Appendix B. NGSS: Applying Crosscutting Concepts in Outdoor Science

The *Fra*mework for K-12 Science Education (See free PDF download at http://www.nap.edu/catalog.php?record_id=13165) is a progressive vision for science education produced by top scientists and educators appointed by the National Research Council, which served as the basis for developing the Next Generation Science Standards (NGSS). It represents the most current, research-based ideas about how to teach science. At its core are the following guiding principles: (1) children are born investigators and have the capacity to reason in sophisticated ways, (2) focusing on core ideas and practices helps build a more wide-ranging understanding of science, (3) deep understanding develops over time and through making connections, (4) science learning involves both knowledge and practice, (5) connecting to student interests and experience helps to sustain their curiosity and wonder, and (6) all students should have opportunities to learn about and engage in science.

The *Framework* describes three dimensions that make up the how and what in science to be taught by the end of high school: (1) Science and Engineering Practices, (2) Crosscutting Concepts, and (3) Disciplinary Core Ideas. These dimensions should be woven together while teaching, so students can develop a more coherent understanding of science that reflects its interconnections in the real world. The *Framework* as a whole is quite educative and thoughtfully written—definitely worth reading and revisiting as instructors are exploring new ways of teaching science.

Crosscutting Concepts

Crosscutting concepts are "big ideas" that are applicable to and can be used as thinking tools across disciplines. For example, the idea that an object's structure is directly related to its function is true in the natural and human-designed world, for structures at the cellular level, and all the way up to the largest living and nonliving things in the universe. It is an idea used by engineers in the design process, biologists when thinking about how structures help organisms survive, and all other disciplines of science.

Outdoor science programs are well-situated to help students apply Crosscutting Concepts in meaningful ways. In the field, students have sustained contact with different aspects of nature, and can use these "big ideas" over time to deepen their understanding of key ideas and different aspects of nature.

Since the advantage of using Crosscutting Concepts is applying useful thinking tools across disciplines, it is especially important that students use them more than once, and in multiple kinds of situations (ideally, a couple times in the course of one activity, and in subsequent activities related to different topics). In addition to using Crosscutting Concepts while you are exploring nature, look for short opportunities for students to apply the "big idea" in a different context (e.g., after Structure and Function focused activities, have students look at a building, make observations about some structure like the shape or texture of the roof, or placement of windows, then discuss how that functions).

In addition to *using* the Crosscutting Concept, it's also important for students to recognize and value Crosscutting Concepts as thinking tools. Students should reflect on how using Crosscutting Concepts help them deepen their thinking. Point out to students when they use a Crosscutting Concept during an activity or while they are exploring nature. Ask them how it changed their thinking, and how they might apply it in another situation. Ultimately, a goal of science learning is that students begin to use Crosscutting Concepts without being prompted by an instructor.

As part of the Next Generation Science Standards, students will be asked to apply Crosscutting Concepts throughout the duration of their schooling and science education, so we recommend focusing on one or two particularly useful Crosscutting Concepts that can be used in outdoor learning experiences. The Crosscutting Concepts of Patterns, Cause and Effect, and Structure and Function are well suited to use in outdoor settings. A useful approach is to organize an entire day's "hike" or a sequence of activities around one Crosscutting Concept (see BEETLES Theme Hikes for an example of what this can look like).

This document focuses on how field instructors can use these Crosscutting Concepts to deepen students' thinking during outdoor science experiences. Each Crosscutting Concept includes a brief description, and examples of how it might be applied during field instruction, as well as in specific BEETLES activities. Use this handout to jump-start your thinking on how to incorporate them into your teaching.

