Chapter 11 -- Partial
California Science Framework

Science Framework

FOR CALIFORNIA PUBLIC SCHOOLS
Kindergarten Through Grade Twelve

Adopted by the California State Board of Education
November 2016

Published by the California Department of Education
Sacramento, 2018

CHAPTER 11

Instructional Strategies for the Next Generation Science Standards for California Public Schools, Kindergarten Through Grade 12 Teaching and Learning in the Twenty-First Century

Note: This document contains only the Framework material relevant to Outdoor and Environmental Learning Experiences

Key Instructional Shifts— Student-Centered Learning Environments

Chapter one of this framework describes three essential elements of CA NGSS instruction that were not given explicit emphasis in California's previous science standards. The CA NGSS are

- *three-dimensional*—students engage in scientific inquiry of phenomena using all three dimensions of NGSS;
- *coherent across the curriculum*—learning builds upon itself from year to year, and science integrates with other parts of the curriculum; and
- *relevant to local communities and student interests*—content and practices build on students' existing experience to learn about and solve real-world societal and environmental problems.

Students benefit the most from these elements when their ideas and questions are at the center of instruction. It is the teacher's role to provide the context and the support to develop, modify, and use student ideas. To make instruction more three dimensional, students must engage in the **science and engineering practices (SEPs)** themselves, internalize the **disciplinary core ideas (DCIs)** so that they can link them with their existing knowledge, and use the **crosscutting concepts (CCCs)** as templates for their own thinking. Making the curriculum more coherent requires that students themselves draw explicit connections between ideas they are learning. Engaging students in relevant issues requires connecting to students' everyday experiences. Student-centered learning environments extend beyond the classroom to the schoolyard, the community, parks, outdoor schools, museums, zoos, aquariums, virtual platforms, and beyond. Throughout this framework, when we refer to learning environments, we are referring to student-centered learning spaces both in the classroom and in the field. Table 11.1 identifies instructional shifts reflective of student-centered learning environments. These environments include shifts in teacher and student activities, both of which are accomplished by deliberate instructional choices.

Table 11.1. Instructional Shifts Required by the CA NGSS

More of this…	Less of this…
Students engage in the CA NGSS practices to build a deeper understanding of science and engineering content and make sense of phenomena and design solutions.	Students study the meaning of science content that teachers explain to them. Students memorize definitions and rote procedures.
Students develop models of systems within the natural world and use them to explain phenomena or solve problems.	Teachers present models that describe phenomena in the natural world.
Students learn science as an iterative, dynamic, creative, and collaborative process similar to how real scientists and engineers do their work.	Students learn science as a collection of facts and learn that these facts were found using a singular and linear "scientific method," disconnected from how real scientists and engineers do their work.
Practices provide students with relevant, real-world learning in which they must investigate and problem solve using critical thinking.	Students learn to conduct investigations following step-by-step instructions.
Students build science and engineering understanding using a variety of practices in investigations, experiments, and project-based experiences.	Students use one practice per investigation/experiment.

Table 11.1. Instructional Shifts Required by the CA NGSS *(continued)*

More of this…	Less of this…
Science content and science practice are integrated.	Science content and practices taught in isolation.
Student reasoning and argumentation play a central role in understanding labs and text.	Student thinking is limited by a "cook-book" approach to lab experiences and problems or end-of-the-chapter questions and test experiences.
Science and engineering notebooks reflect student thinking using the science and engineering practices to understand content and show development and revision of students' scientific models.	Science notebooks reflect only students' ability to take notes or copy teacher models.
Engineering is integrated into all science disciplines.	Engineering is treated as an add-on.
Engaging in science and engineering practices allows students to revise their thinking and understanding.	The science process is just a thing to learn/ apply and "be done."
Students are actively engaged in the practices through investigations and experiments and technologies they have generated.	Students are passively engaged in watching or participating in teacher-directed investigations and experiments.
Crosscutting concepts build a deeper and more connected understanding of science as a whole.	No connection among science content.
Connection of the practices to the goals of literacy in science (purposeful reading and writing to strengthen science understanding).	Reading and writing disconnected from the purpose of learning.
Student-to-student discourse is productive, using practices to explain phenomenon or solve problems.	Student-to-student discourse is limited due to activities that provide only one exact outcome.
Teacher questioning prompts and facilitates students' discourse and thinking.	Teacher questions students to seek a confirmatory right answer.
Learning takes place routinely in a variety of settings: in the classroom, outdoors, in school gardens and in the field, in museums and aquariums, and in the community.	Learning only occurs indoors in the classroom.

