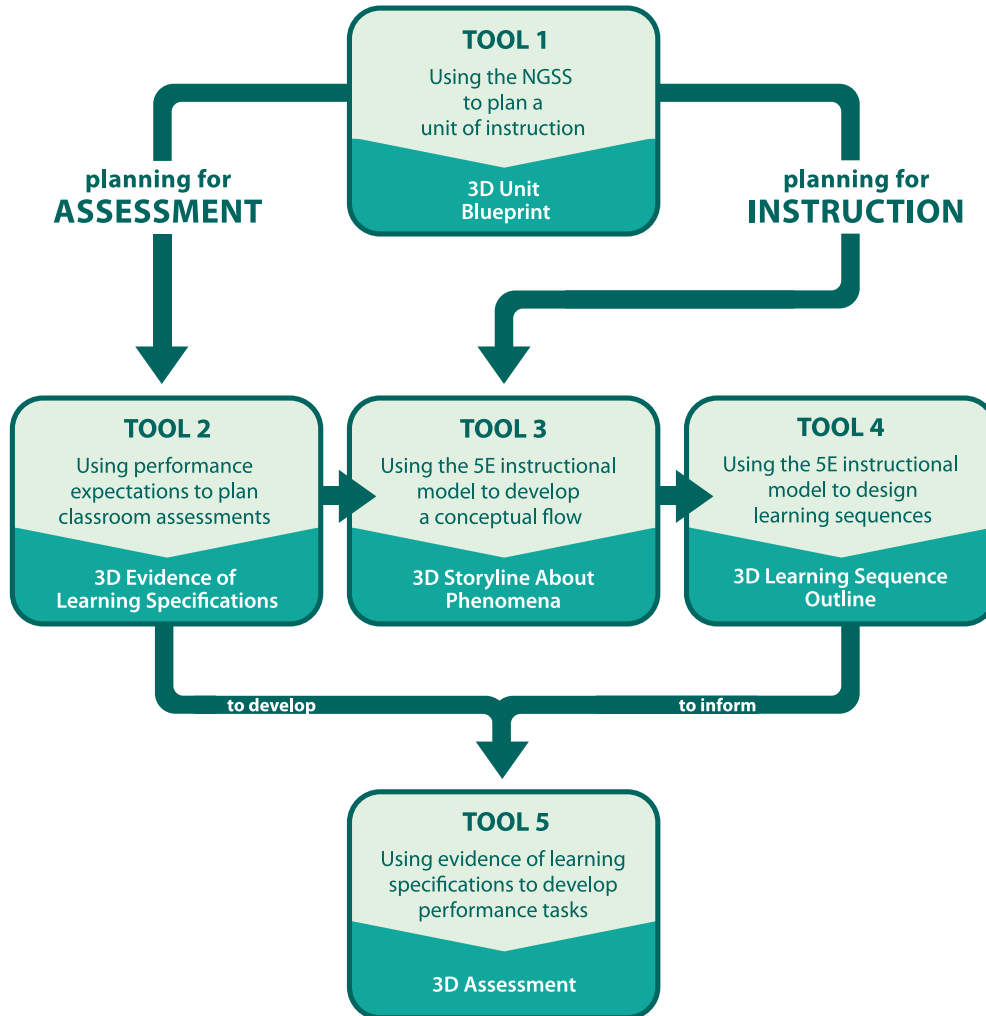
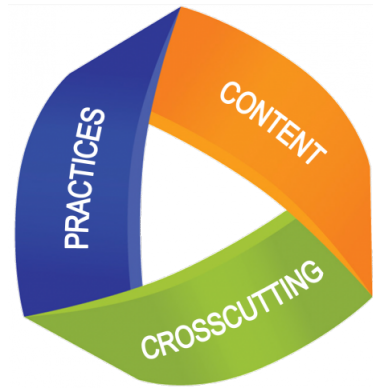


# FIVE TOOLS AND PROCESSES FOR NEXT GENERATION SCIENCE STANDARDS

*A new model for professional development*



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# Five Tools and Processes for Translating the Next Generation Science Standards into Instruction and Classroom Assessment

## FOREWORD

### Introduction

With the 2012 release of *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, the science education community received an early warning of the impending challenges of contemporary educational reform. The framework presented three categories of learning outcomes: science and engineering practices, crosscutting concepts, and disciplinary core ideas. It recommended integrating these three categories into performance expectations—that is, as standards for K–12 science education. A year later, the framework’s recommendations were presented as the Next Generation Science Standards.