	Description of Crosscutting Concept & Student Abilities	Field Examples & Teaching Notes
1. Patterns	Patterns can be found everywhere and noticing patterns can lead to interesting questions about how and why they occur. This is an important lens for scientific investigations—and often how an investigation of a process or phenomena begins. Once you've identified a pattern, it often leads you to thinking about Cause and Effect, so that you can explain what is causing the pattern. *Abilities we can help students develop in outdoor science:* • Recognize and observe patterns in nature. • Identify similarities and differences between objects and parts of nature. • Observe patterns and develop questions based on observations. • Use patterns to identify possible cause and effect relationships. Useful Questions (excerpted from CrossCutSymbols website © 2013 Peter A'Hearn/CrossCutSymbols) • What is the evidence for this pattern? • Do similarities and differences reveal a pattern? • Is this pattern real or imagined? (People sometimes see patterns where there isn't one.) • What predictions can I make based on this pattern? Can I test them? • Is there a cause for this pattern? • How does this pattern compare to other patterns I have learned about?	*General Approach:* Prompt students to notice patterns wherever you take them and whatever they are studying. For example, students might be exploring a grassy hillside and notice a pattern to where the grass grows and where it doesn't; or when catching macroinvertebrates in a stream you might notice a pattern in their coloration, with many of them being brown. You might notice a pattern of streamlined shapes of underwater organisms. *Specific BEETLES activities:* In *I Notice, I Wonder, It Reminds Me Of,* students practice their observation skills and look for patterns in what they observe. In *Lichen Exploration,* students look for patterns of lichen growth, then think about what factors might have caused the patterns they observed. In *Bird Language Exploration,* students listen to different types of bird calls, group them based on similarities, and discuss what each call might mean. In *Spider Investigation,* students look for patterns in the kinds of webs that grow in different plant communities.

Note: *Patterns* is one of the Crosscutting Concepts BEETLES has identified as being particularly suited to outdoor science learning situations.

Many essential scientific thinking processes begin with identifying patterns, including grouping organisms or other parts of nature based on common features, generating questions about why patterns occur. The outdoors are a great place for students to develop the skill of looking for patterns, and an inherently intriguing place for them to start to explain possible causes behind what they observe. A focus on patterns is also a natural lead in to thinking about cause and effect, and noticing patterns of where organisms occur, shapes of rocks in different stream beds, or the occurrence of herbivory in certain areas, reveals underlying processes that relate to many of the key ideas taught at outdoor schools.

	Description of Crosscutting Concept & Student Abilities	Field Examples & Teaching Notes
2. Cause and Effect	When scientists make explanations for how or why something happens, they are thinking about the connection between cause and effect. Much of what we can observe of the natural world are the "effects" of many potential "causes." Understanding cause and effect relationships leads to a deeper understanding of the world, which is helpful in making predictions and scientific explanations about what might happen as a result of similar conditions in the future. *Abilities we can help students develop in outdoor science:* • Observe and identify cause and effect relationships. • Try to figure out and explain what caused observable things in nature. • Discuss possible effects of different actions or events. • Make predictions about possible effects of different actions or events in the environment. • Distinguish between causation and correlation. Useful Questions (excerpted from CrossCutSymbols website © 2013 Peter A'Hearn/CrossCutSymbols) • What evidence is there for a cause and effect relationship? • How can this cause and effect relationship be tested? • What are other possible causes? • Is there more than one cause? • Is the cause and effect relationship real or imagined? • How is this cause and effect relationship similar to and different than others I have learned about?	*General Approach:* When students notice patterns, or intriguing "nature mysteries," ask them to generate possible explanations for what might have caused what they're looking at. Or prompt students to make predictions about what might happen in the future based on what they're observing in the moment. For example, you might ask questions like: What might be causing those holes? How did these bones end up here? What might be causing the trees to be dying around here? What might be effects on the ecosystem if the foxes in this area died off? What might be effects to this stream if we planted more trees along the edges? *Specific BEETLES activities:* In *Bark Beetle Exploration,* students notice features of bark beetle galleries and make explanations about what beetle behaviors might have caused each feature. Later, they predict possible effects of different management strategies of bark beetle outbreaks. In *Case of the Disappearing Log,* students look for evidence of how a log might be changing, then think about what things might have caused the features (effects) they observe. In *NSI: Nature Scene Investigators,* students observe features of a "mystery object" and come up with possible explanations for what might have caused them.

