The central pedagogical principle on which the Next Generation Science Standards (NGSS) are built is that of three-dimensional learning. This principle posits that it is through meaningful integration of the disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCCs) that students will attain an understanding of both the knowledge and processes of science.

Regarding that third dimension, it is noted in A Framework for K–2 Science Education (National Research Council 2012) that “… crosscutting concepts have value because they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas” (p. 218). However, the authors’ experience in working with hundreds of pre- and in-service teachers over the years is that teachers lack the familiarity or confidence to support their students in using the CCCs as intellectual tools in this way.

The purpose of this article, then, is to bring the value of CCCs to the foreground and to provide suggestions and resources for purposefully integrating them into curricula and instruction. As such, this article will supplement previous entries in this journal (Duschl 2012; Metz 2013; Talanquer 2019) that have specifically addressed CCCs and focused more on what they generally represent and how, in a broad sense, they can be utilized by teachers. Science Scope also has included several articles (Fick, Arias, and Baek 2017; German 2017; Mohl et al. 2017; Plonczak and Zwirn 2015) that support teachers in employing the CCCs. To augment these previous works, for each CCC, this article offers

• specific facets of the CCCs that teachers should consider explicitly addressing
• resources that support use of the CCCs, and
• sample activities that show the CCCs in action.

General resources
Before digging into each of the CCCs individually, we thought it would be valuable to direct readers to some general resources on these big ideas:

• Appendix G of the Next Generation Science Standards (see Online Connections) provides a brief description of each CCC, offers nine guiding principles for their use, then presents tentative learning progressions for the development of the CCCs across K–12.
• The Crosscutting Concepts page (Online Connections) within the Exploring Fluid Concepts website discusses each CCC in the context of marine science, then provides links to educational activities.
• A document titled Using Crosscutting Concepts to Prompt Student Responses (Online Connections) provides guidance on how to use “prompts structured around the crosscutting concepts” to support NGSS-aligned formative assessments.
• Related to the previous resource, Page Keeley has a page in her Uncovering Students’ Ideas website dedicated to demonstrating how formative assessment probes can be used to support assessment of the CCCs (Online Connections).
• STEM Teaching Tool 41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction (Online Connections) complements both of the previous two resources in terms of providing ways to assess understanding of CCCs.
• Paul Anderson’s Wonder of Science site has a NGSS Resources page (see Online Connections) that contains a graphic organizer (or two) for each of the CCCs.
• The CrossCutSymbols site (Online Connections) helps students to visualize the CCCs through artistic depictions that allude to what each CCC represents.
Patterns
In the indie movie \(\pi\) (Appendix A), lead character Max Cohen says, “12:45. Restate my assumptions. One: mathematics is the language of nature. Two: Everything around us can be represented and understood through numbers. Three: If you graph the numbers of any system, patterns emerge. Therefore, there are patterns everywhere in nature.” Captured within this monologue are a couple of the elements associated with the use of patterns as outlined in the Crosscutting Concept Matrix of Appendix G of the NGSS (Online Connections):

- (1) Mathematical representations are needed to recognize some patterns.
- (2) Empirical evidence is needed to identify patterns.

The other three elements connect patterns with scale and with engineering. *A Framework for K–12 Science Education* discusses additional aspects of having students use patterns as a tool to make sense of phenomena: noting patterns as a starting point for asking scientific questions, using statistics to determine the significance of mathematical patterns, and basing arguments “on inductive generalizations of existing patterns” (p. 71).

While pattern recognition is a skill that naturally develops in children, honing that skill to be used in the ways described above requires explicit instruction. As Stewart (2017) stated, “I am a mathematician. I experience these wonders through a mind that has spent a lifetime learning how to detect patterns, how to understand patterns, how to analyze patterns, how to use patterns, how to find new patterns …” (p. 215). His book represents an excellent resource for teachers to identify specific aspects of teaching about patterns, and to understand how patterns connect mathematics and science. This book also reminds us that purposefully helping students learn how to analyze and interpret graphs—a key process for finding patterns in data—is a capacity that needs to be intentionally fostered, e.g., by using the activities in the Concord Consortium’s Graph Literacy module (Appendix A). Likewise, NOAA’s data literacy modules (Appendix A) provide opportunities to identify patterns (especially trends) in data associated with complex environmental issues.

