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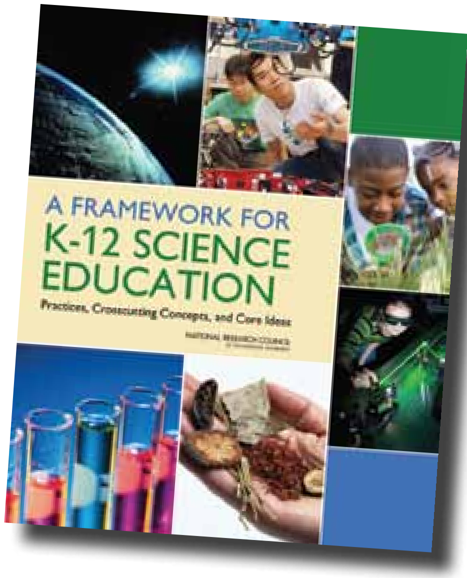
The Second Dimension—Crosscutting Concepts

Understanding *A Framework for K–12 Science Education*

By Richard A. Duschl



For the last half century educators have struggled with the question, "What do we want students to know and what do they need to do to know it?" An alternative perspective for planning and framing science instruction asks "What do we want students to do and what do they need to know to do it?" The recently published National Research Council (NRC) report *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2011) offers a thoughtful research-based agenda that helps guide us in making the shift to a doing-led agenda in K–12 science education. Grounded in the recommendations and conclusions from the NRC research synthesis report, *Taking Science to School* (NRC 2007), which I chaired, the *Framework* proposes that:

1. K–12 science education be coordinated around three intertwining dimensions: Practices, Crosscutting Concepts, and Core Ideas; and
2. curricula, instruction, and assessments be aligned and then coordinated across grade band learning progressions.

In the December 2011 editions of the NSTA journals, Rodger Bybee focused on Science and Engineering Practices, Dimension One of the *Framework*. Here the focus is on the *Framework's* Crosscutting Concepts—Dimension Two. The *Framework* makes very clear that science learning needs to be coordinated around generative conceptual ideas and scientific practices. I begin with the seven Crosscutting Concepts, highlighting features within each that reveal the components of progressions. A big challenge for teachers is thinking about planning lessons and units across grade bands as student learning progresses within a grade and across grades. This will require more work, but designing lessons that move students through the Crosscutting Concept progression while teaching the Core Ideas and engaging students in the appropriate Scientific Practices will help ensure that students are doing science in grades K–12.

Developing an understanding of how the *Framework's* Three Dimensions relate to the Four Strands of Science Proficiency in *Taking Science to School* is important. Figure 1 presents the relationships between the Strands and the Dimensions. The emerging evidence on science learning from *Taking Science to School*, as well as *Ready, Set, Science!* (NRC 2007, NRC 2008) suggests the development of the science proficiencies is best supported when learning environments effectively interweave all four Strands into instruction. A similar recommendation from the *Framework* is to interweave the Crosscutting Concepts and the Science and Engineering Practices with the Core Ideas. What the research tells us is the primary focus for planning and instruction needs to be longer sequences of learning and teaching. The agenda is one of alignment between curriculum-instruction-assessment in classrooms where both teaching and learning is coordinated around "making thinking visible" opportunities employing talk, arguments, models, and representations. Keep this in mind as you read the overviews of the Crosscutting Concepts in the next section. Ask yourself: How would I integrate the concepts into planning, teaching, and assessing science units?

The Second Dimension—Seven Crosscutting Concepts

1. Patterns
2. Cause and Effect: Mechanism and Explanation
3. Scale, Proportion, and Quantity
4. Systems and System Models
5. Energy and Matter: Flows, Cycles, and Conservation
6. Structure and Function
7. Stability and Change

Figure 1

Relationship of Strands and Dimensions (NRC 2011, p. 10–29)