about phenomena. This stage is an essential component of Ambitious Science Teaching and effective science instruction that is not explicitly represented in any of the three dimensions. However, it does relate to the CA NGSS principles of having a coherent curriculum and relating to student interest and prior experience. The third practice ensures that teachers actively engage students, support them, and recognize that changing a preconception takes time. To implement the fourth instructional practice, lessons should provide opportunities for students to generate and interpret evidence (**investigations [SEP-3]** and **analyzing and interpreting data [SEP-4]**) and make their thinking public regarding the development of model-based **explanations [SEP-6]**. In these activities, students can use drawings, diagrams, equations, computer simulations, physical replicas, and more to represent their thinking and make it visible to themselves and others (**developing conceptual models [SEP-2]**). As students engage in activities that require them to modify their models, they develop a deeper understanding of the Nature of Science. Teachers can track their own progression along the continuum of each of these instructional practices using a rubric in Windschitl et al. (2012).

Instructional Strategies for Sequencing Lessons

Different types of instructional strategies can be used during a single lesson or unit depending upon the learning needs of students. The teacher's role varies from the provider of crucial information (e.g., procedural knowledge associated with lab safety requirements or the use of experimental equipment, such as microscopes, measurement tools, and probes) to a learning facilitator (when students are applying science and engineering practices in the context of solving a new problem or explaining a novel phenomenon). This section outlines two sample progressions of lessons throughout a unit. Each follows a consistent pattern in lesson design that promotes three-dimensional learning and engages in Ambitious Science Teaching that aligns with how people learn science. First, we will explain the strategy, then we will demonstrate its use through a snapshot.

Instructional Strategy for 3D Learning: 5E Instructional Cycle

When the sequence of science activities aligns with the way that people learn, students learn more effectively. The science education community has articulated and refined an effective sequence often called the 5E instructional cycle (Bybee et al. 2006). In this cycle, students (1) are *engaged* by some sort of hook that relates to their interest; (2) have time to *explore* ideas on their own before formal instruction; (3) *explain* their observations using models; (4) *elaborate* and *expand* on the new learning by applying it to a new context; and in the end, (5) *evaluate* and reflect on their own learning. Table 11.3 describes these sequences in more detail. The 5E cycle can be effective for sequences of lessons within a multi-week unit, as well as for individual activities within a single day's lesson plan.

Table 11.3. The 5E Instructional Cycle

Engage	Engage segments pique student curiosity and generate interest through activities that are personally relevant. They bring prior knowledge about the upcoming topics to the forefront and set the focus of future lessons. Teachers employ the first two principles of Ambitious Science Teaching (selecting observable phenomena and eliciting student thinking) as students use the CA NGSS practices of **asking questions [SEP-1]** and performing small **investigations [SEP-3]** (often along with other SEPs).
Explore	The exploration should provide students with a common base of experiences. This can happen through **planning and carrying out active investigations [SEP-3]** or through **obtaining and evaluating information [SEP-8]**. Either way, the activities should facilitate conceptual change by having students experiment, probe, inquire, question, and examine their thinking.
Explain	Based upon their discoveries from the Explore segments, students generate explanations and designs, connecting prior knowledge to new discoveries. Like the CA NGSS practice of **developing explanations [SEP-6]**, students are the ones explaining. The students diagram and verbalize their conceptual understanding, demonstrate their use of science and engineering practices, and apply crosscutting concepts. Teachers can introduce formal labels, definitions, provide direct instruction on essential skills and abilities, and focus student attention on key concepts. Teachers facilitate integration of all these components so that the students can **develop models [SEP-2]** and use them to explain the phenomenon or solve the problem introduced in the Explain segments (the third principle of Ambitious Science Teaching).
Elaborate	Students apply their new knowledge, skills, and understandings to novel situations in the Elaborate segments. Through new experiences with other phenomena or systems that involve the same scientific concept, the learners transfer what they have learned and develop broader and deeper understanding of concepts about the contextual situation and refine their skills and abilities (the fourth principle of Ambitious Science Teaching).
Evaluate	Learning becomes more active when students have time to reflect on what they have learned. The Evaluate segments include elements for students to evaluate their own learning and the teacher to perform summative evaluation and assessment. Students assess their understanding of phenomenon, success of designs, offer new applications of scientific principles, and inform the next steps for engineering designs. This stage may include embedded assessments that provide feedback about the extent to which students met the CA NGSS performance expectations.

