or dilemmas. Successful applications of the skills result in explanations, decisions, performances, and products that are valid within the context of available knowledge and experience and that promote continued growth in these and other intellectual skills. . . . Appropriate teaching strategies and learning environments facilitate their growth as do student persistence, self-monitoring, and open-minded, flexible attitudes.” (King, Goodson & Rohani)

In 1956, Bloom suggested a taxonomy of six levels of thinking. Since then the levels have been slightly revised by his colleagues. “In the new version, Anderson and colleagues changed the nouns to verbs to reflect thinking as an active process.

Revised Category #1: Knowledge → Remember
Revised Category #2: Comprehension → Understand
Revised Category #3: Application → Apply
Revised Category #4: Analysis → Analyzing
Revised Category #5: Evaluation → Design
Revised Category #6: Synthesis → Create” (Tankersley, 2005)

In 1998 and 2002, Webb proposed Depth of Knowledge levels, which “designates how deeply students must know, understand, and be aware of what they are learning in order to attain and explain answers, outcomes, results, and solutions. It also designates how extensively students are expected to transfer and use what they have learned in different academic and real world contexts.” (Francis 2016) The DoK does not describe type of thinking or kind of knowledge students are expected to show like Bloom’s Taxonomy does. Instead DoK “establishes the context - the scenario, the setting, or the situation -
which students will express and share the depth and extent of their learning. Are they expected to acquire knowledge (DOK-1)? Apply knowledge (DOK-2)? Analyze knowledge (DOK-3)? Augment knowledge (DOK-4)?” (Francis 2016) In further comparison, Francis explains:

"In teaching and learning for cognitive rigor, Bloom's determines the cognition or thinking students are expected to demonstrate as part of a learning experience. That's the verb that starts the educational objective or academic standard. Webb's designates the context - the scenario, setting, and situation - students are expected to express and share what they are learning." (Francis 2016)

He further proposes that the DoK be looked at like "ceilings" and not as the ubiquitous "DoK Wheel" which does not represent the cognitive rigor accurately. For an example see, Webb’s DoK Model Context Ceilings.

In 2009, Hess and colleagues proposed a matrix which aligns Bloom’s Taxonomy of Thinking Skills and Webb’s Depth of Knowledge. This practical reference tool called the Cognitive Rigor Matrix can be used to ensure a match between level of rigor demanded by standards, curriculum, instruction and assessment. Click on the image to see the full document. A version specifically for Math and Science can also be found in Exploring Cognitive Demand in Instruction and Assessments by Hess.

Table 3 Cognitive rigor (CR) matrix with curricular examples.

Why does Phenomenal Science consider the research and theory with Higher Order thinking and Depth of Knowledge? As stated by Hess and colleagues,

“Students learn skills and acquire knowledge more readily when they can transfer their learning to new or more complex situations, a process more likely to occur once they have developed a deep understanding of content (National Research Council, 2001). Therefore, ensuring that a curriculum aligns to standards alone will not prepare students for the challenges of the twenty-first century. Teachers must therefore provide all students with challenging tasks and demanding goals, structure learning so that students can reach high goals, and enhance both surface and deep learning of content (Hattie, 2002). Both Bloom’s Taxonomy and Webb’s depth of knowledge therefore serve important functions in education reform at the state level in terms of standards development and assessment alignment. (Hess, et al, 2009)

It has been shown that higher order thinking and deeper knowledge are promoted by “implementing a constructivist-oriented pedagogy” and especially by implementing science discourse. (Barak and Dori, 2009) This is due to the nature of the process of building understanding through discourse. As noted by Barak and Dori, students “demand evidence to support opinions and challenge facts, assumptions, and arguments underlying different viewpoints. Since a good discussion involves posing questions, expressing critical views, and providing arguments to support one’s views (Graesser et al. 2002), it enhances higher order thinking skills among its participants.” (Barak and Dori, 2009) To sum up the critical importance of HOTS and DoK for Phenomenal Science, as Hess states, "Because students need exposure to novel and complex activities every day, schools in the twenty-first century should prepare students by providing them with a curriculum that spans a wide range of the cognitive rigor matrix.” (Hess, et al, 2009) Further, as Bloom notes, “Education must be increasingly concerned about the fullest
development of all children and youth, and it will be the responsibility of the schools to seek learning conditions which will enable each individual to reach the highest level of learning possible.” (Bloom as quoted by Farr, 2006)

