

NEXT GENERATION SCIENCE STANDARDS

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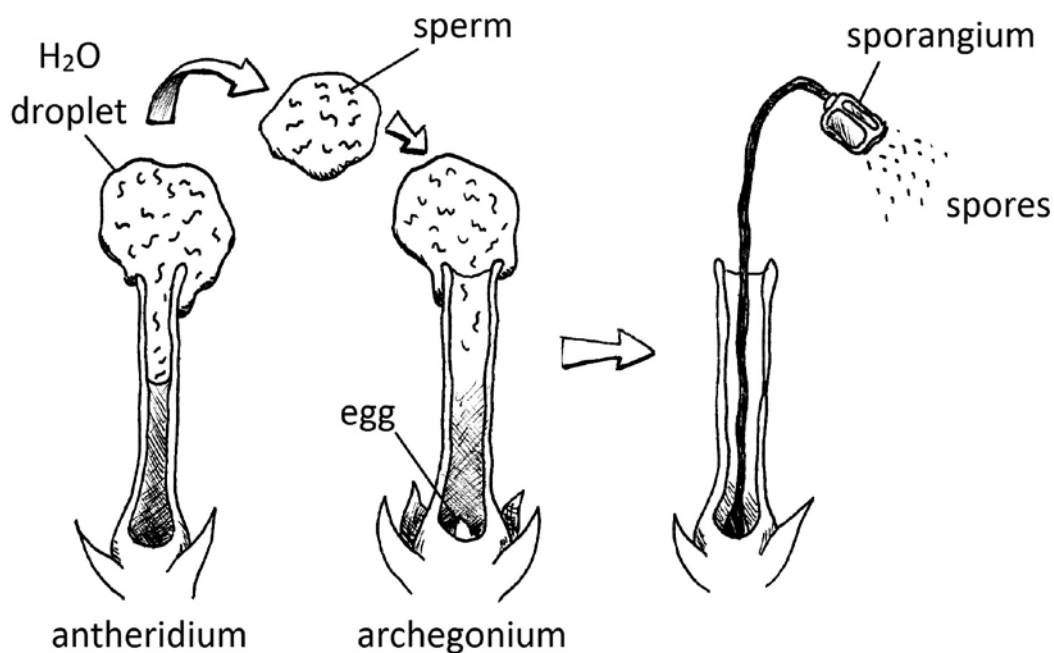
LOST IN THE WOODS?

Have you ever been lost in the woods or disoriented in an unfamiliar city? Do you have a similar uneasy feeling about the *Next Generation Science Standards (NGSS)*? In this article, we hope to illustrate the power of the *NGSS* while providing a road map for more clear navigation. We discuss how student investigations allow for the integration of *NGSS* dimensions (science and engineering practices, disciplinary core ideas, and crosscutting concepts), as well as connections with other standards, such as the Common Core. We also show how these kinds of investigations can facilitate alignment of curriculum, instruction, and assessment of the *NGSS* and help students

develop a deeper understanding of the nature and methods of science. To provide a context for discussion, we describe two separate studies of American beech trees (*Fagus grandifolia*) that examined the abundance of moss and lichen growth and the fascinating implications of a phenomenon called stemflow. Our description of these beech tree explorations is not intended as a specific lesson or activity, but rather an example of how student investigations can integrate the *NGSS* dimensions; make intentional connections to other standards; and align curriculum, instruction, and assessment. First, we need to share the surprising discoveries we made about beech trees.