Source: Adapted from Bybee 2013.

In reality, these segments support one another in an iterative spiral more than a direct linear sequence. The Explore and Explain segments often intermingle since students are expected to be seeking explanations during the Explore segment and go back and test their explanations during the Explain segment. Elaborate segments often look very similar to Explore segments as both often involve **conducting investigations [SEP-4]**, but they differ in the amount of teacher support and structure. While Explore segments provide the shared experiences foundation for **constructing models [SEP-2]**, Elaborate segments are more open-ended; students **refine and apply their models [SEP-2]** to novel situations and **solve problems [SEP-6]**. All segments can occur in a variety of learning environments, outdoors and in the community, as well as in the classroom.

Teachers have multifaceted roles in the 5E instructional cycle. As facilitators, they nurture creative thinking, problem solving, interaction, communication, and discovery. Teachers use questions to prompt and expand student thinking, inspire positive attitudes toward learning, motivate, and demonstrate skill-building techniques. As guides, teachers help bridge language gaps and foster individuality, collaboration, and personal growth. Teachers flow in and out of these roles within each segment.

Instructional Strategies Snapshot 11.1: 5E Instructional Cycle for Middle Grades—Newton's Laws

Forces and motion affect students' everyday life, are at the root of classical physics, and are part of the DCI PS1.A: *Forces and Interactions* in the CA NGSS. Before the CA NGSS, Mrs. S, a middle grades teacher, used a "one-dimensional" approach to teaching these ideas. She began with direct instruction on Newton's three Laws of Motion using lecture and a short video presentation. She assigned textbook reading, and then her students performed a variety of short, engaging activities illustrating various aspects of the three laws including the pull-a-table-cloth-off-a-table-filled-with-other-items trick, bouncing balls, rolling things up and down ramps, and swinging objects around their heads. She assigned a lab report requiring students to answer questions about Newton's Laws and the activities, as well as problem sets on the topic. The unit, of course, ended with a quiz. Mrs. S realized that she could use many of the same activities if she changed the order and modified the teacher's role so that they would align with the 5E cycle.

Engage. Mrs. S grabbed her students' attention using a brief demonstration from McCarthy (2005). She embedded a knife blade in an apple just far enough so that the apple stuck to the blade when she lifted the knife. She had students predict what would happen when she gently tapped the back of the knife blade with the blade of a second knife and had them record their ideas in their science notebooks. Then, she began tapping. Following a few taps, the apple was cut in half. The students' responses included

Instructional Strategies Snapshot 11.1: 5E Instructional Cycle for Middle Grades—Newton's Laws

"oohs," "ahs," and "That's really cool." Students discussed in groups what they thought was happening and why. They made diagrams of the system at various moments during the demonstration and explained in words what was happening at that moment. Mrs. S prompted students to use ideas about force and motion from elementary school. Mrs. S listened carefully to assess her students' prior knowledge as well as their preconceived ideas and existing mental models. During a whole-class discussion, Mrs. S highlighted some common ideas she heard but did not comment on whether or not they were "correct" or "incorrect."

Explore. Mrs. S set up two hands-on investigations that previously had come at the end of the unit. She chose these activities because they separated the concepts of velocity and acceleration and developed the necessary language to talk about them. During the activities, Mrs. S employed different "talk moves" to probe students about what they observed, what they thought was happening, and how they might test their explanations.

Explain. After the students had shared common experiences, they were ready to label certain concepts with specific scientifically accepted labels and terminology. Mrs. S used a short mini-lecture to demonstrate how physicists use force diagrams to represent interactions. Students then used these diagrams to represent the systems they had explored in the previous segment. Mrs. S introduced the formal description of Newton's Laws, again through direct instruction (including an instructional video she found). She asked students to determine which of their diagrams best exemplified each of these principles.

Elaborate. Mrs. S had revised her traditional worksheet so that it had more concept-oriented problems, which required students to look at a scenario and use Newton's Laws to predict what would happen. She then set up a design challenge in which students had to apply Newton's Laws to solve a specific problem.