Another excellent resource is Ball’s book on Patterns in Nature (2016), which links patterns to cause and effect by examining how natural patterns come to be. While Ball’s book can provide some examples of patterns to tie to such topics as genetics, the Wikipedia page on *Patterns in Nature* (Appendix A) offers a nice organizing framework to share with students. Perhaps unsurprisingly, the first pattern identified in this Wikipedia entry is symmetry, and foregrounding symmetry is a useful instructional approach for connecting patterns to structure and function across the science disciplines. Lederman and Hill’s (2004) book provides a deep dive into symmetry across the universe and at different scales. Appendix A contains links to a pair of YouTube videos that explore symmetry, including one that describes how Noether’s theorem (Nadis 2017) connects symmetry to conservation principles.

There are two other aspects of patterns that teachers can support students in understanding through properly designed activities. One is that identifying patterns can allow us to extrapolate beyond a data set and make predictions; Criswell (2006) designed an object-sorting activity to emphasize these ideas as a precursor to having chemistry students explore the periodic table. Recognizing anomalies in patterns and exploring their origins is another critical skill that will allow students to apply pattern recognition in more scientific ways. Criswell (2006) designed two activities on chemical bonding that force students to respond to anomalous pieces of data and determine whether the patterns associated with that data are still valid. Distinguishing irrelevant/discardable data from anomalous data is part of distinguishing patterns from non-patterns and is challenging for students (Shepardson and Moje 1999).

Cause and effect
In her TED talk, Ionica Smeets states, “But jumping to an incorrect conclusion about causality when you see a correlation is the most often made logical mistake” (Appendix A). This is such an important idea to science (and statistics) that it is the first element identified in the NGSS matrix on this CCC. Other elements highlight the critical connection between cause and effect and systems and system models. *A Framework* also links cause and effect with other CCCs: For instance, the point is made that recognizing patterns can be the starting point for exploring and identifying cause-effect relationships (p. 87). And, as with patterns, *A Framework* ties cause and effect to SEPs including constructing explanations (p. 67) and argumentation, which often starts “from students’ own explanations of cause and effect” (p. 89).

While determining the causal mechanisms responsible for phenomena is a central activity of science, *A Framework* points out that “in complex systems causation can be difficult to tease out” (p. 87). However, even simple systems can have multi-faceted cause-effect mechanisms. For instance, consider the simple phenomenon of putting a straw in a drink, putting a finger over the top end of the straw, and then lifting the straw out of the drink with the finger still over the top; the liquid stays in the straw. Why does that happen? McCarthy (2014) describes a mini learning cycle to investigate this; it turns out that there are several causal factors (e.g., pressure and gravity) and these factors interact with each other. It is highly unlikely that most students would be able to make sense of this phenomenon without explicit understanding of different types of causal mechanisms.

Fortunately, Grotzer (2012) provides guidance to teachers on how to promote such understanding, as well as presenting her own and others’ research into how children conceive of causality and the difficulty they experience understanding it. As a companion to the book, she and her colleagues created the *Causal Patterns in Science* web site (Appendix A). While the functionality of the site is limited, there are still numerous use-
ful resources there, including a list of six types of cause-effect relationships and a set of five units emphasizing the use of cause-effect principles.

As noted above, the ability to distinguish between correlation and causation is a critical skill for students to develop; Colburn (2008) discusses this important distinction and provides some examples that can be shared with students. Another key principle is that a single effect can have multiple causes and, conversely, a single cause can produce multiple effects. Bokor Joseph, and Darwiche (2015) describe a learning cycle where students determine the genetic cause of Pompe disease by tracing backwards from the multiple physiological effects it produces. Students need to be made aware that even the temporal sequencing implicit in this exploration—the common-sense notion of the cause preceding the effect(s)—needs to be viewed skeptically, as recent research within the field of quantum entanglement has shown that “the effect can, in fact, happen before its cause occurs” (Mosher 2019). Discussing an example like this can show the links between cause and effect and scale.

