TEACHING SCIENCE PRACTICES IN OUTDOOR SCIENCE SCHOOLS

A Framework for K–12 Science Education

(See free PDF download at http://www.nap.edu/catalog.php?record_id=13165)

The *Framework* 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) core ideas. The idea is that 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.

This handout focuses on how field instructors can use the science and engineering practices to deepen student understanding and interest in science. Because of the extensive opportunities available in outdoor science school for engaging students in exploring and investigating the natural world and answering their own questions, these programs can play an important role in achieving the vision of the *Framework*. The following pages contain interpretations of how the science practices relate to teaching in outdoor science schools. Skills specific to engineering are not included here, but they can also have great value for teaching about solving environmental issues or in habitat restoration projects. Each practice has a description of the practice and the relevant student skills that can be used in the context of doing outdoor science. Additional suggestions for how each practice might look during field instruction, as well as for using specific BEETLES activities, are provided as appropriate. Use this handout to access simplified descriptions of the practices as viewed through an outdoor science lens, and to think about ways to incorporate them into your teaching. As shown here, the practices of science are deep and challenging, yet can be one of the most rewarding approaches for engaging students.

Note that mastery and deep understanding of the practices are intended to fully develop over the length of a student's K–12 education—so don't be concerned about teaching all of them during a short field program! Some practices may also be better suited to classroom science teaching, which is why it makes sense to choose one or two to concentrate on and dig deeply into with students. In general, the practices of Asking Questions, Constructing Explanations, and Engaging in Argument from Evidence are particularly well-suited for outdoor inquiry. The natural world is rich with a wide variety of phenomena for students to wonder about, try to figure out, and to discuss and compare ideas. Programs with significant time dedicated to outdoor investigations can also focus on helping students Plan and Carry Out Investigations.

To begin to address *NGSS* in outdoor science school, regardless of the topic, make sure students are engaged in practices, exploring science ideas, and ***figuring things out*** during science instruction.

> *"In order to be fully engaged in the practices, it's simply not enough to merely learn about the science idea, however creative and hands-on the task may be. To engage in the practices, really participate in them, a student has to frame the task as an exploration. The intellectual work of the classroom has to be centered on figuring out how or why something happens."*
>
> — Cynthia Passmore, UC Davis School of Education

The *Framework* suggests students should be engaged in certain science practices as they learn core ideas and crosscutting concepts. Use these ideas to inform your decisions of which specific practices to engage students in when they're studying various aspects of the natural world. The goal is to try to set up learning opportunities in which students are using science practices to engage with big ideas and concepts while exploring the natural world.

	Description of Practice & Student Abilities	Field Examples & Teaching Notes
1. Ask Questions and Define Problems	Questions are the engine that drives science and engineering. The outdoor environment is rich with mysteries for students to wonder and ask scientific questions about. Outdoor science instructors can address questioning in rich ways by directly engaging students with interesting aspects of nature, giving students an inquiry mindset and skills, providing lots of opportunities for discussion of science ideas, and coaching students in how to participate in productive discussions. For students, coming up with an interesting and testable question is often the hardest part of planning an investigation. Practice in generating and identifying testable questions is valuable, even if they don't actually investigate the questions further. *Question-asking abilities we can help students develop at outdoor science school:* • Asking questions about the natural world; *e.g., What do bees do?* • Distinguishing scientific questions; *e.g., What is causing this log to decompose?* from non-scientific questions; *e.g., Which is cutest?.* • Asking and refining questions that are testable, and can be answered through observations and investigations, *e.g., Which type of tree does this fungus grow on?* • Asking questions about each other's observations, explanations, reasoning, and data interpretation, *e.g., "What's your evidence for that explanation?"*	*General approach:* Find cool stuff, have students ask questions about it, recognize which questions are scientific, try to refine some questions to be testable, and question each other during discussion of science ideas. *Specific BEETLES activities:* During *I Notice, I Wonder, It Reminds Me Of,* students learn to generate lots of different kinds of questions about something in nature, then discuss which questions are scientific. During *NSI: Nature Scene Investigators*, students ask questions about intriguing evidence found in the field, attempt to answer some through observations, and learn to question one another about observations and explanations. In *Interviewing an Organism* students focus on asking questions that can be answered through deeper observations of the organism. In *Discovery Swap* students observe an organism, come up with questions, record them in their journals, and discuss possible explanations for their questions. They share observations and ask each other questions to get to deeper understandings. In *Exploratory Investigation*, students write down questions about the chosen topic, discuss which are immediately testable, and which are not under the conditions of the field experience, attempt to investigate one of their questions, then discuss findings and how the investigation could be improved.