Because the NGSS are quite rigorous and require higher order thinking and also depth of knowledge, we have have integrated many recommended instructional strategies to ensure a matching level of rigor in Phenomenal Science. Some of these recommended strategies are:

- Move from concrete to abstract and back
- Connect concepts
- Teach inference
- Elaborate and explain
- Engage students in developing visual representations
- Teach concept mapping and graphic organizers
- Identify the problem
- Encourage questioning
- Cooperative learning
- Reward creative thinking
- Include analytical, practical, and creative thinking

(Thomas and Thorne, 2009)

- Encourage Questioning
- Connect Concepts
- Teach Students to Infer
- Use Graphic Organizers
- Teach Problem-Solving Strategies
- Encourage Creative Thinking
- Teach Students to Elaborate Their Answers

(Cox, TeachHub)

Some Resources:
- Cox, TeachHub
- Thomas and Thorne, 2009

**Understanding by Design**

The second pillar is Understanding by Design which has shown that learners understand more deeply when teachers aim to help students develop “a conceptual framework of concepts and ideas that facilitates meaningful learning.” (Wiggins & McTighe, accessed 2018)
“The Understanding by Design framework is guided by research from cognitive psychology. A readable synthesis of these findings is compiled in the book How People Learn: Brain, Mind, Experience, and School (Bransford, Brown, & Cocking, 2002).” (McTighe and Seif, accessed 2018) Studies have found that successful curricula focus on “understanding the underlying concepts and then applying learning to new situations.” (Wiggins & McTighe, accessed 2018)

This sort of “authentic pedagogy” in which students are expected to “explore connections and relationships so as to produce relatively complex understandings; to organize, synthesize, interpret or explain complex information; to elaborate on their understanding through extended writing or to make connections to the world beyond the classroom,” was determined to increase student achievement substantially and decrease the gap between high and low performing students. (Wiggins & McTighe, accessed 2018) Further, Wiggins and McTighe have found that “student achievement is strengthened when the curriculum is coherent, developmental, and allows for in-depth learning . . . students engage in . . . academic performance tasks that enable them to apply their learning; when they ask questions and develop strategies for problem solving, . . . (and engage in) meaning and understanding-based instructional strategies.” (Wiggins & McTighe, accessed 2018)

With this pillar of Phenomenal Science, the program has been developed according to the six tenets suggested by Wiggins and McTighe:

“Based on the following key tenets: 1. A primary goal of education is the development and deepening of student understanding. 2. Evidence of student understanding is revealed when students apply knowledge and skills within authentic contexts. 3. Effective curriculum development reflects a three-stage design process called “backward design.” This process helps to avoid the twin problems of “textbook coverage” and “activity-oriented” teaching in which no clear priorities and purposes are apparent. 4. Regular reviews of curriculum and assessment designs, based on design standards, are needed for quality control, to avoid the most common design mistakes and disappointing results. . . . 5. Teachers provide opportunities for students to explain, interpret, apply, shift perspective, empathize, and self-assess. These “six facets” provide conceptual lenses through which students reveal their understanding. 6. Teachers, schools, and districts benefit by “working smarter”—using technology and other approaches to collaboratively design, share, and critique units of study.” (McTighe and Seif, accessed 2018)
Place-Based Education (coming soon)
Attending to Equity

While it is known that there is an achievement gap in science between learners of different family incomes and between learners in dominant and non-dominant communities, it is also recognized that all students can learn science. (NAP, 2011; Bell & Bang, 2015) Research suggests that the gap continues to persist due to inequitable opportunities to learn science and “failures to recognize and leverage the existing science-related competencies of youth and communities.” Further,

“While traditional classroom practices have been found to be successful for students whose discourse practices at home resemble those at school—mainly students from middle-class and upper-middle-class European/American homes [43]—this approach does not work very well for individuals from historically nondominant groups. For these students, traditional classroom practices function as a gatekeeper, barring them because their community’s sense-making practices may not be acknowledged [38, 44-46].” (NAP, 2011)