FIGURE 1

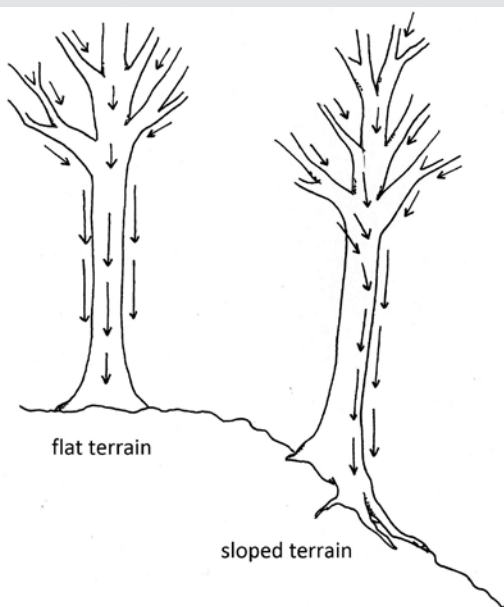
Moss reproduction requires water



AMY MECHER

FIGURE 2

Stemflow on a vertical and leaning tree



AMY MECHER

Patterns in nature

You may have heard that if you're ever lost in the woods without a compass, moss can help you find your way, because it grows on the north side of trees. This advice follows from a not completely accurate understanding of a pattern that occurs in nature. Moss does tend to grow more abundantly on the north side of trees, at least in the Northern Hemisphere, because the north side of trees is shaded, and sexual reproduction in moss requires water (shade reduces the evaporation of moisture relative to the south side). "Swimming" sperm produced in the male antheridium need water to reach and fertilize eggs in the female archegonium (Figure 1), at which point a sporangium develops and releases spores that can germinate (which also requires water) and grow into new moss plants. While an understanding of increased moss abundance on the north side of trees due to shade is mostly correct, it is limited: Any circumstance that provides a sufficient and regular supply of water, such as the crook of a large branch or a cavity in the trunk, can result in preferential moss growth. As science educators, we strive to help students discover the causal explanations

of patterns in nature, including their limitations. Patterns and cause and effect are examples of NGSS crosscutting concepts (Achieve Inc. 2013).

The next section describes an investigation of beech trees in a wooded ravine that was conducted by an undergraduate student (Michelle Frasco) and guided by one of the authors (Dobson) as an independent study (Frasco and Dobson 2010). It originated with the observation of a tree with more moss on its south side. The tree was on a steep slope and leaning somewhat downslope. It was raining, and a stream of water was gushing down the south side of the trunk. Dobson and Frasco were fortunate to notice the stream of water in this initial observation and learned the phenomenon is called stemflow. Stemflow is the accumulation and channeling of rain down a tree's branches and trunk. Beech trees have smooth bark, and stemflow on them is especially pronounced. Because it did not fit their understanding of the pattern of moss growth on trees, Dobson and Frasco were surprised to find so much more moss on the south side. They wondered if stemflow on a leaning tree could affect moss abundance by directing water to its downslope side (Figure 2).