Note: *Cause and Effect* is one of the Crosscutting Concepts BEETLES has identified as being particularly suited to outdoor science learning situations.

Looking at cause and effect relationships is one of the main goals of science. It's also incredibly easy to do outdoors, since almost anything students lay eyes on (rocks in a certain area, patterns of mud after a rainstorm, the shape of a stream bank, holes in leaves, weathering patterns, tracks, etc.) is essentially an "effect" of one (or more likely, many) causes. Helping students to look at nature as a collection of mysteries to be explored can help them to apply this Crosscutting Concept. It is also applicable in many topics that are common focuses of outdoor science schools, such as interdependent relationships in ecosystems. Cause and Effect is also useful in building environmental literacy, since it pertains to predicting possible effects on systems if conditions change, which is a thinking process essential to creating management strategies.

	Description of Crosscutting Concept & Student Abilities	Field Examples & Teaching Notes
3. Structure and Function	The idea that Structure and Function complement each other is a useful tool for explaining things in science. In the designed world and in any natural system, the shape and material of a structure is related to what it does, and vice versa. Students might observe an organism's structures, and make possible explanations for how each one helps the organism survive in a specific environment. In other words, students look at structures and think about how they might function. *Abilities we can help students develop in outdoor science:* • Observe structures of animals, plants, nonliving things, and human-made objects in detail. • Think about how the specific characteristics of a structure help it to function. Useful Questions (excerpted from CrossCutSymbols website © 2013 Peter A'Hearn/CrossCutSymbols) • How does the function depend on the structure? • How does the structure support the function? • Are there other structures that can serve the same function? • How does this relationship between structure and function compare to others that I have learned about?	*General Approach:* As students observe organisms, prompt them to focus on its structures, and discuss how those structures might function in the context of living in the environment. For example, if students spot a deer, ask them, "What are some specific characteristics of the deer's structures? What specific things can we say about the color, texture, shape, etc. of its different body parts? How might those help it to survive in its habitat?" *Specific BEETLES activities:* In *Discovery Swap*, students consider an environment where organisms live and discuss what kinds of structures might function to help an organism survive there. Later, they observe organisms' structures and make possible explanations for how the structures function. In *Structures and Behaviors,* students catch organisms, observe their structures, and think about how the structures might function. In *Adaptation Intro- Live!,* students observe an organism, and think about whether its structures and behaviors are adaptations or not. In *Blend In, Stand Out,* students observe the colors and patterns of organisms, and think about how those characteristics function to help the organism blend in to or stand out from its surroundings.

Note: *Structure and Function* is one of the Crosscutting Concepts BEETLES has identified as being particularly suited to outdoor science learning situations.
A critical aspect of figuring out how structures function is seeing them in context, so the outdoors are an ideal location for students to study organisms' structures and think about how those structures function to help organisms survive. Seeing a deer, fish, or other organism in its habitat leads students to think more accurately about how its structures specifically function in its environment, and is an opportunity that's not usually available in most classrooms.
Focusing on this Crosscutting Concept can be a way to build foundational understanding for more complex content, like Adaptations and Natural Selection.

