

DCIs, SEPs, and CCs, Oh My!

Understanding the Three Dimensions of the NGSS

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The *Next Generation Science Standards'* three dimensions—disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCs)—were headliners at NSTA's national conference in Chicago and featured in many of the organization's other professional-development efforts this year (NGSS Lead States 2013). To some, the idea of DCIs, SEPs, and CCs may seem obvious and not all that new (Figure 1). Haven't we been doing science inquiry since the release of the *National Science Education Standards (NSES)* in 1996? What is new and different about the *NGSS*, and what do these three dimensions mean for curriculum, instruction, and assessment?

There are, in fact, several major differences in how the new standards portray science education. These differences call for substantial shifts in terms of our learning goals, instructional strategies, and assessment. In the next sections, we highlight what is new and different about each dimension. We do not address explicitly intertwining the three dimensions; a forthcoming article will discuss their integration.

Much of what we discuss below draws directly from *A Framework for K–12 Science Education* (NRC 2012), which guided the development of the *NGSS* and is the foundation for the new standards. While the *NGSS* do provide some information from the *Framework* (in the blue, orange, and green boxes; see Figure 1) to elaborate on the performance expectations, these are only snippets of the more elaborate descriptions found in the *Framework*. We therefore urge readers to turn to the *Framework* when trying to understand the three dimensions and the standards.

DCIs

There are DCIs for each of the four major disciplines: physical sciences, life sciences, Earth and space sciences, and engineering (engineering, technology, and applications of science). Each of these disciplines includes no more than four DCIs, reflecting a concerted effort to cull the numerous ideas that all students are expected to know. While there are somewhat fewer

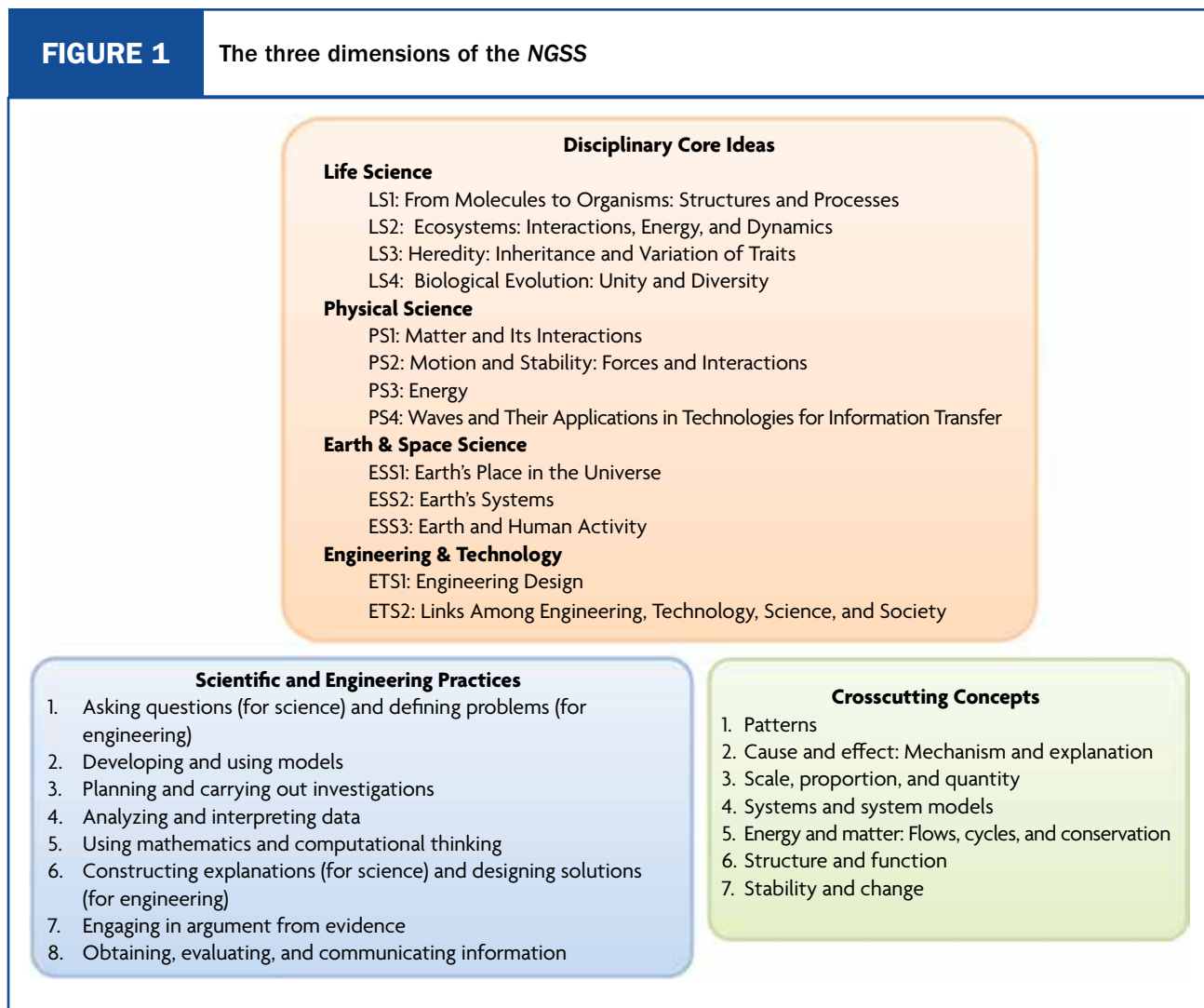
ideas to teach, each is complex, with ample depth to delve into over the course of schooling.