	Description of Practice & Student Abilities	Field Examples & Teaching Notes
2. Develop and Use Models	Models are used as tools in science to represent ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. All models are inaccurate in some way(s), otherwise they'd be the "real thing." Modeling tools are used to: develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and make it possible to go beyond the observable and imagine a world not yet seen. *Modeling abilities that we can help students develop at outdoor science school:* • Making drawings or diagrams to represent events or systems. • Using a drawing/model as the basis of an explanation, or to make predictions. • Using different types of models to represent phenomena. • Discussing the limitations of models and suggesting ways they could be made more accurate.	*General Approach:* Food webs, food chains, nutrient cycles, and food/energy pyramids are all different models that can be used to explain some aspect of ecosystems that can't be directly experienced. For example: Use a food web to predict what might happen to the ecosystem if wolves were re-introduced, or use both a food web and a nutrient cycle to represent interactions that occur in an ecosystem. Whenever students are exposed to any kind of model, they should be encouraged to come up with things that are inaccurate about the model, and ways the model might be made more accurate. NOTE: If you have students play a predator-prey game, that doesn't necessarily mean that they're doing modeling. Some outdoor science simulation games might be considered models, but only if they are used to make predictions, or if they are used by students to make explanations. It's also important that the model is evaluated for both its accuracies and inaccuracies. *Specific BEETLES activities:* In the *Moon Balls* activity, students use a model of the Sun, Earth, and Moon to explain (and test their explanations for) the phases of the Moon. In the activity, *Food, Build, Do, Waste*, students make a chart that is a model of the inputs and outputs in the system of a living organism.

	Description of Practice & Student Abilities	Field Examples & Teaching Notes
3. Planning and Carrying Out Investigations	There are many ways to conduct investigations in science—not just one scientific method. Scientists investigate and observe the world with essentially two goals in mind: (1) to systematically describe the world and (2) to develop and test explanations of how the world works. The first goal is accomplished through systematic observations, where a scientist makes a plan, decides on the conditions, follows the plan, then carefully observes and records what happens over time. These investigations often lead to questions that can be explained through experimentation. In an experiment, a scientist makes a comparison between two situations, keeping all conditions the same except one (i.e., the variable). Because variables are often hard to control outdoors, field investigations tend to be long-term, systematic observations. Scientists often begin by conducting several shorter exploratory investigations where the main goal is to figure out how to refine the question and investigation methods. *Investigation abilities we can help students develop at outdoor science school:* • Coming up with questions that can be tested/investigated during the field experience. Ideally, these should come from students' interests and ideas. • Deciding what data should be collected, what tools are needed, and how data should be recorded. • Deciding how much data is needed to be reliable. • Planning field-research procedures, identifying variables and controls (when appropriate). • Discussing flaws in investigations, and how they might be improved.	*General Approach:* During a brief experience at outdoor science school, students can't usually develop and conduct extensive, or even fully reliable science field investigations. But it can be possible to engage students in authentic "exploratory investigations" in which students come up with a scientific question, do some preliminary observations, discuss how their understanding changed as a result, and think about how to improve the investigation. For example, after exploring lichen, bark beetles, or another aspect of nature, students can come up with a question based on patterns they observed. Students then engage in a "quick and dirty" investigation, by briefly observing and collecting some data (e.g., *Let's count how many holes are in this area, and how many of them have spider webs in them*). If there's more time available, students can do more extensive and careful studies that occur over several days. *Specific BEETLES activities:* In *Exploratory Investigation*, students come up with testable questions, plan an "exploratory investigation" to answer one question, carry out the exploratory investigation, discuss how the investigation could be improved if it were to be done again, then come up with tentative explanations for their results. For example, students might engage in a stream study by designing and conducting an investigation to find out if there are more macroinvertebrates in slow-moving or fast-moving water. Or students could engage in a habitat study through designing and conducting an investigation to answer if there are more animals in riparian or conifer communities. In *Spider Investigation*, students discuss the parameters of carrying out a fair test to find out whether there are more spider webs located in one area as compared to another.