	Description of Crosscutting Concept & Student Abilities	Field Examples & Teaching Notes
4. Energy and Matter	Tracking the transfer of matter and energy into, out of, and within a system enables scientists to learn about the relationship between the various elements that make up and drive all kinds of systems. For example, thinking about how matter moves through a system can help students gain a deeper understanding of relationships between living and nonliving parts of an ecosystem. *Abilities we can help students develop at outdoor science school:* • Track the cycling of matter among living and nonliving parts of an ecosystem. • Explain how matter is never destroyed even when it seems to disappear, and help students to see examples of this in their surroundings. • Specifically, help students recognize how matter cycles between forms that are visible (e.g., a log) and invisible (e.g., carbon dioxide gas). • Discuss how energy flows among living and nonliving parts of an ecosystem. Useful Questions (excerpted from CrossCutSymbols website © 2013 Peter A'Hearn/CrossCutSymbols) • How are energy and matter related in this system? • Where does the energy for this system come from? Where does it go? • How does matter in this system change? How does it enter and exit the system? • Is the role of energy and matter in this system similar to other systems I have learned about? How is it different?	*General Approach:* When students discuss relationships between various living and/or non-living parts of an ecosystem or observe evidence of an interaction between parts, prompt them to think about how matter or energy is transferred via those relationships and interactions. For example, if students find scat on the trail, ask them, "Where did the matter that makes up this scat come from?" Challenge them to trace the matter back to the food of the animal who's scat it is, or even farther, to think about where the matter that makes up that food might have come from. Also ask them, "What might happen to the matter that makes up the scat over time? Where will it go?" *Specific BEETLES activities:* In *Food, Build, Do, Waste,* students trace matter as it cycles through organisms, and think about the flow of energy between the organism and other parts of the ecosystem. In *Case of the Disappearing Log,* students think about where the matter in a decomposing log is now. In *Decomposition Mission,* students observe decomposition, think about it as a process, and discuss how matter cycles within an ecosystem.

	Description of Crosscutting Concept & Student Abilities	Field Examples & Teaching Notes
5. Systems and Systems Models	The world is complex! Using a system model provides a simpler, more contained unit of study (e.g., discussing just the organisms and features of one ecosystem, as opposed to thinking about every single ecosystem on the planet). Defining the artificial boundaries of a system and studying the interactions between parts of the system, as well as the flows into and out of the system, can help scientists understand and make predictions about how changes to one part of a system may affect other parts of the system, the system's overall processes, or other systems. *Abilities we can help students develop at outdoor science school:* • Describe a system in terms of its components and their interactions. • Understand a system is a group of related parts that make up a whole. • Define the boundaries of a system. • Identify flows into and out of a system. • Predict how changes to one part of a system will affect another part of the system. Useful Questions (excerpted and adapted from CrossCutSymbols website © 2013 Peter A'Hearn/CrossCutSymbols) • What are the boundaries of this system? • What other systems affect this system? How? • What parts make up this system? How do they interact? • What are the advantages to thinking about this as a system? • In what ways is this system like others I have learned about? How is it different?	*General Approach:* As students investigate organisms, prompt them to define the boundaries of the system in which the organisms live, identify parts of the system, and think about how the organisms they are focused on interact with the other parts of the system. Challenge older students to identify systems at different scales, and to identfy flows into and out of the system. For example, if students are observing macroinvertebrates from a pond, ask them to identify other living and nonliving parts of the pond ecosystem, and to discuss how those parts interact with the invertebrates. For a challenge, ask them, "How are things outside of the pond system affecting the pond? How is the pond system affecting things outside of it? If we thought of the pond as one part of a bigger system of interacting parts, what are other parts of that system?" *Specific BEETLES activities:* In *Discovery Swap*, students could define the area they are looking at as a system, identify the boundaries of the system, label its parts, and describe the interactions between the parts of the system. In *Interview an Organism*, students identify living and nonliving parts of the system in which an organism they are observing lives. They think about how their organism interacts with those parts of the system and how it would be impacted if various parts of the system changed. In *What Lives Here,* students make an interaction web based on organisms they have found in an area, then use those webs to make predictions about what might happen if certain conditions (like the presence of certain living or nonliving factors) changed).