Instructional Strategy Resources: 5E Instructional Cycle

Bybee, Rodger. 2013. Translating the NGSS for Classroom Instruction. Arlington, VA: NSTA Press. http://www.cde.ca.gov/ci/sc/cf/ch11.asp#link2
Describes steps for translating NGSS expectations into 5E sequences and provides examples from all K–12 levels.

Volkmann, Mark J., and Sandra K. Abell. 2003. "Rethinking Laboratories: Tools for Converting Cookbook Labs into Inquiry." The Science Teacher 70 (6) 38–41. http://www.cde.ca.gov/ci/sc/cf/ch11.asp#link3.
Provides a checklist and guiding principles for changing lesson sequences so that they better match a 5E-style Instructional Cycle (though 5E is not mentioned explicitly). Focus on secondary-level labs.

Instructional Strategy for 3D Learning: Problem-Based Learning

In problem-based learning (PBL), students work either individually or in cooperative groups to solve challenging problems with real-world applications. Problem-based learning is a subset of *project*-based learning, a process in which students engage in a single thematic topic for an extended amount of time and work toward a specific culmination. Students learn key concepts and content as the need arises in the project or problem-solving process. An authentic real-world context, sustained inquiry, and student self-direction are key components of both strategies.

Problem-based learning is particularly well suited to the CA NGSS because of its focus on **designing solutions [SEP-6]**. In PBL, the teacher poses the problem or challenge, assists when necessary, and monitors progress. As students solve problems, teachers highlight any contradictions between different groups of students and challenge the students to resolve them by coming up with ways to investigate and compare conclusions and solutions. Students must be allowed to make mistakes in PBL, so teachers "need to create a classroom atmosphere that recognizes errors and uncertainties as inevitable features of problem-solving" (Martinez 2010). In PBL, failure and error become recognized as learning opportunities.

Engineering design problems can be the basis for PBL, but science learning must be integrated as an explicit element. For example, students can use trial and error to design a bridge made out of spaghetti strands for an engineering challenge and never deepen their understanding of the three dimensions of the CA NGSS. The challenge can become PBL when students are required to write an **explanation [SEP-6]** that describes what design elements are crucial to the strength of their design (**structure and function [CCC-6]**) and draw diagrams as **models [SEP-2]** of forces within the **system [CCC-4]**. The teacher and students now have a need to introduce and master core ideas and CCCs.

Like the 5E instructional cycle, the key shift of PBL is in the order or sequence in which learning occurs. In 5E, however, engineering challenges were introduced in the "Elaborate" segments as opportunities for students to apply models to new contexts. Problem-based learning shifts the emphasis to solving a problem as the primary goal and learning occurs embedded within the problem solving. In PBL, the problem is introduced at the beginning as the motivation for an entire unit. For example, a high school unit might begin by introducing the problems caused by climate change. During the unit, students will develop solutions that minimize the release of carbon dioxide into the atmosphere from burning fossil fuel. Along the way, they will develop scientific concepts of energy (physics), natural resources (Earth and space science), and fuel (chemistry) to support their development of engineering solutions (which might include energy conservation techniques and alternative energy sources).

Instructional Strategy Resources: Project-Based Learning

While many PBL resources exist on the Web, teachers need to scrutinize them and may need to modify them so that the engaging problem or project also achieves learning in all three NGSS dimensions.

Buck Institute for Education (BIE)
http://www.cde.ca.gov/ci/sc/cf/ch11.asp#link4.
Project-based-learning activity samples and lesson plans with student work samples.

Reinventing Project-Based Learning by Suzie Boss and Jane Krauss
A guide for maximizing the benefits of project-based learning in today's technology-rich environment. This guide is useful for teachers, administrators and professional development specialists.

Instructional Strategy for 3D Learning: Outdoor Learning Experiences

Outdoor and environmental learning experiences are powerful tools for implementing key instructional shifts required by the CA NGSS and California's Environmental Principles and Concepts (EP&Cs). Teachers can effectively use the outdoors as a learning context periodically throughout the year as they teach science. There is also particular value in providing students with longer, concentrated opportunities to explore and explain the natural world by participating in one of California's rich networks of Residential Outdoor Science Schools.