Finally, explicitly examining cause and effect with students can allow teachers to address different ways of knowing about the world. Smith (1998) contrasts the approach to understanding nature adopted by the Anasazi (Indigenous Peoples) from that adopted by Western scientists: “Unlike the Anasazi mind that accepted rather than explained in causal terms, the Western mind seeks to know all things in terms of cause and effect” (p. 35). He then later considers the broader implications of these differences: “As a result of knowing the world in cause-and-effect terms, the Western mind exhibits another of its world-views—in the relationship between humans and the rest of the world, humans by right hold the upper hand” (p. 35). These ideas are embedded in an astronomy unit that allows students to deepen their understanding of cause and effect, while at the same time surfacing important beliefs they may have about the very nature of causality and man’s place in the world. Exploring different ways of knowing—something that a teacher can augment through resources such as Cajete’s (2016) book Native Science: Natural Laws of Independence and Martha Canipe and Sara Tolbert’s (2016) article Many Ways of Knowing—can broaden students’ perspectives on how we come to understand nature.

## Scale, proportion, and quantity

Students are fascinated with orders of magnitude such as powers of 10. Show them the classic Powers of Ten video by Charles and Ray Eames (Appendix A) or the IMAX movie Cosmic Voyage (Appendix A), and you can hear a pin drop. However, studies have shown that when it comes to accurately conceptualizing the size and scale of objects, distance, or time, they are challenged when observing beyond the human or visible scale, either larger or smaller (Tretter, Jones, and Minogue 2006; Dodick and Orion 2003). Although advanced students and experts can flexibly move between temporal and spatial scales when conceptualizing mechanisms, objects, and relationships, most students struggle with such transitions. Fortunately, the Framework and its supporting documents provide a research-supported learning progression for scale, proportion, and quantity. For example, students in grades 9–12 should be able to recognize:

- the importance of scale when investigating phenomena
- that patterns observed at one scale may not be observable at another scale
- that algebraic thinking can facilitate thinking to be used to predict the effect of changing one variable on another variable.

In addition to these elements, students in this grade band should also recognize the need to study a phenomenon indirectly given the size or rate of the phenomena, and they should also be able to accurately use models to demonstrate how a scale varies by orders of magnitude.

Visualizations, models, and algebra are just a few tools to which teachers can turn for scaffolds to develop proficiency in this CCC. In the Earth sciences, the PALEOMAP project (Appendix A) includes renderings of the Earth over geologic time, and by coupling this with HHMI BioInteractive’s EarthViewer (Appendix A), students can investigate changes over longer time scales. Simulations such as those found on the PhET can provide a peek into the very large or very small without the aid of a microscope or telescope (e.g., Acid-Base Solutions; Appendix A). Ratio and proportion apps such as the ones on PhET (Appendix A) provide review or practice for this grade band, after which students can apply their skills to those within the context of new lessons.

The use of physical or conceptual models within a lesson to assist students in developing this lens for viewing the very large or very small is one way to scaffold the development of an understanding of scale. For instance, students who are having difficulty with microscopic scale phenomena could be presented with conceptual models of a phenomenon and then asked to make observations while connecting these observations to the visible scale of the phenomena. This could be effective with some chemical and biological concepts.

An approach to use in the field of ecology is to employ graphs that are models of phenomena, to ensure students have practice with applying these graphs in new contexts. For example, population studies include growth and decay curves that can be applied when studying radioactive decay in chemistry or the Earth sciences. When thinking about deep (geologic or astronomical) time, lessons that incorporate ratios can be used to create visualizations to conceptualize orders of magnitude in time. An example of this is the classic activity where students accurately place Earth’s history on 5 meters of adding machine paper. When possible, these models should remain visible throughout the unit to activate the application of this CCC. Finally, we cannot say enough about the importance of discussions and probing questions to make student thinking visible. For scale, propor-
tion, and quantity, questions related to unpacking the mechanisms behind a large- or small-scale phenomena should extend students’ thinking about whether the same mechanisms are at play at different scales of the phenomena, such as in local or global climate systems.