To rise to the level of a DCI, an idea must meet four criteria. First, it must be a key organizing principle within the discipline or across several disciplines; that is, it should be a core idea in the eyes of scientists. Second, it must have broad explanatory power: It should help learners understand and be able to reason about an array of phenomena and problems in the discipline. In this sense, it needs to be a useful thinking tool that is generative for students, and it should help them think about phenomena and problems they may encounter in and out of the classroom, both now and in their future. Third, a DCI needs to be relevant and meaningful for students. It should relate to phenomena and problems that students find intriguing. Fourth, the idea needs to have depth that allows for continued learning over the course of schooling. There are two complementary

implications of this last point. First, the DCI, in some basic form, must be accessible to young learners, and, second, it must have enough complexity that it can be unpacked and deepened in higher grades. Many of the concepts (e.g., ionic bonds, mitochondria) and even topics (e.g., volcanoes, taxonomy) currently taught in school do not meet these criteria. As educators, it is incumbent upon us to closely evaluate what we are teaching and to dramatically prune the unwieldy tree of concepts we try to cover.

Taken together, the DCIs create a conceptual toolkit that students can use to reason about and explain phenomena. The focus on explaining phenomena represents an important shift in the goals of instruction. Rather than teaching ideas in the abstract or in isolation, the new aim is to engage students in using these ideas to explain interesting phenomena. For example, instead of having students describe the water cycle and its com-

FIGURE 1 The three dimensions of the NGSS



ponents, students should be explaining cloud formation or precipitation patterns by using understandings about the water cycle and thermal-energy transfer to describe how weather events come about. Over time, these explanations become deeper (accounting for more of the mechanism) and broader (explaining a wider array of relevant phenomena or contexts).

It is important to stress here that deepening a DCI does not mean teaching more details. A deeper understanding of how matter and energy cycle in ecosystems does not mean knowing more details about chemical pathways in cellular respiration or photosynthesis. Similarly, a deeper understanding of the structure and properties of matter does not mean knowing the details of the periodic table. There is a widespread belief that teaching more details about an idea or process will lead to a better understanding of it; this is often not the case. Rather, the details and minutiae tend to obscure the big picture and can leave students with a fragmented and often incorrect understanding. For example, students may be able to draw the Calvin cycle of photosynthesis without really understanding that the carbon in a plant (its mass) can be traced to atmospheric carbon dioxide. Conversely, understanding how inorganic carbon (e.g., CO_2) and organic carbon (e.g., sugars) are related in a cycle can help students predict how an increase in atmospheric carbon might impact the growth of plants or alter the acidity of the ocean. Therefore, rather than teaching more details about a concept, we should help students understand core aspects of the underlying mechanisms (the “how” and “why”) and the ways in which these mechanisms play out across different phenomena (Pellegrino and Hilton 2012).