The science education community now has to respond by translating the Next Generation Science Standards (NGSS) into understandable and usable science curriculum programs and classroom teaching practices. Central to this translation is providing science teachers with the knowledge and abilities they will need to implement new programs and practices. There is a critical need for professional development as well as resources and tools designed to support this era of science education reform.

### The Challenge: Addressing the NGSS Innovations

Implementing the NGSS requires educators to address five innovations. I suggest using the term *innovations* because, compared to the 1996 National Science Education Standards, there are new and different characteristics to the NGSS. To be blunt, educators are cautioned not to review the NGSS and say, “We are already doing that,” because they aren’t. To capture these innovations in a few words, the NGSS integrates **three-dimensional learning**; emphasizes **student experiences with phenomena**; includes **performance expectations**; includes the **nature of science and engineering** with traditional science content; describes **learning progressions** for grades K through 12; and makes **connections between science and English-language learning and mathematics**. Let me briefly explain these innovations.

First, implementing curricular programs and classroom teaching practices based on the NGSS requires an integration of science and engineering practices, disciplinary core ideas, and crosscutting concepts. These three domains represent learning outcomes. The new standards, presented as performance expectations, include these three dimensions. Here is an example for middle school life sciences, specifically Heredity: Inheritance and Variation of Traits.

**Figure 1. Middle School Performance Expectation**

**PERFORMANCE EXPECTATION**  
MS-LS3-1 Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of an organism.

This performance expectation first presents a science and engineering practice: *Develop and use a model to describe phenomena* (genetic mutations). Second, it presents a disciplinary core idea: *Genes are located in the chromosomes of cells; genes control the production of proteins, which in turn affect the traits of organisms*. Finally, the standard includes a crosscutting concept: *structure and function*.

So, what is the connection to science teachers? This innovation directs professional developers' attention to the role of, and strategies for, instruction, and the need for examples of instructional sequences that exemplify three-dimensional teaching. In this example, teachers are asked to design an instructional sequence that gives students opportunities to create and use a model to show the results of structural changes to genes.

Second, implementing the NGSS emphasizes experiences with natural and designed phenomena and the expectation that student learning will be enhanced and assessed. Here, with the standards expressed as performance expectations, students will study phenomena, and assessments will include three dimensions. From the point of view of professional development, this innovation underscores the context for instruction and the importance of including meaningful experiences for all students.

Third, the NGSS incorporates the nature of science and engineering design as part of science and engineering practices and crosscutting concepts. Science teachers have expressed concerns about their understanding of engineering and the nature of science. These concerns extend to the processes and strategies for teaching about these domains, with implications for professional development.

The fourth innovation involves learning progressions that include statements about the three dimensions and the nature of science and engineering design in grade-level bands for K–12 programs. This innovation should be addressed by redesigning the school science curriculum and classroom assessments. Specifically, there is the need for universal coherence and coordination of content and assessments across the K–12 continuum.

Finally, the NGSS makes explicit connections to the contemporary emphasis on mathematics and English-language arts. Although the Common Core has come under political criticism, the need to improve mathematics and English-language achievement remains a priority in American education. Activities in science present excellent opportunities to introduce math content in a meaningful context and provide students with opportunities to engage in meaningful nonfiction reading and writing in science.

## **The Response: Providing Tools for Professional Development**

In collaboration with BSCS and the K–12 Alliance at WestEd, the Gottesman Center for Science Teaching and Learning at the American Museum of Natural History developed and field-tested five tools and processes for professional development leaders. These tools are a timely and appropriate response to the challenges of translating the NGSS into instruction and classroom assessment. These tools and processes establish a meaningful context for teachers of science to develop an understanding of the framework and the NGSS, as well as a means to begin implementing changes in their classrooms.

**Tool 1** has participants plan a unit or blueprint for classroom instruction based on the NGSS. This context immediately responds to teachers' initial concerns, namely, "How do we get started on implementing the NGSS in our classrooms?" As participants begin planning their unit, they must, of necessity, read selections from *A Framework for K–12 Science Education* and the Next Generation Science Standards. The plan for a unit of instruction may be rough and general, but the first tool sets a meaningful stage for developing the knowledge and abilities needed to translate the NGSS into practice.