**Systems and system models**

Our climate is changing, and we must act now to slow or prevent it from happening. Statements like this and about other pervasive issues are part of our everyday experience, and represent a call to action. However, how does one identify solutions for a complex system such as our climate system? Key to identifying solutions for a complex system is to apply a systems-thinking lens, which includes identifying subsystems and the mechanisms that connect components of the system and subsystem, and to be able to conceptualize a systems model to test solutions. The systems and system models crosscutting concept develops proficiency in unraveling the complexity of and within systems, and in applying systems thinking while sensemaking about complex systems such as climate change.

Students and teachers find recognizing the aspects of this CCC to be barriers to using this lens effectively and flexibly. The first step is to create scaffolds, activities, and lessons that foster this type of thinking. For instance, students and teachers new to systems thinking tend to think linearly regarding causality, and they tend to only consider surface features rather than the underlying interconnections and mechanisms within a system (Sweeney 2007). To scaffold this conceptual barrier, developing the use of system models makes what is invisible in complex systems visible, and the act of revising models deepens understanding of those nuances key to the functioning of a system.

For those new to systems and system models as employed in various fields of science, PBS Learning has a collection called System Literacy (Appendix A), which includes videos, lessons, and a short professional development course—all of which provide entry points to systems thinking and terminology. “What is a system?”, a brief video hosted by Linda Booth Sweeney, provides a quick explanation, complete with an analogy that gets at a couple of key characteristics of systems. A resource for consideration to use as scaffolds embedded in lessons are the “Habits of a Systems Thinker” cards (Appendix A) from the Waters Center for Systems Thinking (Appendix A). These two-sided cards present a characteristic of a systems thinker on one side (e.g., identifies the circular nature of complex cause-and-effect relationships), and on the flip side, additional information can be found along with probing questions. Additional systems thinking resources can be found at the Creative Learning Exchange (Appendix A), and resources to support the pedagogical use of models and modeling can be found at the website for the American Modeling Teachers Association (Appendix A). Lessons and interactives that foster systems thinking and modeling can be found on the Concord Consortium High Adventure Science website (Appendix A). For example, in the “What is the future of Earth’s climate?” module, students learn about our climate system over time through a series of systems thinking and modeling activities.

Courses that address complex topics like climate change and ecosystems provide the perfect venues for students to develop proficiency in systems thinking, as well as the use of other CCCs. For example, in an environmental science course, conceptual boundaries are initially applied as students explore topics such as our food system, water quantity and quality, or sustainable living; concepts within these topics are then integrated to provide systems perspectives. Within lessons, teachers assist students by challenging them to zoom in and zoom out of the issues to determine if mechanisms that work at one scale (or subsystem) apply to a larger scale (e.g., local agricultural practices at a global scale).
When studying our food and agricultural systems, students might start with a model of their local food supply. As the unit progresses, they link agricultural practices, inequities in quality food access, and the science supporting the understanding of these embedded topics. Models and model revisions assist students’ understanding of the parts of systems that are too large or too small to see, as well as flows of matter and energy in and out of a system (e.g., biogeochemical cycles). Students make their thinking visible with models and, as the unit progresses, they revise their models to include the mechanisms relevant to the system under study.

Computer models and simulations such as HHMI BioInteractive’s “Understanding Global Change” (Appendix A) assist students as they learn to make the intricate connections among system components. Once the connections are established with the mechanisms connecting the components, students can use their models to make predictions. Systems thinking and modeling tools can be used to explore the complex phenomena associated with COVID, and the British Society for Immunology’s hands-on activities provide opportunities to apply these (Appendix A).