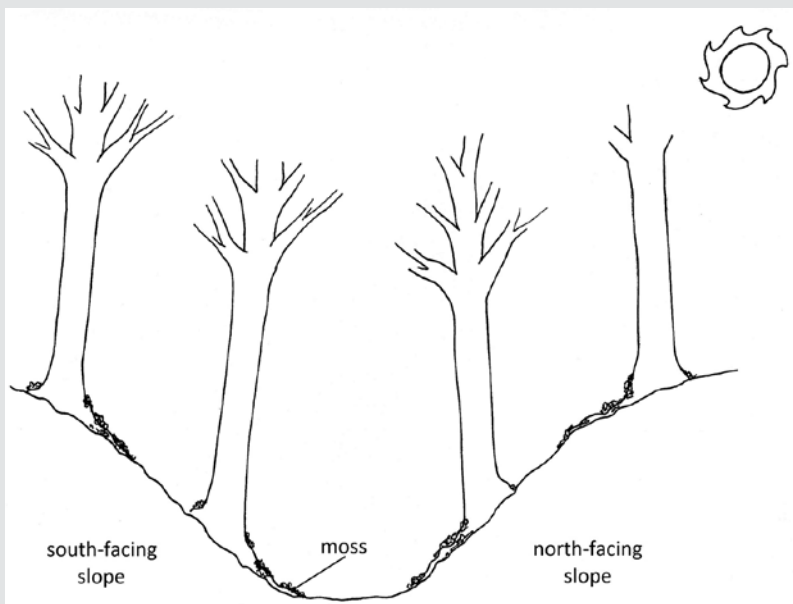
Hypothesis testing

A hypothesis is a possible explanation for some observed phenomenon. Hypotheses lead to specific predictions, and checking to see if they come true is hypothesis testing. Dobson and Frasco's hypothesis was that stemflow can increase moss abundance on one side of a tree by providing a regular source of water. Based on this, they predicted that moss should be more abundant on the downslope side of leaning trees. They examined leaning beech trees on a north- and south-facing slope (Figure 3) and found significantly more moss on the downslope side of trees, on both slopes. They were amazed that the trees on the south-facing slope had more moss on the side of their trunk with southern exposure.

Now Dobson and Frasco had an improved understanding of the pattern of moss growth on trees. Moss is usually more abundant on the north side of trees, but if lost in the woods, make sure to look at more than one or two trees (sample size), because there are exceptions to this rule. You should also be cautious when

FIGURE 3

Moss abundance on leaning trees



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FIGURE 4

Lichen tracks follow stemflow



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looking at leaning beech trees, because stemflow can increase moss abundance on one side, regardless of cardinal direction. During the investigation, they also discovered that lichen tracks follow stemflow. Lichen is a symbiotic relationship between a fungus and a photosynthetic partner, an algal or bacterial species. Like moss, lichen benefits from a regular supply of water and grows abundantly in the path of stemflow. This finding made it possible in the study to determine where stemflow occurs even when it was not raining. Figure 4 shows a lichen track, indicating stemflow, leading directly to a healthy patch of moss.

This paragraph describes an investigation by two of the authors, Stephanie Haley and Patricia Radtke (undergraduate students) that was guided by Dobson (instructor). It was a follow-up study, conducted as part of an undergraduate ecology course for preservice elementary teachers, and specifically examined stemflow on vertically growing beech trees. With the results of Frasco and Dobson (2010) in mind, we (Dobson, Haley, and Radtke) looked at the effect of various structural features on a trunk that can influence stemflow, such as knots or grooves in the bark, as well as the particular location of branches. All of these structural features can readily change the direction of stemflow, affecting the abundance of moss or the location of lichen tracks (Figure 5). We wanted to know if there were more lichen tracks on the north or south side of trees. A vertically growing beech tree can have more than one distinct path of stemflow, resulting in multiple lichen tracks on one trunk. So we hypothesized that the various structural features on a tree, as well as their particular location, affected how many lichen tracks a trunk would contain. We also reasoned that the supply of water from stemflow is more influential on moss and lichen growth on vertical trees than which side of the tree is shaded. Based on this, we predicted that we would find a similar number of lichen tracks on the north and south side of trees because there was no reason to expect more stemflow-influencing structural features on either side. Not surprisingly, this is what we found. So if you are ever lost in the woods, remember that beech trees will be absolutely no help in finding your way!

Integration, nature of science, and connections to other standards

Now we turn our attention to the final version of the *Next Generation Science Standards*, released in April 2013, a noteworthy improvement over the previous national standards (NRC 1996). Each NGSS performance expectation explicitly integrates the three di-

FIGURE 5

Groove in trunk directing stemflow down lichen track



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mensions (science and engineering practices, disciplinary core ideas, and crosscutting concepts) from the *Framework for K–12 Science Education* (NRC 2012). To illustrate, our beech tree investigations address the middle school life science standard Ecosystems: Interactions, Energy, and Dynamics, specifically the following two performance expectations (Achieve Inc. 2013):

- MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
- MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

See Figure 6 for the organizational structure of standards, performance expectations, and dimensions. The disciplinary core idea contained in both expectations (Interdependent Relationships in Ecosystems) emphasizes that organisms depend on living and non-living interactions with their environments, including

FIGURE 6

Standard with performance expectations integrating three dimensions

Standard: MS-LS2. Ecosystems: Interactions, energy, and dynamics**Performance expectations**

MS-LS2-1. **Analyze and interpret data** to provide evidence for the **effects** of resource availability on organisms and populations of organisms in an ecosystem.