Strands from *Taking Science to School*	**Dimensions in *Framework***	**How the *Framework* is Designed to Deliver on theCommitment in the Strand**
1. Knowing, using, and interpreting scientific explanations of the natural world	• Disciplinary core ideas, • Crosscutting concepts	*Specify big ideas, not lists of facts:* • Core ideas in the framework are powerful explanatory ideas, not a simple list of facts, that help learners explain important aspects of the natural world. • Many important ideas in science are cross-cutting, and learners should recognize and use these explanatory ideas (e.g., systems) across multiple scientific contexts.
2. Generating and evaluating scientific evidence and explanations **4. Participating productively in scientific practices and discourse**	• Practices	*Learning is defined as the combination of both knowledge and practice, not separate content and process learning goals*: • Core ideas in the framework are specified not as explanations to be consumed by learners. The performances combine core ideas and practices. The practices include several methods for generating and using evidence to develop, refine, and apply scientific explanations to construct accounts of scientific phenomena. Students learn and demonstrate proficiency with core ideas by engaging in these knowledge-building practices to explain and make scientifically informed decisions about the world.
3. Understanding the nature and development of scientific knowledge	• Practices, • Crosscutting concepts	*Practices are defined as meaningful engagement with disciplinary practices, not rote procedures:* • Practices are defined as meaningful practices, in which learners are engaged in building, refining, and applying scientific knowledge, to understand the world, and not as rote procedures or a ritualized "scientific method." • Engaging in the practices requires being guided by understandings about why scientific practices are done as they are—what counts as a good explanation, what counts as scientific evidence, how it differs from other forms of evidence, and so on. These understandings are represented in the nature of the practices and in crosscutting concepts about how scientific knowledge is developed that guide the practices.

Look familiar? The set of Crosscutting Concepts in the *Framework* is similar to "unifying concepts and processes" in the *National Science Education Standards* (NRC 1996), "common themes" in *Science for All Americans* (AAAS 1989), and "unifying concepts" in *Science: College Board Standards for College Success* (College Board 2009) (see Figure 2). Regardless of the labels used in these documents, each stresses, like the *Framework*, the importance that "students develop a cumulative, coherent, and usable understanding of science and engineering." (p. 4-1) The Crosscutting Concepts are the themes or concepts that bridge the engineering, physical, life and Earth/space sciences; in this sense they represent knowledge about science or science as a way of knowing. As such, the Crosscutting Concepts are very important for addressing the science literacy goals.

Figure 2

Disciplinary bridging concepts.

NSES unifying concepts	AAAS common themes	CB unifying concepts
• Systems, Order, and Organization • Evidence, Models, and Explanation • Change, Constancy, and Measurement • Evolution and Equilibrium • Form and Function	• Systems • Models: Physical, Conceptual, Mathematical • Constancy and Change • Constancy • Stability and Equilibrium, Conservation, Symmetry • Patterns of Change • Trends, Cycles, Chaos • Evolution • Possibilities, Rates, Interactions • Scale	• Evolution • Scale • Equilibrium • Matter and Energy • Interaction • Form and Function • Models as Explanations, Evidence, and Representations

The first two concepts are "fundamental to the nature of science: that observed *patterns* can be explained and that science investigates *cause-and-effect* relationships by seeking the mechanisms that underlie them. The next concept—*scale, proportion, and quantity*—concerns the sizes of things and the mathematical relationships among disparate elements. The next four concepts—*systems and system models, energy and matter, structure and function, and stability and change*—are interrelated in that the first is illuminated by the other three. Each concept also stands alone as one that occurs in virtually all areas of science and is an important consideration for engineered systems as well." (NRC 2011, p. 4-2)

Progressions for Teaching Grades K–12

The *Framework* presents each Crosscutting Concept in two sections, a description followed by a synopsis statement that outlines the developmental features of increasingly sophisticated enactments by pupils. The statements below are from the Crosscutting Concepts Chapter of the *Framework*. The grade band progression descriptions are representative and are not fixed; any one may begin sooner or later according to the development, experiences, and conceptual understandings of the students.

1. *Patterns.* Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

K–2 Pattern recognition occurs before children enter school. Develop ways to record patterns they observe. Engage pupils in describing and predicting patterns focusing on similarities and differences of characteristics and attributes.

3–5 Classifications should become more detailed and scientific. Students should begin to analyze patterns in rates of change.

6–8 Students begin to relate patterns to microscopic and atomic-level structures.