**Tool 2** responds to teachers' second major concern: "How will assessments change?" Using performance expectations from the NGSS, participants plan assessments for classroom instruction. Participants are challenged to determine what counts as evidence for student learning, and how to develop evidence of learning specifications that show students have indeed learned the science and engineering practices, crosscutting concepts, and disciplinary core ideas expressed in performance expectations.

In **Tool 3**, the BSCS 5E instructional model takes center stage. The 5E model provides a concrete and meaningful guide for participants. Teachers' professional lives center on instruction, and the 5E instructional model is built on a sequence of lessons and is based on a foundation of research about learning. Tool 3 extends the initial experience of planning a curriculum unit by helping teachers develop a conceptual flow of the science content and refine a storyline about a phenomenon.

**Tool 4** brings these prior experiences together, as participants use Tool 1 (the unit blueprint) and Tool 3 (the 5E instructional model and conceptual flow) to develop an instructional sequence for a section of the unit plan. By placing an emphasis on what teachers do and what students do in each phase of the 5E instructional model, participants gain a deeper understanding of what three-dimensional teaching is, and how to implement the teaching of phenomena in science classrooms.

In **Tool 5**, participants return to Tool 2 (evidence of learning specifications) and the performance expectations used as the basis for their unit. They create three dimensional performance tasks that serve as summative assessments for each of the instructional sequences in their unit.

## Conclusion: Beyond the Next Generation Science Standards

Developing and releasing the Next Generation Science Standards fulfills the first step in a much longer process of improving science teaching and student learning. Yet between the new standards and student learning lies the need for professional development for science teachers. As I see the situation, this need for professional development creates a paradox. The changes in instruction called for by the standards must be implemented at the level of individual teachers in K–12 grade levels. Yet recommending personal professional development for individual teachers is unrealistic. On the other hand, presentations for groups tend to leave some teachers with the feeling that their unique concerns and different disciplines have not been addressed. This set of professional development resources, "Five Tools and Processes for Translating the NGSS into Instruction and Classroom Assessment," addresses these individual concerns within a group context in what I think is an appropriate and adequate response to the paradox.

Science teachers have the challenge of implementing reforms to their curricular programs and making changes to their instruction that will bring about learning for the 21st century. They may be able to meet these challenges alone, but I say that with concern and doubt. With the support of strong professional development leaders, using effective tools and processes with teachers, this concern is reduced and doubt becomes hope.

**Rodger W. Bybee**  
January 2016

## APPENDIX A

**CONCEPTUAL SHIFTS IN THE NEXT GENERATION SCIENCE STANDARDS**

The Next Generation Science Standards (NGSS) provide an important opportunity to improve not only science education but also student achievement. Based on *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (*Framework*), the NGSS are intended to reflect a new vision for American science education. The following conceptual shifts in the NGSS demonstrate what is new and different about the NGSS:

**1. K–12 science education should reflect the interconnected nature of science as it is practiced and experienced in the real world.**

The framework is designed to help realize a vision for education in the sciences and engineering in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields. (NRC, 2012, p. 12)

The vision represented in the *Framework* is new in that students must be engaged at the nexus of the three dimensions:

- **Science and Engineering Practices,**
- **Crosscutting Concepts, and**
- **Disciplinary Core Ideas.**

Currently, most state and district standards express these dimensions as separate entities, leading to their separation in both instruction and assessment. Given the importance of science and engineering in the 21st century, students require a sense of contextual understanding with regard to scientific knowledge, how it is acquired and applied, and how science is connected through a series of concepts that help further our understanding of the world around us. Student performance expectations have to include a student’s ability to apply a practice to content knowledge. Performance expectations thereby focus on understanding

and application as opposed to memorization of facts devoid of context. The *Framework* goes on to emphasize that

learning about science and engineering involves integration of the knowledge of scientific explanations (i.e., content knowledge) and the practices needed to engage in scientific inquiry and engineering design. Thus the framework seeks to illustrate how knowledge and practice must be intertwined in designing learning experiences in K–12 science education. (NRC, 2012, p. 11)

**2. The Next Generation Science Standards are student performance expectations—NOT curriculum.**

Even though within each performance expectation Science and Engineering Practices (SEPs) are partnered with a particular Disciplinary Core Idea (DCI) and Crosscutting Concept (CC) in the NGSS, these intersections do not predetermine how the three are linked in curriculum, units, or lessons. Performance expectations simply clarify the expectations of what students will know and be able to do by the end of the grade or grade band. Additional work will be needed to create coherent instructional programs that help students achieve these standards.