	Description of Practice & Student Abilities	Field Examples & Teaching Notes
4. Analyzing and Interpreting Data	Scientific investigations produce data that must be analyzed in order to make sense of it. Because data patterns and trends are not always obvious, scientists use various tools, such as graphing, to identify significant features and patterns in the data. Scientists look for what may have caused errors in investigations, and calculate the degree of certainty in the results. Certain kinds of field surveys lend themselves to collecting this type of quantifiable data; e.g., species counts, measuring of environmental factors such as temperature, water pH, stream flow, etc. *Data analyzing & interpreting abilities we can help students develop at outdoor science school:* • Recognizing the need for collecting data and sharing with others. • Analyzing data, looking for patterns, or examining data to see if it supports a previous explanation. • Recognizing surprises, when data is in conflict with expectations, and using this as an opportunity to adjust explanations based on results. • Summarizing data using charts, graphs, tables, etc. • Recognizing patterns in data that suggest relationships worth investigating further. • Distinguishing between causal and correlational relationships in nature *(e.g., The size and shape of the holes found in the tree are evidence that they were caused by boring beetles. However, the turkey vulture numbers increasing in the same year that the local team wins the World Series is correlational, not causal).*	*General Approach:* An instructor can share data collected previously and ask students if they notice trends or patterns that differ from the data they collected themselves. After collecting data in the field, ask students to create a visual representation that indicates what they learned from the data. For example, students can use data collected during a stream study to create charts and graphs to visually display their data and make interpretations and explanations. *Specific BEETLES activities:* In *Exploratory Investigation*, students try to make sense of the results of their investigations. Students use a stem plot graph to analyze the data collected during the *Spider Investigation* activity, and try to explain any patterns they identify.

	Description of Practice & Student Abilities	Field Examples & Teaching Notes
5. Use mathematics and Computational Thinking	In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks, such as: constructing simulations; solving equations; and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches can enable scientists and engineers to predict the behavior of systems and test the validity of such predictions. *Mathematics and computational thinking abilities we can help students develop at outdoor science school:* • Using grade-level-appropriate mathematics and statistics in making calculations and analyzing data.	*General Approach:* Have students collect, calculate, and summarize quantitative data. For example, students can use data collected during a stream study to calculate the average number of macro-invertebrates found at each study site, the diversity (i.e., number of different species) of macro-invertebrates found, and the speed of the water flow at each study site. Or, after a rain, students can count the number of earthworms in a square meter of soil on a large field, measure the field, then multiply to estimate the total number of individuals present. Students can use a formula to calculate the approximate deer population in an area based on the quantity of deer scat.

	Description of Practice & Student Abilities	Field Examples & Teaching Notes
6. Construct Explanations and Design Solutions	The overall goal of science is to attempt to explain the mysteries around us and develop the best explanations based on all available evidence. In science, an explanation is a non-fiction, evidence-based story about how or why something in the natural world appears or happens. Scientific explanations must connect data (which can include observations) or phenomena with accepted scientific knowledge; *e.g., an explanation that claims leaves come from animals contradicts an understood, undisputed fact in the natural world.* Students enjoy coming up with explanations for things they wonder about in nature, and this can be a powerful way for them to interact and develop a relationship with the natural world. The overall goal for students is to construct logically coherent explanations of phenomena that incorporate their current understandings of science, and are consistent with the available evidence. *Explanation-making abilities we can help students develop at outdoor science school:* • Developing an inquiry lens and mindset, which they can use to explore and engage with nature in various settings. • Coming up with evidence-based explanations for things they observe and wonder about in nature. • Using what is known about accepted scientific knowledge in making explanations. • Linking explanations to evidence and models; i.e., food webs or nutrient cycles. • Using evidence (either directly observed or secondhand, i.e., something they've read) to support or refute explanations. • Developing explanations for what may have caused something to happen. • Identifying gaps or weaknesses in explanations (i.e., in their own explanations, or those of others).	*General Approach:* Encourage the overall practice of students finding interesting "mysterious" things in nature, thinking of questions about them, coming up with possible explanations, and discussing strengths and weaknesses of their explanations, based on evidence. *Specific BEETLES activities:* During *NSI: Nature Scene Investigations*, the instructor coaches students on how to develop and politely discuss reasonable evidence-based explanations to explain their observations. They compare their ideas to those of others and weigh their strengths. They also evaluate the strength of the sources of secondhand information. In *The Case of the Disappearing Log*, students make observations about a decomposing log, use a key to identify evidence of different organisms, read about the organisms on information cards, and come up with explanations for what is happening to the log, discussing the strengths and weaknesses of each explanation. In *Tracking*, students consider the size of the assumption (the conceptual leap) they are making when creating an explanation based on their evidence.