MS-LS2-2. Construct an **explanation** that predicts **patterns** of interactions among organisms across multiple ecosystems.

Science practices

- Analyzing and interpreting data
- Constructing explanations

Disciplinary core idea

LS2.A.

- Interdependent relationships in ecosystems

Crosscutting concepts

- Patterns
- Cause and effect

access to resources. As an example, moss and lichen interact with their environments by growing on beech trees and are affected by access to water through stemflow. In addition to this core idea, the performance expectations also integrate two science practices (Analyzing and Interpreting Data; Constructing Explanations) and two crosscutting concepts (Patterns; Cause and Effect). The bolded portions of each performance expectation in Figure 6 highlight the integration of science practices and crosscutting concepts with the core idea. See Bybee (2011) and Duschl (2012) for more thorough explanations of science practices and crosscutting concepts, respectively.

Over the course of two beech tree investigations, students and the instructor analyzed and interpreted data to understand the cause-and-effect relationship between resource availability and moss and lichen growth (MS-LS2-1). We constructed and modified an explanation for the pattern of moss and lichen growth we found (MS-LS2-2). We also conceptually modeled stemflow down beech trees (Figure 2) to help facilitate our understanding and guide our investigations. Developing and Using Models is an additional NGSS science practice, and Krajcik and Merritt (2012) identified this as a particular challenge of NGSS science practices—students are expected to construct models to explain phenomena that are based on evidence, and be able to make predictions based on these models. The authors described middle school students' drawings of odor as "models" of molecular motion that improved over time as they encountered additional evidence. Models are like hypotheses; they lead to specific predictions. In our investigations of beech trees, we used a conceptual model of stemflow to

predict which side of trees would contain more moss or lichen tracks. Checking to see which side actually had more moss or lichen was hypothesis testing. In summary, we analyzed data and developed a model to construct an explanation (science practices) for the cause of the pattern (crosscutting concepts) of the interdependent relationships (disciplinary core idea) among moss, lichen, and beech trees, integrating the three NGSS dimensions.

A revision incorporated in the final version of the NGSS makes explicit the inclusion of the nature of science. It specifies that students should gain an understanding of the nature of science as not just a practice but "of the enterprise of science as a whole" (Achieve Inc. 2013). Investigations provide students an opportunity to experience science as a way of knowing, realize the need for evidence, view conclusions as open to revision, and so on. In addition, they allow for intentional connections across standards; in different topics at the same grade level (MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms); in similar topics across grade levels (2-LS2-1. Plan and conduct an investigation to determine if plants need sunlight and water to grow) (Achieve Inc. 2013); and with the *Common Core State Standards* for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects (WHST.6-8.1 Write arguments focused on discipline-specific content) (NGAC and CCSSO 2010). This illustrates how extended investigations can address multiple performance expectations (MS-LS2-1 and MS-LS2-2) and also connect to a number of other standards (MS-LS1-5, 2-LS2-1, and WHST.6-8.1).

Alignment of curriculum, instruction, and assessment

Extended investigations, such as our exploration of beech trees, lend themselves to the alignment of curriculum, instruction, and assessment. They occur over several class periods and allow students to more deeply engage in the process of science. Consider the eight NGSS science practices:

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Students in our investigations participated in all eight practices over a period of several weeks. They made initial observations that led to the formation of questions. They conducted reviews of the literature to see what was already known about the topic. Then they wrote proposals that outlined their plan for data collection and analysis to answer their questions. Finally, they created PowerPoint presentations and submitted formal written reports in scientific format. In the presentations and reports, students used basic descriptive statistics (mean, standard deviation, range) and statistical tests (t-tests) to present and defend their conclusions to the instructor and fellow classmates. They essentially emulated the scientific process from beginning to end, which could not happen in one or even two class periods.