As stated previously, past science standards at both the state and district levels have treated the three dimensions of science as separate and distinct entities, leading to preferential treatment in assessment or instruction. It is essential to understand that the emphasis placed on a particular Science and Engineering Practice or Crosscutting Concept in a performance expectation is not intended to limit instruction, but to make clear the intent of the assessments.

An example of this is illustrated in two performance expectations in high school physical sciences that use the practice of modeling. Models are basically used for three reasons: (1) to represent or describe, (2) to collect data, or (3) to predict. The first use is typical in schools because models and representations are usually synonymous. However, the use of models to collect data or to predict phenomena is new. For example:

Construct models to explain changes in nuclear energies during the processes of fission, fusion, and radioactive decay and the nuclear interactions that determine nuclear stability.

and

Use system models (computer or drawings) to construct molecular-level explanations to predict the behavior of systems where a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.

In the first performance expectation, models are used with nuclear processes to explain changes. A scientific explanation requires evidence to support the explanation, so students will be called on to construct a model for the purpose of gathering evidence to explain these changes. Additionally, they will be required to use models to both explain and predict the behavior of systems in equilibrium. Again, the models will have to be used to collect data, but they will be further validated in their ability to predict the state of a system. In both cases, students will need a deep understanding of the content, as well as proficiency in the ability to construct and use models for various applications. The practice of modeling will need to be taught throughout the year—and indeed throughout the entire K–12 experience—as opposed to during one two-week unit of instruction.

The goal of the NGSS is to be clear about which practice students are responsible for in terms of assessment, but these practices and crosscutting concepts should occur throughout each school year.

### 3. The science concepts in the Next Generation Science Standards build coherently from K–12.

The focus on a few Disciplinary Core Ideas is a key aspect of a coherent science education. The *Framework* identified a basic set of core ideas that are meant to be understood by the time a student completes high school:

To develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months. . . . This sense of development has been conceptualized in the idea of learning progressions. . . . If mastery of a core idea in a science discipline is the ultimate educational destination, then well-designed learning progressions provide a map of the routes that can be taken to reach that destination.

Such progressions describe both how students' understanding of the idea matures over time and the instructional supports and experiences that are needed for them to make progress. (NRC, 2012, p. 26)

There are two key points that are important to understand:

- First, focus and coherence must be a priority. What this means to teachers and curriculum developers is that the same ideas or details are not covered each year. Rather, a progression of knowledge occurs from grade band to grade band that gives students the opportunity to learn more complex material, leading to an overall understanding of science by the end of high school. Historically, science education was taught as a set of disjointed and isolated facts. The *Framework* and the NGSS provide a more coherent progression aimed at overall scientific literacy with instruction focused on a smaller set of ideas and an eye on what students should have already learned and what they will learn at the next level.
- Second, the progressions in the NGSS automatically assume that previous material has been learned by students. Choosing to omit content at any grade level or band will impact the success of students in understanding the core ideas and will put additional responsibilities on teachers later in the process.

### 4. The Next Generation Science Standards focus on deeper understanding of content as well as application of content.

The *Framework* identified a smaller set of Disciplinary Core Ideas that students should know by the time they graduate from high school, and the NGSS are written to focus on the same. It is important that teachers and curriculum/assessment developers understand that the focus is on the core ideas—not necessarily the facts that are associated with them. The facts and details are important evidence, but not the sole focus of instruction. The *Framework* states:

The core ideas also can provide an organizational structure for the acquisition of new knowledge. Understanding the core ideas and engaging in the scientific and engineering practices helps to prepare students for broader understanding, and deeper levels of scientific and engineering investigation, later on—in high school, college, and beyond. One rationale for organizing content around core ideas comes from studies comparing experts and novices in any field. Experts understand the core principles and



theoretical constructs of their field, and they use them to make sense of new information or tackle novel problems. Novices, in contrast, tend to hold disconnected and even contradictory bits of knowledge as isolated facts and struggle to find a way to organize and integrate them. . . . The assumption, then, is that helping students learn the core ideas through engaging in scientific and engineering practices will enable them to become less like novices and more like experts. (NRC, 2012, p. 25)

### **5. Science and engineering are integrated in the Next Generation Science Standards from kindergarten through twelfth grade.**

The idea of integrating technology and engineering into science standards is not new. Chapters on the nature of technology and the human-built world were included in *Science for All Americans* (AAAS, 1989) and *Benchmarks for Science Literacy* (AAAS, 1993, 2008). Standards for science and technology were included for all grade spans in the *National Science Education Standards* (NRC, 1996).