There is wide-ranging evidence to support the value of using natural environments, local communities, and other outdoor settings as a real-world context for science learning that engages student interest as they investigate places around them (Lieberman and Hoody 1998; Lieberman 2013; American Institutes for Research 2005; Glenn 2000). Students should have rich opportunities to observe and investigate the multitude of natural and human social systems found throughout California.

The most effective opportunities to use outdoor environmental learning experiences occur when they are an integral component of three-dimensional science instruction—fully integrated into units of study that do more than offer students isolated out-of-classroom activities. High-quality outdoor and environmental learning is built on research-based instructional strategies like those identified by the BEETLES Project (Lawrence Hall of Science 2017):

- Engaging students directly with nature (for example, on the school campus, at an outdoor science school, or in their community)
- Thinking like a scientist (using NGSS Science and Engineering Practices)

- Learning through discussions (using strategies to promote conversations about science, for example, "talk moves")
- Experiencing instruction based on how people learn (for example, the 5E Instructional Cycle, and using the environment as a context for learning).

Table 11.4 provides examples showing how well-designed outdoor and environmental learning experiences can be used to implement the key instructional shifts of the CA NGSS as students master the ideas represented by California's EP&Cs.

Table 11.4. Achieving the Key Instructional Shifts of CA NGSS and EP&Cs Using Environmental and Outdoor Learning Experiences

Key Instructional Shifts	Examples of Environmental and Outdoor Learning Experiences Supporting the Key Instructional Shifts and California's EP&Cs
Three Dimensional	Natural phenomena found in students' local surroundings provide diverse opportunities to engage in three-dimensional scientific inquiries as they learn the EP&Cs. For example, in fourth grade, students can • undertake a field investigation in the neighborhood [SEP-3], and record the plants and animals they see in their science notebooks [SEP-8]; • look for patterns [CCC-1] in the types and functions of external structures among the different animals [LS1.A]; and, • discover that changes to natural systems can influence [CCC-2] the functioning of plants' and animals' external structures [EP&C II a].
Coherent across the curriculum	Students' investigations of their local community and natural surroundings help them make connections across multiple scientific disciplines, and to read, write, and engage with mathematical analysis, history–social sciences, and technology. For example, middle grades students can • collect weather data [SEP-3] for the area and compare it to long-term climate data collected by the school over 35 years; • ask questions about the data and define a problem [SEP-1] about changes in Earth's climate [ESS3.D] that can be researched using online sources [SEP-8]; • obtain information about the effects temperature changes [CCC-2, CCC-7] have on the snowpack in the Sierra Nevada; • identify human activities that diminish the snowpack in the Sierra Nevada [EP&C IV]; and, • use mathematical thinking [SEP-5] to create meaningful comparisons, using tables and graphs, about the local climate over the past 50 years [history].

Table 11.4. Achieving the Key Instructional Shifts of CA NGSS and EP&Cs Using Environmental and Outdoor Learning Experiences *(continued)*

Key Instructional Shifts	Examples of Environmental and Outdoor Learning Experiences Supporting the Key Instructional Shifts and California's EP&Cs
Relevant to local communities and student interests	Solving real-world problems in their local environment and community gives students the opportunity to learn about issues where they live and then apply what they learn to design engineering solutions that have personal meaning. For example, continuing from above, in the middle grades, students can • identify human activities in their community that release greenhouse gases and influence the global climate [EP&Cs II, IV]; • ask questions to identify evidence [SEP-1] of the possible effects of global climate change [CCC-2, CCC-7] on local habitats and biodiversity [ESS3.C] found in the natural systems at a local wildlife refuge; and, • design possible solutions [ETS.1.B.] to problems caused by local emissions and communicate their findings to the school and community [SEP-8] [EP&Cs V].

Instructional Strategy Resources: Outdoor Learning Experiences

Beetles-Science and Teaching for Field Instructors. 2017. http://www.cde.ca.gov/ci/sc/cf/ch11.asp#link5. Outdoor science education resources that can be used in a wide variety of outdoor science education settings.

Lieberman, Gerald. 2013. *Education and the Environment: Creating Standards-Based Programs in Schools and Districts.* Cambridge: Harvard Education Press.

Yager, Robert, and John Falk, eds. 2007. *Exemplary Science in Informal Education Settings.* Arlington, VA: National Science Teachers Association.