This issue is compounded by the looming need for STEM literacy needed in our nation’s workforce now and in the future. It has also been shown that different perspectives (due to culture or gender, positively impact our understanding of science research. (Medin, Lee & Bang 2014; Bell & Bang, 2015; NAP, 2011) When students experience success, they are motivated to continue learning and persevering. Unfortunately, that is usually not the case when students are struggling through so many roadblocks and cultural barriers only to come up short. This shapes their identity in regards to science and can be the death-knell of student interest or perseverance. (NAP, 2011)

So, what are science educators to do to begin to better attend to equity issues and eliminate this achievement gap? The NRC Framework for K-12 Science Education, Chapter 11 is an excellent resource along with the Next Generation Science Standards’ Appendix D - “All Standards, All Students”: Making the Next Generation Science Standards Accessible to All Students. Generally, though there is much agreement about what will make a difference for students at a disadvantage.

Because students are actively engaged in doing science through the practices, the NRC suggests that the “Science and engineering practices can actually serve as productive entry points for students from diverse communities—including students from different social and linguistic traditions, particularly second-language learners.” (NAP, 2011) In light of Phenomenal Science’s three-dimensional nature, this is encouraging to note. Further it is suggested, that students begin with “lived experiences” which will level the playing field, just as the Phenomenal Science experiences begin with real phenomena, and engage students with shared hands-on experiences. As explained in the Framework:

“Calabrese Barton therefore argues for allowing science and science understanding to grow out of lived experiences [28]. In doing so, people “remove the binary distinction from doing science or not doing science and being in science or being out of science, [thereby allowing] connections between [learners’] life worlds and science to be made more easily [and] providing space for multiple voices to be heard and explored” [28]. . . . Everyday experience provides a rich base of knowledge and experience to support conceptual changes in science. Students bring cultural funds of knowledge that can be leveraged, combined with other concepts, and transformed into scientific concepts over time.” (NAP, 2011)

This idea of “cultural funds of knowledge” is another great tool for teachers to leverage to ensure all students are learning. It refers to the idea that all students bring stores of knowledge from informal
learning and home experiences that can be “assets to build on.” Oftentimes, though, because of the diversity of these ideas, they go unrecognized in school settings for the assets they are. Some examples:

"researchers have documented that children reared in rural agricultural communities, who have regular and often intense interactions with plants and animals, develop a more sophisticated understanding of the natural world than do urban and suburban children of the same age [56]. Other researchers have identified connections between children’s culturally based stories and the scientific arguments they are capable of making [50, 57]." (NAP, 2011)

And

“For example, the authors synthesize research on how students use sophisticated math in everyday practices like practicing basketball, playing dominoes, and selling candy.” (Shea, 2015)

It has been shown that valuing this fund of knowledge that students bring with them, enables students to build new ideas and make connections to their current understandings. As noted by Shea, “learning improves when varied student experiences are made relevant in informal and formal learning environments. . . . Robust learning environments support equity, in part, by acknowledging and building on diverse student experiences.” (Shea, 2015b) Finally, beyond just valuing existing student knowledge, research shows that it is also a rich resource for a whole class of learners. (NAP, 2011) As noted by “This research acknowledges and builds on the idea that in a community of learners both adults and children can bring ideas and resources from their everyday lives to the classroom and informal learning spaces in order to create a richer learning environment for the whole class.” (Shea, 2015a)

Engaging students in discourse and sense-making is valuable for all learners and builds a bridge to connect students individual funds of knowledge. This is effective for all students even those whose first language is not English, because “engagement in the discourse and practices of science, built as it is around observations and evidence, also offers not only science learning but also a rich language-learning opportunity for such students. For both reasons, inclusion in classroom discourse and engagement in science practices can be particularly valuable for such students.” (NAP, 2011) Further, “Many equity-focused interventions have leveraged the discourse (i.e., sense-making) practices of youth to productively engage them in the language and discourse styles of science and in the learning of science. . . . Recognizing that language and discourse patterns vary across culturally diverse groups, researchers point to the importance of accepting, even encouraging, students’ classroom use of informal or native language and familiar modes of interaction [47-49].” (NAP, 2011)

There are many opportunities for teachers within Phenomenal Science Units to engage students in discourse and sense-making. The further challenge is to listen and watch for evidence of students’ current understandings that they bring with them to the discourse or sense-making session and to build upon them. As noted below, research has shown there are several tips and tricks for doing this effectively:

● “Build flexible learning plans
● Listen for sense-making in student conversations and to incorporate these understandings in classroom science inquiry

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● Assume that children will draw on their own ideas and experiences to make sense of new content and
● (Assume that children) will ask questions based on their own understandings as they extend what they know." (Shea, 2015a)

And:
● “Highlight how students can demonstrate competence through multiple means of expression and in multiple contexts.” (NAP, 2011)
● And:
● Notice sensemaking repertoires. Consider students’ diverse sensemaking as connecting to science practices.
● Support sensemaking. Support students to use their sensemaking repertoires and experiences as critical tools in engaging with science practices.
● Engage diverse sense-making. Students’ scientific practices and knowledge are always developing and their community histories, values, and practices contribute to scientific understanding and problem solving. (Bell & Bang, 2015)

And:
● “Practice-linked instruction is a powerful motivator for engaging students. Students should be encouraged to investigate phenomena of interest whenever possible. After a large-group inquiry, the process can be reconstructed in written or verbal language—in developmentally appropriate ways and using scientific language.
● The four language-intensive NGSS practices—Argumentation, Communication, Explanation, and Questioning—can be taught using language practices that are both receptive (listening and reading) and productive (speaking and writing).
● NGSS instruction is largely dependent on language, and it may inadvertently exclude English Learners from full participation if steps aren't taken. Multilingual students have important insights to contribute to learning, and scientific communities greatly benefit from the diversity of thought and experience these students bring.
● “Second language learners often have rich family and community practices and histories that can be leveraged to more deeply engage these students in STEM learning. Keep "big ideas" in science grounded in everyday examples that are accessible to all learners.” (Wingert & Podkul, 2014)

Some Resources:
● AST Attending to Equitable Student Talk for How and Why Reasoning Toolkit
● Why are Academic Discussions So Important for our ELLs? How science discourse helps ELLs, Also some tips for good discussions
● Point of View Affects How Science Is Done - examples of diversity impact on scientific research

Current Science Education Research

“Traditional Science Instruction” has been described as focusing on a behaviorist view, focusing on a product (student knowing facts), students as passive direction-followers, and teachers in control and transmitting all the content to students. (Silber, 2018) It has been also characterized as product / performance focused, not process-focused. (Vigeant, 2016) “In the past, when students have offered explanations inconsistent with science (such as ascribing the seasons to the changing distance...
between the Earth and the Sun), these ideas were seen as problematic misconceptions needing to be “stamped out” by the teacher with the correct ideas ‘stamped in.’” (Campbell, Schwarz & Windschitl, 2016)

Obviously, the traditional mode of science instruction is not helping students achieve conceptual science understanding as evidenced by test scores (Falkenberg, McClure & McComb, 2006) or persevere into STEM careers. Calls for change in instruction hearken all the way back to the turn of the previous century. (Lederman, 2006) Research supports that this traditional science instruction is not supportive of growth in science conceptual understanding. According to How Students Learn Science, “Simply telling students what scientists have discovered, for example, is not sufficient to support change in their existing preconceptions about important scientific phenomena.2 Similarly, simply asking students to follow the steps of “the scientific method” is not sufficient to help them develop the knowledge, skills, and attitudes that will enable them to understand what it means to “do science” and participate in a larger scientific community. And the general absence of metacognitive instruction in most of the science curricula we experienced meant that we were not helped in learning how to learn, or made capable of inquiry on our own and in groups. Often, moreover, we were not supported in adopting as our own the questioning stance and search for both supporting and conflicting evidence that are the hallmarks of the scientific enterprise” (NAP, 2005)

In Taking Science to School, there were four factors determined to be necessary for students to make sense of science: “That report defined the following four strands of proficiency, which it maintained are interwoven in successful science learning:

1. Knowing, using, and interpreting scientific explanations of the natural world.
2. Generating and evaluating scientific evidence and explanations.
3. Understanding the nature and development of scientific knowledge.
4. Participating productively in scientific practices and discourse.”