Despite these early efforts, however, engineering and technology have not received the same level of attention in science curricula, assessments, or the education of new science teachers as the traditional science disciplines have. A significant difference in the NGSS is the integration of engineering and technology into the structure of science education. This integration is achieved by raising engineering design to the same level as scientific inquiry in classroom instruction when teaching science disciplines at all levels and by giving core ideas of engineering and technology the same status as those in other major science disciplines.

The rationale for this increased emphasis on engineering and technology rests on two positions taken in the *Framework*. One position is aspirational, the other practical.

From an aspirational standpoint, the *Framework* points out that science and engineering are needed to address major world challenges such as generating sufficient clean energy, preventing and treating diseases, maintaining supplies of food and clean water, and solving the problems of global environmental change that confront society today. These important challenges will motivate many students to continue or initiate their study of science and engineering.

From a practical standpoint, the *Framework* notes that engineering and technology provide opportunities for students to deepen their understanding of science by applying their developing scientific knowledge to the solution of practical problems. Both positions converge on the powerful idea that by integrating technology and engineering into the science curriculum, teachers can empower their students to use what they learn in their everyday lives.

### **6. The Next Generation Science Standards are designed to prepare students for college, careers, and citizenship.**

There is no doubt that science and science education are central to the lives of all Americans. Never before has our world been so complex and science knowledge so critical to making sense of it all. When comprehending current events, choosing and using technology, or making informed decisions about one's health care, understanding science is key. Science is also at the heart of the the ability of the United States to continue to innovate, lead, and create the jobs of the future. All students no matter what their future education and career path must have a solid K–12 science education in order to be prepared for college, careers, and citizenship.

### **7. The Next Generation Science Standards and Common Core State Standards (English Language Arts and Mathematics) are aligned.**

The timing of the release of NGSS comes as most states are implementing the Common Core State Standards (CCSS) in English Language Arts and Mathematics. This is important to science for a variety of reasons. First, there is an opportunity for science to be part of a child's comprehensive education. The NGSS are aligned with the CCSS to ensure a symbiotic pace of learning in all content areas. The three sets of standards overlap in meaningful and substantive ways and offer an opportunity to give all students equitable access to learning standards.

Some important work is already in progress regarding the implications and advantages to the CCSS and NGSS. Stanford University recently released 13 papers on a variety of issues related to language and literacy in the content areas of the CCSS and NGSS (Stanford University, 2012).

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# NGSS Innovations

By Rodger W. Bybee

The architecture of the NGSS differs significantly from prior standards for science education. In the NGSS, the three dimensions of Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCCs) are crafted into performance expectations that describe what is to be assessable following instruction. The NGSS performance expectations are therefore a measure of competency. The foundation boxes for each of the three dimensions provide additional information and clarity for the design or redesign of school programs.

A comprehensive program should provide opportunities for students to develop their understanding of DCIs through their engagement in SEPs and their application of CCCs. This three-dimensional learning leads to eventual mastery of performance expectations. In this perspective, a quality program should clearly describe or show how the cumulative learning experience works coherently with previous and following experiences to build scientific literacy.

The following innovations in the NGSS are hallmarks of current thinking about how students learn science, and they set a vision for future science education. These innovations will not only cause a shift in instructional programs in American classrooms but should also affect and refocus the efforts of curriculum developers and the design of comprehensive school science programs.

## **Innovation 1: K–12 science education reflects three-dimensional learning.**

In the NGSS, science is described as having three distinct dimensions, each of which represents equally important learning outcomes: (1) SEPs, (2) DCIs, and (3) CCCs (The Next Generation Science Standards 2013). The NGSS expectations for students include making connections among all three dimensions. Students develop and apply the skills and abilities described in the SEP, as well as learn to make connections between different DCIs through the CCC to help gain a better understanding of the natural and designed world. Current research suggests that both knowledge (DCIs and CCCs) and practice (SEPs) are necessary for a full understanding of science.