9–12 Observe and recognize different patterns occurring at different scales within a system. Classifications at one scale may need revisions at other scales.

2. *Cause and effect: Mechanism and explanation.* 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.

K–2 Children look for and analyze patterns in observations or in quantities of data. Begin to consider what may be causing the patterns.

3–5 Students routinely ask about cause-effect relationships particularly, with unexpected results—how did that happen?

6–8 Engage in argumentation starting from students' own cause-effect explanations and compare to scientific theories that explain causal mechanisms.

9–12 Students argue from evidence when making a causal claim about an observed phenomenon.

3. *Scale, proportion, and quantity.* 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.

K–2 Begin with objects, space, and time related to their world using explicit scale models and maps. Discuss relative scales—fastest/slowest—without reference to units of measurement. Begin to recognize proportional relationships with representations of counting, comparisons of amounts, measuring, and ordering of quantities.

3–5 Units of measurement are introduced in the context of length, building to an understanding of standard units. Extend understandings of scale and units to express quantities of weight, time, temperature, and other variables. Explore more sophisticated mathematical representations, e.g., construction and interpretation of data models and graphs.

6–8 Develop an understanding of estimation across scales and contexts. Use estimation in the examination of data. Ask if numerical results are reasonable. Develop a sense of powers of 10 scales and apply to phenomena. Apply algebraic thinking to examine scientific data and predict the effects changing one variable has on another.

9–12 Students acquire abilities to move back and forth between models at various scales and to recognize and apply more complex mathematical and statistical relationships in science.

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

K–2 Express thinking using drawings and diagrams and through written and oral descriptions. Describe objects and organisms by parts; note functions and relationships of parts. Modeling supports clarifying ideas and explanations.

3–5 Create plans; draw and write instructions to build something. Models begin to reveal invisible features of a system—interactions, energy flows, matter transfers. Modeling is a tool for students to gauge their own knowledge.

6–8 Mathematical ideas—ratios, graphs—are used as tools for building models. Align grade-level mathematics to incorporate relationships among variables and some analysis of the patterns therein. Modeling reveals problems or progress in their conceptions of systems.

9–12 Identify assumptions and approximations built into models. Discuss limitations to precision and reliabilities to predictions. Modeling using mathematical relationships provides opportunities to critique models and text and to refine design ideas.

5. *Energy and matter: Flows, cycles, and conservation.* Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

K–2 Focus is on basic attributes of matter in examining life and Earth systems. Energy is not developed at all at this grade band.

3–5 Macroscopic properties and states of matter, matter flows, and cycles are tracked only in terms of the weights of substances before and after a process occurs. Energy is introduced in general terms only.

6–8 Introduce role of energy transfers with flow of matter. Mass/weight distinctions and idea of atoms and their conservation are taught. Core ideas of matter and energy inform examining systems in life science, Earth and space science, and engineering contexts.

9–12 Fully develop energy transfers. Introduce nuclear substructure and conservation laws for nuclear processes.

6. *Structure and function.* The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

K–2 Examine relationships of structure and function in accessible and visible natural and human-built systems. Progress to understandings about the relationships of structure and mechanical functions (wheels, axles, gears).

3–5 Matter has a substructure that is related to properties of materials. Begin study of more complex systems by examining subsystems and the relationships of the parts to their functions.

6–8 Visualize, model, and apply understandings of structure and function to more complex and less easily observable systems and processes. The concept of matter having submicroscopic structures is related to properties of matter.

9–12 Apply the knowledge of structure and function when investigating unfamiliar phenomena; when building something or deciphering how a system works, begin with examining what it is made of and what shapes its parts take.

7. *Stability and change.* For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of the system are critical elements of study.

K–2 Children arrive to school having explored stability and change. Develop language for these concepts and apply across multiple examples. Help foster asking questions about why change both does and does not happen.

3–5 Explore explanations for regularities of a pattern over time or its variability. A good model for a system should demonstrate how stability and change are related and offer an explanation for both.

6–8 As understanding of matter progresses to the atomic scale, so too should models and explanations of stability and change. Begin to engage in more subtle or conditional situations and the need for feedback to maintain a system.