As can be seen here, “proficiency in science is multifaceted and therefore requires a range of experiences to support students’ learning.” (NAP, 2011)
As noted previously, it has long been recognized that students bring their own naive conceptions of science concepts with them to the science classroom. (NAP 1999) However, “an early focus on finding and fixing misconceptions can confuse students about why their own ideas aren’t accurate and fails to engage students in reasoning or idea revision. When their misconceptions are “corrected,” students learn that their own ideas need to be replaced by other ideas that they don’t fully understand. When this happens, students will likely memorize official “school” knowledge but fall back on their original ideas when thinking about and explaining the outside world, since they naturally reason with their own real-world experiences, language, and rules for validating claims.” (Campbell, Schwarz & Windschitl, 2016; NAP 1999) “This finding requires that teachers be prepared to draw out their students' existing understandings and help to shape them into an understanding that reflects the concepts and knowledge in the particular discipline of study.” (NAP 1999) However, as noted by. Falkenberg and colleagues, there is a disconnect between how science is taught and the research describing how people learn. Often, it seems that science continues to be taught “superficial memorization level and do not teach science in ways that support deep student learning.” (Falkenberg, McClure & McComb, 2006)

It becomes apparent, then, that educators can’t keep doing the same thing and expecting different results. In order for students to master science concepts, there are two key factors identified in How People Learn. First we must work toward deep understanding, “transforming it (content) from a set of facts into usable knowledge” (NAP, 1999) and facilitate development of students’ conceptual framework. “The conceptual framework allows experts to organize information into meaningful patterns and store it hierarchically in memory to facilitate retrieval for problem solving. And unlike pure acquisition of factual knowledge, the mastery of concepts facilitates transfer of learning to new problems.” (NAP, 1999) Secondly, it has been shown that experts are metacognitive in that they determine when they need more information, when there is a disconnect with new information and old, and consider alternatives and are mindful of whether the one chosen is leading to the desired end. (NAP, 1999) This is what mastery looks like. However, as noted in Taking Science to School, children bring to science class a natural curiosity and a set of ideas and conceptual frameworks that incorporate their experiences of the natural world and other information that they have learned. Since these experiences vary, children at a given age have a wide range in their skills, knowledge, and conceptual development. A teacher therefore needs to be able to evaluate each child’s knowledge and conceptual and skill development, as well as the child’s level of metacognition about his or her own knowledge, skills, and concepts, in order to provide a learning environment that moves each child’s development in all these areas. (NAP, 2007)

So if mastery of science is our goal for all students, what is the course of action recommended by the research in regard to science education? In order to match the research about how students learn to science education, The Framework and NGSS were developed. According to the Framework, “The four strands (described by Taking Science to School) imply that learning science involves learning a system of thought, discourse, and practice—all in an interconnected and social context—to accomplish the goal of working with and understanding scientific ideas. This perspective stresses how conceptual understanding is linked to the ability to develop explanations of phenomena and to carry out empirical investigations in order to develop or evaluate those knowledge claims.” (NAP 2011) According to Krajcik, "Perhaps the most significant shift . . . is that students need to make sense of phenomena or design solutions for problems by scientific and engineering practices, disciplinary core ideas and crosscutting concepts working together. . . . Making sense of phenomena and designing solutions drives the teaching and learning process. (Krajcik, 2018) From these frames of reference, we developed Phenomenal Science as a Phenomena-Based curriculum with resonating Core Principles and research-based Key Instructional Strategies which focus on sense-making.
Some specific recommendations for teaching that have been determined by the research follow:

- “Rather than seeing student knowledge from a deficit view, where “wrong” answers need to be eliminated, a resources perspective emphasizes how students can reason with different kinds of valuable knowledge to make sense of new situations and ideas.” (Campbell, Schwarz & Windschitl, 2016)
- “If students have the guidance and space to reason aloud with one another, they can fill the classroom with ideas about how to solve problems and why the ideas make sense in the particular context being examined (Cohen and Ball, 1990).” (Campbell, Schwarz & Windschitl, 2016)
- “As students identify the strengths and weakness of their ideas, they position themselves to better understand the problems at hand, the extent to which the ideas may offer solutions (Bransford and Schwartz 1999), and how these ideas might help in similar contexts later.” (Campbell, Schwarz & Windschitl, 2016)
- “Strategies can be taught that allow students to monitor their understanding and progress in problem solving. Although this monitoring goes on as an internal conversation, the strategies involved are part of a culture of inquiry, and they can be successfully taught in the context of subject matter. In teaching them, the monitoring questions and observations are modeled and discussed for some time in the classroom, with the ultimate goal of independent monitoring and learning.” (NAP, 1999)
- “Make thinking visible.
  - **Student thinking:** Have students engage in activities that make visible the processes of their thinking, rather than merely the conclusions of their thinking.
  - **Expert thinking:** Model expert thinking, being careful to make explicit the strategies and techniques that are implicit in expert thinking.” (Vanderbilt CFT, accessed 2018; NAP, 1999)
- “Be aware of knowledge level of students. The knowledge (and misunderstandings) they bring with them into the class will shape what they learn in the class.” (Vanderbilt CFT, accessed 2018; NAP, 1999)
- “Use contrasting cases as examples. Contrasting cases—two examples whose differences highlight a particular point or set of points—can illustrate the particular points you are highlighting as an instructor. Note that experts are more likely than novices to see the relevant contrast between two complex cases that are similar in many respects. So it’s best to start with relatively simple cases and then move to complexity as understanding deepens.” (Vanderbilt CFT, accessed 2018; NAP, 1999)
- “Teaching that is responsive to students’ ideas can create opportunities for rigorous sense-making talk by young learners. . . . We found that rigorous episodes of whole-class talk were associated with the teacher’s use of open-ended questions, follow-up prompts, references to activity or representations, prediscussion tasks, and asking students to comment on their peers’ ideas. Overall, higher rigor talk co-occurred with these conditions when used in combination. Despite being responsive to students’ emerging ideas, all four classes addressed the science ideas for the unit—an outcome we attribute to the use of an anchoring phenomenon and the teacher’s awareness of the concepts required to construct evidence-based explanations for it.” (Colley & Windschitl, 2016)
- “The findings suggest the importance of beginning a lesson with high quality Instructional tasks—complex tasks that bear appropriate levels of epistemic uncertainty for a particular group of students in a particular moment.” (Kang, Windschitl, Stroupe & Thompson, 2016)
- “With the use of complex tasks, higher quality opportunities to learn were observed in lessons in which: (i) the tasks were framed as a process of understanding contextualized phenomena; (ii) the specific disciplinary concepts in the task were related to big science ideas that transcended the activities themselves; and (iii) students’ implementation of these tasks were structured using tools that supported changes in thinking” (Kang, Windschitl, Stroupe & Thompson, 2016)
Finally, How People Learn determined that “environments that best promote learning have four interdependent aspects—they focus on learners, well-organized knowledge, ongoing assessment for understanding, and community support and challenge.” (Vanderbilt CFT, accessed 2018; NAP, 1999)

More details can be seen in the text inset below:

1. **Learner-centered**: Learner-centered environments pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting. Teachers must realize that new knowledge is built on existing knowledge—students are not blank slates. Therefore, teachers need to uncover the incomplete understandings, false beliefs and naïve renditions of concepts that students have when they begin a course. If these are ignored, students may develop understandings very different from what the teacher intends them to gain.

2. **Knowledge-centered**: Knowledge-centered environments take seriously the need to help students learn the well-organized bodies of knowledge that support understanding and adaptive expertise. Teachers are wise to point their students directly toward clear learning goals—to tell students exactly what knowledge they will be gaining, and how they can use that knowledge. In addition, a strong foundational structure of basic concepts will give students a solid base on which to build further learning.

3. **Assessment-centered**: Assessment-centered environments provide frequent formal and informal opportunities for feedback focused on understanding, not memorization, to encourage and reward meaningful learning. Feedback is fundamental to learning, but feedback opportunities are often too scarce in classrooms. Students may receive grades on tests and essays, but these are summative assessments that occur at the end of projects. What are needed are formative assessments that provide students with opportunities to revise and improve the quality of their thinking and understanding. The goal is for students to gain meta-cognitive abilities to self-assess, reflect and rethink for better understanding.

4. **Community-centered**: Community-centered environments foster norms for people learning from one another, and continually attempting to improve. In such a community, students are encouraged to be active, constructive participants. Further, they are encouraged to make—and then learn from—mistakes. Intellectual camaraderie fosters support, challenge and collaboration. (Vanderbilt CFT, accessed 2018; NAP, 1999)