Each NGSS standard integrates one specific SEP, CCC, and DCI into a performance expectation that details what students should be proficient in by the end of instruction. In past standards the separation of skills and knowledge often led to an emphasis (in both instruction and assessment) on science concepts and an omission of inquiry and practices. It is important to note that the NGSS performance expectations do not specify or limit the intersection of the three dimensions in classroom instruction. Multiple SEPs, CCCs, and DCIs that blend and work together in several contexts will be needed to help students build toward competency in the targeted performance expectations. For example, if the end goal (the performance expectation) for students is to plan an investigation to determine the causes and effects of plant growth (2-LS2-1), they can build toward this goal through asking good questions about patterns that they have seen in plant growth and engaging in argument about what kinds of data would be important to collect in an investigation to answer these questions.

It should also be noted that one performance expectation should not be equated to one lesson. Performance expectations define the three-dimensional learning expectations for students, and it is unlikely that a single lesson would provide adequate opportunities for a student to demonstrate proficiency in every dimension of a performance expectation. A series of high-quality lessons or a unit in a program are more likely to provide these opportunities.

### **School programs must change:**

**From:** providing discrete facts and concepts in science disciplines, with limited application of practice or the interconnected nature of the disciplines. Where crosscutting themes were included, they were implicit and not noticed or used by the student. Assessments within the programs exclusively addressed disciplinary concepts of science; neither the processes, inquiry, or SEPs nor the CCCs, unifying themes, or big ideas were included in the assessments.

**To:** providing learning experiences for students that blend multiple SEPs, CCCs, and DCIs — even those SEPs, CCCs, and DCIs not specified within the targeted performance expectations — with the goal that students are actively engaged in scientific processes to develop an understanding of each of the three dimensions. CCCs are included explicitly, and students learn to use them as tools to make sense of phenomena and make connections across disciplines. Assessments within the programs reflect each of the three distinct dimensions of science *and their interconnectedness*.

## **Innovation 2: Students engage in explaining phenomena and designing solutions.**

In educational programs aligned to the NGSS, the goal of instruction is not solely for students to memorize content. Content becomes meaningful to students when they see its usefulness — when they need it to answer a question. Therefore, in programs aligned to the NGSS, an important component of instruction is to pique students' curiosity to help them see a need for the content.

The ultimate goal of an NGSS-aligned science education is for students to be able to explain real-world phenomena and to design solutions to problems using their understanding of the DCIs, CCCs, and SEPs. Students also develop their understanding of the DCIs by engaging in the SEPs and applying the CCCs. These three dimensions are tools that students can acquire and use to answer questions about the world around them and to solve design problems.

### **School programs must change:**

**From:** focusing on disconnected topics, with content treated as an end in itself.

**To:** focusing on engaging students with meaningful phenomena or problems that can be explained or solved through the application of SEPs, CCCs, and DCIs. Instructional units that focus on students explaining relevant phenomena can provide the motivation students need to become invested in their own learning.

### **Innovation 3: The NGSS incorporate engineering design and the nature of science as SEPs and CCCs.**

The NGSS include engineering design and the nature of science as significant elements. Some of the unique aspects of engineering design (e.g., identifying and designing solutions for problems), as well as common aspects of both science and engineering (e.g., designing investigations and communicating information), are incorporated throughout the NGSS as expectations for students from kindergarten through high school. In addition, unique aspects of the nature of science (e.g., scientific investigations use a variety of methods; scientific knowledge is based on empirical evidence; science is a way of knowing; science is a human endeavor) are included as SEPs and CCCs throughout the grade bands.

#### **School programs must change:**

**From:** presenting engineering design and the nature of science as supplemental or as disconnected from science learning (e.g., design projects that do not require science knowledge to complete successfully), with neither included in assessments.

**To:** incorporating learning experiences that include the DCIs of engineering design as well as the SEPs and CCCs of both engineering and the nature of science, with both included in assessments. Both engineering design and the nature of science are taught in an integrated manner with science disciplines (e.g., design projects require science knowledge in order to develop a good solution; the engineering process contributes to building science knowledge).

### **Innovation 4. SEPs, DCIs, and CCCs build coherent learning progressions from kindergarten to grade 12.**

The NGSS provide for sustained opportunities from elementary through high school for students to engage in and develop a progressively deeper understanding of each of the three dimensions. Students require coherent learning progressions both within a grade level and across grade levels so they can continually build on and revise their knowledge to expand their understanding of each of the three dimensions by grade 12.