Acquainting students with specific systems thinking/modeling tools, such as connection circles, can provide scaffolds for supporting the use of this CCC. The Creative Learning Exchange website (Appendix A) has sample lessons that integrate the use of such tools. For example, in “Do You Want Fries with That?” students are introduced to the basic features of connection circles, then use this representation to examine whether french fry consumption is correlated with health risks (Appendix A). Similarly, in “Keystone Species in an Ecosystem Using Connection Circles to Tell the Story: The Shape of Change,” students read an article that provides evidence of an ecosystem in peril, and then use a connection circle to diagram subsystems and feedback loops within the ecosystem as a way to unpack cause and effect (Appendix A). These are a few resources supporting the systems and system models CCC within Earth and space science, biology, and environmental science courses. Students making sense of the many complex and invisible natural and human-made phenomena found in physical science courses would also benefit from the routines outlined here.

Energy and matter
As the text beneath the first in a series of energy literacy videos states, “Energy plays a major role in the everyday functions of our planet and all its life forms. From weather patterns and food chains, to human society’s daily electricity and heating needs, energy is the driver of everything we know.” (U.S. DOE, n.d.; Appendix A). The Particle Adventure site (Appendix A) notes that one of the eternal questions asked by humanity is, “Of what is the world made?” Understanding matter—the central pursuit of the field of chemistry (Georgia Public Broadcasting 2021)—is the crucial component of understanding energy. Of course, Einstein’s equation $e = mc^2$ fundamentally connects energy and matter.

The CCC matrix in Appendix G has five elements essential to understanding matter and energy in the 9th–12th grade band. Three of those are linked to the foundational notion of conservation of energy and mass (e.g., “The total amount of energy and matter in closed systems is conserved”) and the other two focus on the cycling of energy and matter within and between systems. Research by Neuman et al. (2013) provides some critical insights as to how a K–12 learning progression related to energy should be structured to ensure attainment of those goals: “Our findings may suggest that within an energy curriculum, initial teaching should focus on developing an understanding of energy with respect to forms and sources first. Then, the concept of transfer and transformation should be covered, before introducing energy dissipation and conservation” (p. 184). Even if the kind of K–12 vertical alignment needed to enact this recommendation schoolwide is not possible, high school teachers can consider designing curricula that match this sequence within their individual courses.

The Energy Literacy Framework (U.S. DOE, n.d.) is a very useful resource to supplement the ideas about energy described in Appendix G. It lays out seven essential principles and concepts, two of which focus on the flow of energy—one related to physical processes and the other to biological processes. Besides the Energy Literacy Framework (ELF) itself (Appendix A), the supporting web page contains a video series, a document aligning the ELF with the NGSS, and an Energy Literacy Principles chart that can be printed for display in a classroom. Another resource that connects the physical and biological processes of the flow of energy and matter is the CarbonTime web curriculum. While this curriculum, focused on the carbon cycle, was designed for use in middle schools, it would be very easy to integrate the units and activities into high school biology and environmental science courses. Further, the CarbonTime curriculum has a dedicated unit on Systems and Scale that could help connect energy and matter to these other two crosscutting concepts.

One of the great challenges of teaching about energy is the concern with how to define it (Saglam-Arslan 2010). The FT Exploring website (Appendix A) provides a description of how to develop a conceptual understanding of what energy is on its page “Energy Changes Make Things Happen.” This focuses on energy as processes of transfer and transformation. Similarly, Crissman et al. (2015) present a framework for exploring energy-related phenomena built around a series of questions that seek to identify observable evidence of change and quantify the indicators associated with that change. Numerous kits offered by the National Education Energy Development (NEED; Appendix A) group provide the phenomena to which this framework could be applied. While both the Crissman et al. article and the NEED kits were designed with use in elementary grades as their targets, it would be facile to adapt the framework and activities for application in high school science classrooms.

Although teaching about matter does not have the same inherent conceptual challenges associated with it that teach-
FOCUSING THE LENS OF THE CROSSCUTTING CONCEPTS ON SECONDARY SCIENCE LEARNING

ing about energy does, there are still concerns to be addressed. Smith et al. (2006) surface a number of these concerns and provide examples of how assessments can be designed to make visible student thinking related to matter, as well as how to ensure that students have achieved adequate understandings of core principles in this area. Additionally, this journal has published several articles that can support meaningful explorations of matter in alignment with the principles of NGSS (e.g., Clift 1998; Kelly 2012; Paolucci 1998; also, LEGO Atoms and Molecules, Appendix A).