Assessment was aligned with curriculum and instruction through the evaluation of student questions, hypotheses, methods, and explanations both in written proposals (formative) and final presentations and reports (summative). Before they began data collection, students submitted proposals outlining their questions, how they planned to answer them, and what they expected to find. This allowed the instructor to gauge student understanding and help modify methods in the preliminary stages of the investigation. For example, were students asking descriptive or causal questions? Causal questions can be difficult to answer with a high degree of certainty because many factors can influence the outcome of some pattern detected in nature. Descriptive

questions are easily answered by recording a large number of observations, such as which side of the trees has more moss and whether those particular sides tend to have a regular supply of stemflow. Then a conclusion can be reached about a causal question, such as why moss is more abundant on one side of a tree. See Zeeff, Palazzolo, and Dobson (2007) for another example of how students can use a series of descriptive questions to answer causal questions. An interesting alternative is to assess students' ability to apply what they learn through their investigations. For example, how would students who have studied stemflow on beech trees describe what to do if lost in the woods?

Assessment can also occur informally throughout an investigation, at multiple stages, as students develop more sophisticated understandings and abilities. For example, instructors can assess how students' observations or hypothesis thinking improve. Students build these skills over time throughout the course of a study. Additional assessments can be of what data students decided to collect, how they chose to organize and present their data, how well their conclusions followed from evidence, and how well they explained their conclusions, incorporating information obtained elsewhere (related articles, books, and websites). These are exactly the NGSS science practices we want students to develop.

See Dobson (2008) for a more detailed discussion of considerations in guiding student investigations, including criteria used for assessment. Be sure to keep safety in mind, and survey an area for harmful plants or animals before any outdoor exploration with students. You may want to restrict student observations to "eyes and ears only," and it is always a good idea to wash hands upon return to the classroom.

It may not be practical to facilitate many extended investigations during the school year, even if you agree they are valuable experiences for students. We suggest viewing them along a continuum from more open inquiry, in which students generate their own questions and methods, to more structured experiences. For example, provide the results of some previous investigation to your students and ask them to conduct a follow-up study. In our case, students who studied vertically growing beech trees had access to the report on leaning beech trees to use as a template and expand on. An even less time-consuming alternative is to have students plan a theoretical investigation, without actually conducting it. They can construct questions, design a method to collect and analyze data, and formally describe what they expect to find (predictions) based on their understanding of what is going on (hypothesis/model). Another option is to have students focus on one aspect of

an investigation: Provide students with several interesting observations related to some phenomenon in nature (moss growth on beech trees) and have them propose a model to explain what they think is responsible.

These alternatives also provide opportunities for classrooms in suburban settings that do not have access to more natural areas. Does your school have a small pond containing frogs? If so, students can investigate behavior by observing whether frogs are fully submerged, partially submerged, or completely out of water and sunning on a lily pad or rock. Students can make their observations on different days or at different times of day (morning/afternoon) and record conditions, such as water and air temperature. From this, they can discover that amphibians regulate body temperature through behavioral mechanisms. Or consider the ubiquitous and popular pill bug (roly poly). Most school yards are home to several populations, and students can easily examine their habitat preferences (usually dark and moist). With safety in mind, the teacher can turn over rocks, wood, etc. The possibilities are endless, and explorations need not take place outside at all; the Wisconsin Fast Plants Program and Bottle Biology provide excellent resources for conducting extended investigations completely inside classrooms (see Resources).

Conclusion

In this article, we described an investigation of moss and lichen growth on beech trees as the context for a discussion of the recently released *Next Generation Science Standards*. We used our example to illustrate the integration of science practices and crosscutting concepts with disciplinary core ideas in performance expectations. We also attempted to show how extended investigations can help your students develop an understanding of the nature of science; connect to other standards; and align curriculum, instruction, and assessment. Perhaps we provided some insight or clarification on the structure of the new standards and made a case for using student investigations to address them. Mostly, we hoped to show the potential power the NGSS holds for fostering the knowledge and abilities our students need to be scientifically literate citizens of the 21st century. ■

Acknowledgments

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Resources

- Bottle Biology—www.bottlebiology.org
- Next Generation Science Standards—www.nextgenscience.org
- Wisconsin Fast Plants Program—www.fastplants.org

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