#### **School programs must change:**

**From:** a curriculum that lacks coherence in knowledge and experiences; provides repetitive, discrete knowledge that students memorize at each grade level; and often misses essential knowledge that has to be filled at later grade levels.

**To:** providing learning experiences for students that develop a coherent progression of knowledge and skills from elementary through high school. The learning experiences focus on a smaller set of disciplinary concepts that build on what has been learned in previous grades and provide the foundation for learning at the next grade span as detailed in the NGSS learning progressions.

## **Innovation 5. The NGSS connect to English language arts (ELA) and mathematics.**

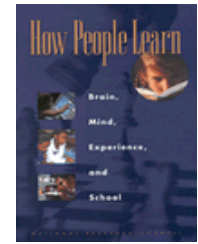
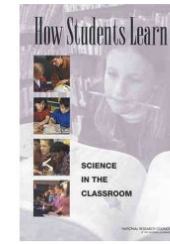
The NGSS not only provide for coherence in science teaching and learning but also unite science with other relevant classroom subjects: mathematics and ELA. This connection is deliberate because science literacy requires proficiency in mathematical computations and in communication skills. In fact, there are many inherent overlaps in the mathematics, ELA, and science practices. Therefore as the NGSS were being drafted, the writers ensured alignment to and identified some possible connections with the Common Core State Standards for ELA/literacy and mathematics as an example of ways to connect the three subjects. In instruction within the science classroom, mathematical and linguistic skills can be applied and enhanced to ensure a symbiotic pace of learning in all content areas. This meaningful and substantive overlapping of skills and knowledge helps provide all students equitable with access to the learning standards for science, math, and literacy. The fact that science can be connected to the “basics” should not go unnoticed. Indeed, it presents science as a basic.

### **School programs must change:**

**From:** providing siloed science knowledge that students learn in isolation from reading, writing, and arithmetic — the historical “basic” knowledge.

**To:** providing science learning experiences for students that explicitly connect to mathematics and ELA learning in meaningful and substantive ways and that provide broad and deep conceptual understanding in all three subject areas.

# Synthesis of Research from *How People Learn: Brain, Mind, Experience, and the Classroom* *How Students Learn: Science in the Classroom*



Adapted by BSCS from:

National Research Council. (2000). *How People Learn: Brain, Mind, Experience, and School*, Washington, DC: National Academies Press. Available for free download at [www.nap.edu](http://www.nap.edu)

National Research Council. (2005). *How Students Learn: Science in the Classroom*, Washington, DC: National Academies Press. Available for free download at [www.nap.edu](http://www.nap.edu)

## KEY FINDINGS ABOUT HOW STUDENTS LEARN SCIENCE

### 1. Students' prior knowledge must be engaged.

A fundamental insight about learning is that *new understandings are constructed on a foundation of existing understandings and experiences*. Students come to the classroom with preconceptions about how the world works. The understandings they carry with them into the classroom will shape significantly how they make sense of what they are taught. If students' initial knowledge is not engaged, the students might fail to grasp the new concepts and information that are taught; they might distort the new information to make it fit with their prior experience, or they might memorize facts for purposes of a test but revert to their preconceptions outside the classroom. NOTE: It is not just inattentive students who misinterpret science instruction; students who are trying hard to make sense of the science ideas will want to make the new science ideas fit with their own experience which can lead to misinterpretations of the science ideas.

With respect to science, everyday experiences often reinforce the very conceptions that scientists have shown to be limited or false, and everyday modes of reasoning are often contrary to scientific reasoning. Research shows that many high school and college students still hold the same misconceptions as young students, despite having studied the scientific explanations in high school and college. Students also have misconceptions about how scientists think and work, often failing to appreciate the centrality of conceptual knowledge in the scientific inquiry process.

#### Implications for Teaching

Draw out and work with the preexisting understandings that students bring with them.

- Abandon the model of the student as an empty vessel to be filled with knowledge and instead think of students' heads as filled with a myriad of wonderful ideas and experiences relevant to the science you are teaching. Actively inquire into students' thinking, creating classroom tasks that will reveal student thinking. Then plan ways to help students find the scientific conceptions useful and meaningful so they can change their initial conceptions to accommodate the new ideas. Students need opportunities to explore their own ideas, to appreciate the limitations of their ideas, to understand how scientific explanations are different from their own, to make sense of scientific explanations, and to use this learning process to change their everyday conceptions to ones that are more scientifically accurate and that make sense to the learner.
- The use of frequent formative assessment helps make student thinking visible to themselves, their peers, and their teacher. Given the goal of learning with understanding, assessments of all types must tap students' understanding and develop their ability to use and apply knowledge rather than merely repeating facts or performing isolated skills.