Structure and function
Our hands are incredible tools, the thumb a most unusual and yet critical tool that works together with the other digits. Investigations into the importance and significance of our opposable thumbs by completing a series of seemingly simple tasks, then repeated by restraining or restricting the use of the thumb, become the means for teachers to lead students to view the connection between structure and function and how “their interconnections … reveal a system’s function and/or solve a problem” (Framework, Appendix G). The first of the two elements for this CCC in Appendix G of the NGSS describes the need to use an understanding of structure and function in investigating or designing new systems; the second element focuses on how the function and properties of objects and systems can be traced to their underlying structures, including those at the molecular level (thus connecting to the CCC of scale).

We might tend to extend the focus of this CCC to living organisms and the parts or organs that comprise them. However, looking at what makes life possible—the presence of water—and how the structure of the water molecule allows it to hold a number of critical properties, many of which can be investigated and measured through a series of short demonstrations (see Appendix A). By examining these various vital properties, we obtain information that extends more specifically than just “water is life,” but how these different characteristics inform us of the function water has as it moves and exists in the Earth system.

One way to present this CCC in the context of nonliving objects is to focus on a river or stream. Rivers are the connection between land and sea. All rivers, even the smallest streams, have basic common structures, which the stream has either carved out or created through deposition of its own sediment load. These structures are not without function. Although appearing to be passive, floodplains, terraces, natural levees, and cut banks and point bars not only have geologic but ecologic functions. Human interference and attempts to control a river’s structure (and function by proxy) can have significant environmental implications.

While structure and function are linked in the natural world, they exist in the human-designed world as well. A powerful way to link these two worlds, and to help students develop the capacity to envision how structure affects function, is to engage them in exploring the field of biomimicry. Janine Benyus’s (2002) book is a wonderful starting point for informing yourself (as the teacher) or your students about this topic, and her two TED talks (Appendix A) are both engaging and enlightening. There are a couple of captivating web resources—Ask Nature and Biomimicry 3.8 (Appendix A)—that can allow students to investigate the principles underlying biomimicry, as well as to learn how scientists and engineers translate nature’s structures into man-made functions. Learning with Nature (Appendix A) provides free curricula that can be used in various courses—biology, chemistry, physics—to support students in engineering design inspired by nature.

Engineers, especially mechanical engineers, design tools that meet specific needs. How that tool is designed and structured reflects and determines its function. As noted above, one element of this CCC requires students to infer function from structure and how this can inform the design of objects (or systems). Students already familiar with a bicycle can now step back and re-evaluate their understanding of those individual parts (see Bicycle and Helmets, Appendix A) and the reason for their appearance, placement, and positioning. And this can lead to combining a macro and micro perspective by exploring an engineer’s concept of density. This can get students to examine the structural design of a bike as a whole but also investigate the atomic level structure in developing a new bike, perhaps to be used for Olympic or Tour de France racing (NRC 2012). The connection or extension of any activity investigation exists between the macro level visible structure of an object or system as well as that we cannot readily see, but instead view using microscopes or models, such as the cell (Appendix A) or an atom.

One challenge in implementing this CCC may be how different domains of science define and interpret the phrase “structure and function” and the domain-specific definition of the individual words “structure” and “function.” The potential for ambiguity as a student progresses in their science course sequence may be confusing to students (Yoho et al. 2018), given

While structure and function are linked in the natural world, they exist in the human-designed world as well. A powerful way to link these two worlds, and to help students develop the capacity to envision how structure affects function, is to engage them in exploring the field of biomimicry.
how different STEM disciplines and professional societies apply these terms and the “structure and function” phrase.