The NGSS add several concepts to the set of ideas students are expected to learn, such as a focus on information processing and the brain (life science) and human impacts on Earth systems (Earth and space sciences). However, the most noticeable addition is the explicit inclusion of engineering in two DCIs. Aspects of engineering and the application of science were included in prior versions of the standards (*NSES* 1996), but not to the same extent as in the NGSS. This change requires engaging students in developing design solutions to complex problems by drawing on the other DCIs. Engineering is not devoid of science; that is, it is not an exercise in “building the best rocket through trial and error.” Engineering requires a deep understanding of science concepts and how these can be harnessed to better understand a problem and develop a viable solution. Engineering also includes other considerations and constraints (costs, for example) that play a lesser role in basic research. Ultimately, a

design solution must meet certain goals within a set of limitations and fulfill its intended purpose.

Lastly, along with changes to what we should be teaching, there are research-based changes to when ideas should be taught. For example, the common topic of states of matter (solids, liquids, and gases), often addressed in elementary school, has been shifted to middle school. This change results from research showing that to really understand states of matter, one needs a particle theory of matter—an idea that most young students cannot conceptualize (Smith et al. 2006). The notion that matter is made up of smaller bits is introduced in fifth grade and then deepened in middle school (adding the motion of particles) and beyond. When planning curriculum and instruction, it is therefore necessary to look across the grades at how a particular DCI is expected to develop in order to better understand the boundaries of what students should know at a particular grade. Appendix E of the NGSS provides progressions for each DCI and can be helpful in understanding the rationale behind the scope and sequence of the NGSS across grades.

SEPs

One of the most common questions about the SEPs is: How are the SEPs different from inquiry-based instruction? Or, in a more provocative form: Why do we need new words to describe what we are already doing? The answer is that, yes, the use of the word *practices* is meant to signal a shift in how we view inquiry-based teaching and learning and that many “inquiry-based” lessons do not meet the intent of the *Framework* or the NGSS.

Common laboratory experiments, such as observing seeds sprouting in light and dark conditions or investigating how the temperature of water affects its density, highlight some aspects of scientific inquiry. These types of activities emphasize accurate measurement, careful control of variables, and data analysis. Yet most of these types of activities miss what is at the heart of science: building knowledge. Science’s main goal is the development of explanations and models of the natural world. The above activities often stop short of developing and critiquing explanations of these phenomena (e.g., Why is cold water denser than warm water?). Students’ hypotheses in these experiments are often simplistic “if X then Y” statements that are not based on plausible explanations of the phenomenon. Moreover, students rarely understand why they need to control some elements of the experimental setup (e.g., how much water is given to the sprouting seedlings), but not others (e.g., the size of the seed, the

temperature of the soil). In fact, students often believe that there is one single, appropriate way to conduct an experiment and that if you follow the stepwise scientific method, you will arrive at the correct answer.

Scientists, however, do not generate hypotheses in a vacuum; rather, their hypotheses are often aimed at distinguishing between two or more competing explanations. Deciding what to measure and what to control is not obvious, either. Rather, the decision depends on the specific explanations the scientists are trying to build or test and is also subject to critique and argument. Therefore, what counts as acceptable evidence, and the means to obtain that evidence, depends on the questions scientists are trying to answer and the explanations they are trying to generate. Different fields of science have different criteria for what counts as good evidence, how to conduct experiments, and what sorts of arguments are convincing. These criteria are subject to negotiation and do change over time as understandings and technologies advance. Lastly, developing explanations and models is both a creative and evidence-based endeavor. Different scientists may interpret data differently and come up with alternative accounts of what happened and why. Science is challenging and fun because it allows us to imagine how entities and processes we cannot see cause phenomena we experience every day, from the simplicity of melting ice to the complexity of global climate change. Scientific knowledge is a human invention. We, however, trust science to generate valid and reliable knowledge because of the constant critiques and evidence-based argumentation that the scientific community engages in as it develops and refines explanations of phenomena.

What does all this have to do with SEPs? The SEPs described in the *Framework* and *NGSS* are an attempt to capture the essence of how the scientific community works to generate knowledge. First, the plural “practices” suggests that there is no single method in science; rather, a constellation of inquiry activities are involved. The *NGSS*’s SEPs include familiar aspects of inquiry such as Asking Questions, Planning and Carrying Out Investigations, and Analyzing Data. More importantly, however, the SEPs include those activities and norms that are at the core of science—Developing and Using Models, Constructing Explanations, and Engaging in Argument from Evidence.