## KEY FINDINGS ABOUT HOW STUDENTS LEARN SCIENCE

### 2. Organizing science knowledge into conceptual frameworks is essential in developing scientific understanding.

To develop understandings that truly change the way students think about the world around them, students need a deep foundation of usable knowledge that is organized in their minds as a connected, conceptual framework that they know how to use to make predictions, solve problems, explain new situations, and so forth. This kind of deep understanding contrasts with the kind of learning so commonly tested in science classrooms – memorization of lists of science terms and facts. This idea of learning with understanding has two parts: (1) To be meaningful beyond passing a test, factual knowledge **MUST** be placed in a conceptual framework (a set of connected “big ideas”), and (2) Concepts are given meaning through experiences with multiple representations that are rich in science ideas and details and through experiences with multiple phenomena that the ideas help explain. The scientific concepts take on meaning as students see their usefulness in explaining a variety of real-world situations and phenomena.

Students can be supported in building conceptual understandings by actively engaging in processes of scientific inquiry. Opportunities to learn science as a process of inquiry involve drawing from first-hand data and observations and using knowledge of the data and science ideas to reason about the phenomena under study. This process can be used to challenge and build on students’ initial ideas and everyday experiences of the world. It can also provide evidence to help students see a need for different explanations and why scientific explanations make sense.

#### Implications for Teaching

Teach science in depth, providing many examples in which the same concept is at work and providing a firm foundation of knowledge of science ideas.

- Superficial coverage of all topics in science should be replaced with in-depth study of fewer topics that allows key science concepts to be understood.
- Teachers need in-depth knowledge of the science content they will teach, the nature of scientific inquiry and the terms of scientific discourse, and the relationship between science concepts and real-world phenomena.
- Assessments for purposes of accountability (e.g., statewide assessments) must test deep understanding rather than surface knowledge. A teacher is put in a bind if she or he is asked to teach for deep conceptual understanding, but in doing so produces students who perform poorly on standardized tests. Much work needs to be done to minimize the trade-off between assessing depth and assessing objectively (e.g., multiple choice tests).



## KEY FINDINGS ABOUT HOW STUDENTS LEARN SCIENCE

### 3. Learning to monitor one's own thinking is essential in learning to think like a scientist.

A “metacognitive” approach (“thinking about thinking”) to instruction can help students learn to take control of their own learning by engaging them in understanding learning goals and monitoring their progress in achieving them. A metacognitive, or self-monitoring, approach can help students develop the ability to reflect on their own thinking and learning processes.

In science, we can help students think like scientists by using metacognitive approaches that make scientific thinking processes visible and engage students in reflecting on how their own thinking is similar to and different from scientific ways of thinking. For example, students can examine the tendency of us all to attempt to confirm rather than rigorously test (and possibly refute) our current ideas. The approach is deepened when you help students learn why and how to create models of phenomena that can be put to an empirical test. Through metacognition, students reflect on their role in inquiry and on the monitoring and critiquing of their own claims, as well as those of others. Applying a metacognitive habit of mind helps students compare their personal ways of knowing with those developed through centuries of scientific inquiry. Being metacognitive about science is different from simply asking whether we comprehend what we read or hear; it requires taking up the particular critical lens through which scientists view the world.

#### Implications for Teaching

The teaching of metacognitive thinking should be integrated into the science curriculum.

- Help students understand the discourse that scientists use as they make sense of their data and observations – both their internal dialogue and external communication with a community of scientists. It is not enough to give students tasks that require them to think and reason. In addition, students need to learn how scientists think and reason and how that might contrast with their own ways of thinking and making sense. For example, students should learn to ask questions such as: *How do we know that? What's your evidence?*
- To help students monitor their developing understandings, engage them in reflecting on their learning, their changing ideas, and their remaining questions and wonderings. A lesson summarizing activity, for example, might prompt students to reflect on how their ideas have changed and why. Alternatively, the class might pause after a science discussion to reflect on ways they did and did not think and communicate in scientific ways during the discussion.



## Five Tools and Processes For Translating the NGSS Into Instruction and Classroom Assessment