We suggest explicitly defining and discussing this CCC throughout a science course, something that is even more critical in a multi-discipline or integrated course (like Earth science, which comprises geology, meteorology, and astronomy). Another challenge may be in moving from qualitative descriptions of structure and function to quantitative ones; D’Arcy Wentworth Thompson, in his classic book *On Growth and Form* (1992) noted the importance of this: “For the harmony of the world is made manifest in Form and Number, and the heart and soul and all the poetry of Natural Philosophy are embodied in the concept of mathematical beauty.” (pp. 1096–1097). Activities like physically modeling muscles (Goodwyn and Salm 2007) or computationally modeling proteins (Hunter 2015) can support this transition.

Stability and change

The natural world is filled with examples of stability and change. We observe the Moon changing its position in the sky every night—the change. And yet, the Moon follows the same orbit around the Earth month after month, year after year—the stability. We note generations of a species’ traits appear to remain the same, but over thousands of such generations, micromutations allow for them to evolve and change. The domain of chemistry provides us with the consistency of atomic structure and elements—element number 1 is always hydrogen, number 6 is always carbon. Yet, the Chinese word for chemistry, Huàxué, means the study of change (Wiktionary 2019); atoms and molecules reacting, dissolving, decaying drive change.

One of the CCC elements for this level is for students to recognize and explain how components of the natural (and human-made) world change and remain stable. Doing this may entail thinking over different temporal and spatial scales. We can question why certain natural systems remain stable, and what forces this same system to change. Is the stability and change occurring on a micro or macro scale, or is one happening at one level and the other at a different scale? And how are these two constructs connected? Even with a number of variables to consider, “An understanding of dynamic equilibrium is crucial to understanding the major issues in any complex system.” (Framework, Appendix G).

Framing lessons around stability and change can be achieved with phenomena such as the layers of the sedimentary rock or igneous rocks coupled with mineral deposits found in your home state that formed in past geologic eras. Rocks and minerals had to form under certain conditions, and these conditions are drastically different than present-day environments and climate—the long-term change. Immersive virtual trips into the Grand Canyon can provide you the connection to this CCC if you are less familiar with local geology (Appendix A). Touring the layers of the canyon offers the perspective of a seemingly stable, ageless wonder, yet the canyon’s formation, and the rock layers that make up the walls of the canyon span well over one billion years. This may seem to fall into the realm of stability, but the environments and conditions that formed those canyon rocks are the change, and these are clearly etched in the rocks you can see in the virtual tours. The Earth Viewer (see Resources) also allows for exploration of Earth land masses and biodiversity over time and space, by allowing students to see changes from different locations and perspectives.

But the changes in this CCC can be shorter time spans—human lives. An excellent resource to demonstrate this is the Images of Changes and Climate Time Machine (Appendix A). The scope of the pictures and simulations, often paired before and after, and allowing the user to visualize the changes in sea ice, sea temperatures, etc., over such short time frames also enables teachers to focus on the parameter or location of their choosing. This resource allows teachers and students to address the CCC element of not only the stability and change, but even to quantify the rate of change. Students are able to measure and describe both quantitatively and qualitatively the rate and magnitude different regions of the Earth have changed, as well as make predictions about the extent of such change into the future. This evidence is the springboard for students providing potential reasons that have influenced such change, and the impact the change may have on different ecosystems, the atmosphere, and landforms within the region.

Conclusion

The core principle underlying the *Next Generation Science Standards* is three-dimensional teaching and learning, with the three dimensions being the DCIs, SEPs, and CCCs. It would be easy for the CCCs to become the forgotten thread in the tapestry of 3D teaching and learning because the DCIs are connected to the process and inquiry skills with which science teachers are familiar (albeit different from them; see Bybee 2011). In this article, we have tried to make the case for giving the CCCs the full and explicit attention they deserve as a way to support students in using them as intellectual tools for making sense of phenomena. More importantly, we have provided some specific focal points for teaching in that way, as well as examples of activities and a plethora of resources for putting our suggestions into practice. We hope this helps teachers focus the lens of the CCCs.

ONLINE CONNECTIONS