	Description of Crosscutting Concept & Student Abilities	Field Examples & Teaching Notes
6. Stability and Change	If scientists understand how stable a system (or organism, or object) is, when it will change, and what causes it to change, they can make predictions about cause and effect relationships in nature. The lens of stability and change can also be an important tool for understanding flows of matter and energy into, out of, and within a system. Some systems may seem stable at one scale but may be changing at another scale (e.g., the bank of a river that seems stable at shorter timescales, but erodes noticeably over longer timescales; a log that seems stable at one scale but shows evidence of decomposition when you zoom in to a smaller scale). When you prompt students to think about stability and change, make sure you are asking them to focus on observing things at a scale at which you can actually observe changes, and/or encourage them to extrapolate what changes might happen over a longer period of time. *Abilities we can help students develop at outdoor science school:* • Understand what causes stability and change within a natural system they are observing. • Ask questions about what causes a system to change. • Look for evidence of change within a system, and think about the rate of change. • Understand how one change may lead to another within systems. Useful Questions (excerpted and adapted from CrossCutSymbols website © 2013 Peter A'Hearn/CrossCutSymbols) • What causes change in this system? • What causes stability in this system? • Are there feedbacks that make this system more or less stable? • If the system is stable, how long is this system likely to remain stable? • If the system is stable, what would cause it to change? • If the system is changing, what would make it become stable? • How does stability and change in this system compare with other systems I have learned about?	*General Approach:* As students explore and investigate cause and effect relationships or evidence of changes in an ecosystem, prompt them to think about the factors that may affect the stability of the system (or object) they are investigating. Encourage them to make predictions about the changes that might occur at different timescales. For example, if students are discussing a decomposing log, ask them to find evidence that the log is changing. Prompt them to think about how much the log might change over an hour, a day, a month, or a year. Challenge students to consider whether the decomposition of the log may cause changes to their parts of the ecosystem. *Specific BEETLES activities:* In *Fire Discussion*, students seek to understand the how the stability of a forest ecosystem is impacted by wildfires, and would be affected by different fire management strategies. In *Bark Beetle Exploration*, students seek to understand how the stability of a forest ecosystem is impacted by bark beetle outbreaks, and would be affected by different environmental management strategies. In *Stream Mysteries,* students observe a stream, learn about how currents and streams work, then think about what the stream might have looked like in the past, and make predictions about how it will change in the future.

	Description of Crosscutting Concept & Student Abilities	Field Examples & Teaching Notes
7. Scale, Proportion, and Quantity	Scientists rely on a foundational understanding of scale, proportion, and quantity when they make observations about nature. Understanding and attending to scale is a crucial step towards making sense of any system's process and any structure's function. In outdoor science contexts, this Crosscutting Concept is especially applicable when looking at the night sky, and thinking about the relative sizes and scales of different observable objects. *Abilities we can help students develop at outdoor science school:* • Observe the scale of objects and phenomena in nature. • Compare the relative scale of different objects and phenomena in nature. • Use standard units to make measurements of objects and phenomena in nature. Useful Questions (excerpted and adapted from CrossCutSymbols website © 2013 Peter A'Hearn/CrossCutSymbols) • How does this interaction affect the global scale? • How does this system look at a smaller and larger scales? • What is new and what is the same? • How does this scale relate to you? How much bigger or smaller is it than what you are used to experiencing? • How can we study nature at this scale? • How can we accurately measure this at this scale?	*General Approach:* When students observe objects or phenomena in nature, guide them to pay attention to scale of the things they are observing. Encourage them to think about what the scale of an object can tell them about possible structure-function relationships, and what the scale of an object or event can reveal about cause and effect relationships. For example, you might ask questions like: How many? How long? How tall? How fast? How big? Which environment had more ______ and why do you think so? What does the size of this structure tell you about its function? What do you think happened first and how do you know? *Specific BEETLES activities:* In *How Big and How Far*, students measure how tall a student looks when observed from different distances to realize that perspective affects how large objects seem. They apply this idea of relative size to understand the scale of objects in the night sky. In *Night Sky Scavenger Hunt*, students think about the mind-boggling scales of objects in the night sky. They discuss the relative sizes of and distances to various objects. In *Spider Investigation*, students collect data on and compare the number of spider webs in two different plant communities.