All of the SEPs are heavily dependent on the existence of a community, because building scientific knowledge is a communal activity. This leads us to perhaps the most important change that a focus on SEPs entails—all are inherently social and based in a community of practice. Individuals who practice a particular craft belong to a community with established ways

of thinking, acting, talking, and interacting. Newcomers apprentice to the ways of the community and gradually take on these ways of thinking and interacting. In science, the SEPs center on the processes of generating new, valid, and reliable knowledge (theories). Science education should adopt the same goal, helping students build scientific knowledge through engagement in SEPs that we know are effective for generating such knowledge.

This is not to say that students are expected to reinvent theories from scratch; we are not advocating for a free-for-all discovery approach to instruction. Students’ engagement with the practices should be scaffolded and supported. There are a slew of useful resources through NSTA’s website and journals to help teachers find effective ways to engage students productively with the SEPs (Krajcik and Merritt 2012; Reiser, Berland, and Kenyon 2012; Rinehart, Duncan, and Chinn 2014; Windschitl 2008; and Sneider 2014, among many others). Learning science entails engaging in all these SEPs in an iterative and cyclical way. New models lead to new questions, and those in turn lead to new investigations in an endless cycle of knowledge refinement. One cannot teach any DCI by engaging in only one or two SEPs; it really takes active engagement with all eight to generate new knowledge.

CCs

The *Framework* and *NGSS* include seven CCs, some of which have been featured before in the American Association for the Advancement of Science’s *Benchmarks for Science Literacy* (AAAS 1993) and the *NSES*. The CCs provide a set of lenses that can be used to explore and explain phenomena. It is not merely the case that these concepts, such as Structure and Function, are common themes throughout much of science; they also provide guiding principles when scientists are investigating the causal mechanisms of a variety of phenomena. For example, when scientists are trying to understand why some members of a species seem to do better after an environmental change compared to others, they search for differences in the structures in these organisms that yield a functional advantage in the changed environment. The search for advantageous structures and functions is a key aspect of these evolutionary investigations and resulting explanations.

Viewing the CCs as lenses suggests that phenomena can be studied from different perspectives, leading to new and different insights about them. Consider a phenomenon such as the inheritance of a genetic disorder. Scientists can look for relevant structures (e.g., genes, proteins) and try to figure out how changes to these

structures and their functions can cause effects at the organism level. These CCs frame the problem under investigation (we are looking for structures, functions, and their effects) and open up the mechanism underlying how information in genes causes physical effects in the organism. For many disorders, however, the severity of the symptoms is hard to predict because of the complexity of the organism in which the genes are operating. To understand this piece of the puzzle, scientists need to employ a different lens, Systems and System Models, to understand these complex interactions within the organism. Both the Cause and Effect and the Systems and System Models CCs come into play when scientists explain this phenomenon, and each is critical in explaining a different piece of the story.

What does this mean for instruction? Teachers must help students view the CCs as these alternative lenses for understanding phenomena and be able to move fluidly and comfortably between them, depending on what they are trying to investigate and explain. A key approach is to point out which lenses are being used to investigate a particular phenomenon and the tradeoffs in what these lenses show and what they hide.

It is important to emphasize that we should not be teaching the CCs as stand-alone ideas, because in the abstract, they are not that useful. Rather, they are thinking tools students can use when trying to understand phenomena in the world around us. Several can be used together, and each helps us “see” and think about a phenomenon from a different angle. The goal is to teach students to understand when and how to use the CCs as tools to explore the world, much like scientists do. The CCs, therefore, represent useful ways to think about, teach, and learn the DCIs.

Conclusion

Taken together, the DCIs, SEPs, and CCs represent a markedly different way of teaching science. Can one use existing lessons to teach in this way? Not really. Most existing lessons that claim to be “inquiry-based” do not truly engage students with building knowledge of DCIs through engagement with SEPs and CCs. The new standards provide a different view of what it means to do and learn science. Understanding the three dimensions is an essential first step in the process of becoming a “next generation” teacher. Resources from the NGSS@NSTA Hub (<http://ngss.nsta.org>) as well as *A Framework for K–12 Science Education* (NRC 2012) can provide a great starting point for this journey. ■

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