	Description of Practice & Student Abilities	Field Examples & Teaching Notes
7. Engage in Argument from Evidence	Scientific argumentation is a crucial part of how science knowledge is generated. A scientist proposes an argument that explains something about the natural world, then, along with other scientists, attempts to identify its weaknesses and limitations. Argumentation is based on the notion that science is a collaborative endeavor, and "group-think" and critique leads to more accurate explanations. Scientists also use argumentation to debate and decide issues about things like the best investigation design, and how to make sense out of data. Discussion of ideas is a crucial part of learning for students, so giving them the opportunity to engage in argumentation not only represents the nature of science accurately—it's also a great way for students to learn together. *Argumentation abilities we can help students develop at outdoor science school:* • Becoming curious about mysteries in the natural world, and attempting to explain them. • Listening to the ideas of others and keeping an open mind. • Coming up with evidence-based explanations and sharing them with others. • Comparing the strengths and weaknesses of different explanations. • Politely disagreeing using evidence and reasoning. • Distinguishing evidence from opinion. • Using reasoning and evidence to identify possible weaknesses in scientific arguments (appropriate to the students' level of knowledge). • Identifying flaws in their own arguments and improving them based on critique from others. • Constructing a scientific argument/explanation and explaining how evidence supports the claim. • Recognizing that a scientific argument includes a claim, evidence, and reasoning.	*General Approach:* When students are coming up with explanations based on evidence to explain mysterious things in nature, and when they are comparing and discussing the merits of different explanations, they are engaged in scientific argumentation. This approach can be cultivated throughout any field experience. For example, during a hike, students may come across a pile of bones. Students disagree about which animal the bones are from, and they can use features of the bones as evidence to try to convince one another. Or, students may observe feathers strewn about an area and wonder "what has happened here?" They can come up with different explanations and discuss the strengths and weaknesses of each one. *Note:* This type of argumentation is very different from the everyday definition of "argument" (i.e., an angry disagreement). A scientific argument is a statement or series of statements for or against something, that includes a claim, evidence, and reasoning. For example: "I think the deer was going down to drink some water [claim], because the tracks look like the deer tracks in the field guide [evidence], and the tracks look like they are headed in the direction of the creek [reasoning]. *Specific BEETLES activities:* During *NSI: Nature Scene Investigations*, students compare their explanations to those of others and weigh their strengths and weaknesses. In *The Case of the Disappearing Log*, students come up with explanations for what is happening to the log, discussing the strengths and weaknesses of each explanation. In *Bark Beetle Exploration*, students discuss the ramifications of bark beetle population increases.

	Description of Practice & Student Abilities	Field Examples & Teaching Notes
8. Obtain, Evaluate, and Communicate Information	Scientists need to be able to communicate clearly and persuasively about the ideas and methods they investigate. Reading, interpreting, discussing, and producing text (all forms of communication) take up the majority of a scientist's working time. Exposure to the language of science is particularly important for students who hear less academic language outside of school than others, or who don't speak English as their first language. Even students who can decode text well may struggle with comprehending informational texts in science. All students need exposure to and guidance about different forms of non-fiction texts, including field guides, diagrams, graphs, etc. Using field journals is an authentic way of providing the opportunity for students to communicate through writing and drawing. *Science text & communication abilities we can help students develop at outdoor science school:* • Reading and using appropriate scientific text, including field guides, diagrams, words, tables, and graphs to communicate their understanding or to ask questions. • Creating scientific text, including writing, drawing, and making diagrams in field journals. • Citing and evaluating sources of information, *e.g., "My source is Sponge Bob show, but that's probably not a very strong source for science information."*	*General Approach:* Have students access science texts (such as identification keys and field guides) when appropriate, in order to build knowledge of the organisms and ecosystems they are investigating. Make a habit of having students record information in field journals that they can use as the basis for discussions and sharing information. For example, students can use symbols, drawings, and written descriptions in their journals to make a map of an area focusing on the presence of certain plant species, then use their notes to talk to peers about trends and patterns they noticed. After conducting a habitat study, a group of students creates a poster presentation to share their findings with the rest of their class. Students may use journals to record observations and questions about three different types of leaves using both drawing and writing. When describing connections between organisms on a food web, students can take note of how certain they are based on the source of their information. *Specific BEETLES activities:* During *Discovery Swap*, students draw and record observations and questions about an organism, generating science "text." They also use science text in the form of a key to identify their organism, and a booklet with information on their organism. During a "Cool Organism Convention," they discuss their findings, questions, & ideas with others. During an *NSI* activity, students name the sources for the information they share with the group.