9–12 Students can model even more complex systems and attend to more subtle issues of stability and change. Examine the construction of historical explanations that account for the way things are today by modeling rates of change and conditions when systems are stable or change gradually, accounting for sudden changes, too.

The message from the *Framework* is that there are important interconnections between Crosscutting Concepts and Disciplinary Core Ideas. "Students' understandings of these crosscutting concepts should be reinforced by repeated use in the context of instruction in the disciplinary core ideas… the crosscutting concepts can provide a connective structure that supports students' understanding of sciences as disciplines and that facilitates their comprehension of the systems under study in particular disciplines" (p. 4–13). What this says is that the Crosscutting Concepts are to be embedded within and conjoined across coherent sequences of science instruction. The *Framework*'s three Dimensions—Science Practices, Crosscutting Concepts, Core Ideas—send a clear message that science learning and instruction must not separate the knowing (concepts, ideas) from the doing (practices). Thus, the assessment strategies teachers adopt for pupils' understandings of and enactments with the seven Crosscutting Concepts must also conjoin the knowing and doing.

Assessing Crosscutting Concept Learning With Learning Performances

The *Framework*'s three Dimensions represent a more integrated view of science learning that should reflect and encourage science activity that approximates the practices of scientists. What that means for the Crosscutting Concepts is that assessment tasks should be cumulative across a grade band and contain many of the social and conceptual characteristics of what it means to "do" science; e.g., talk and arguments, modeling and representations. The assessments of Crosscutting Concepts would be less frequent; each term or annually there would be a performance assessment task that would reveal how students are enacting and using the three Dimensions. The majority of assessment tasks for Crosscutting Concepts will be constructed-response and performance assessments. If the goal is to gauge students' enactments of Crosscutting Concepts when asked to ascertain patterns, generate mechanisms and explanations, distinguish between stability and change, provide scale representations, model data, and otherwise engage in various aspects of science practices, then the students must show evidence of "doing" science and of critiquing and communicating what was done.

The *Framework* provides teachers with an agreed upon set of curricular goals. The *Next Generation Science Standards* (*NGSS*) assessments will be in a "learning performances" format. For example, consider a task to explain how a smell travels through a room. It could be assessed using the grade band information described in section 5, Energy and Matter: Flow, Cycles, and Conservation. The expectation is for students to use some conceptual knowledge (e.g., states of matter) with a practice (e.g., modeling) to develop a mechanism (gas/particle diffusion) that explains the odor's movement. What a teacher is seeking is evidence that students are developing a model of matter made of particles. Related tasks could be mechanisms for the diffusion of a colored dye in water, the separation of sediments in water, or the role of limiting factors in an ecosystem or chemical reaction. The tasks can be gathered over the grade band to develop a portfolio of evidence about students' understandings and enactments of Crosscutting Concepts.

Summary

The inclusion of Crosscutting Concepts in the *Framework* continues a 50-year history in U.S. science education that both scientific knowledge and knowledge about science are important K–12 science education goals. It's the dual agenda for science. The Crosscutting Concepts are best thought of as the learning goals for science literacy. But success hinges on doing the science. The coordination of the three Dimensions reinforces the importance of not separating the doing from the knowing. The alignment of curriculum-instruction-assessment models coordinated around learning progression ideas and research has great potential to organize classrooms and other learning environments around adaptive instruction (targeted feedback to students) and instructed-assisted development. In science over the last century, we have learned how to learn about nature. In education over the last century, we have learned how to learn about learning. As we proceed deeper into the 21st century, let us learn how to meld together these two endeavors. The *Framework* and the forthcoming *NGSS* are a great beginning, but successful implementation will only come about through the participation and commitment of teachers.

The shift to a "doing" science curriculum focus enacted through the seven Crosscutting Concepts and the eight Science and Engineering Practices will provide students with experiences over weeks, months, and years that will shape their images about the Crosscutting Concepts, the Practices, and, thus, the nature of science. The teacher is the key that will help us unlock how to fully understand the best coherent sequences for learning and teaching. ■

Richard A. Duschl (rad19@psu.edu) *is the Waterbury Chair of Secondary Education at The Pennsylvania State University, and co-chair of the Earth/Space Science writing team for the* Next Generation Science Standards.

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