MOSS, BEECH TREES, AND STEMFLOW: INTEGRATED SCIENCE

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A Mossy Misconception

Have you ever been lost in the woods? Have you heard that, "moss grows on the north side of trees," from someone presumably imparting navigational wisdom? Is there anything to this popular old adage? Well… yes and no. Wandering through the woods, you will find that moss does not grow exclusively on the north side of trees and that this common misconception may not lead you home. However, you might observe that moss can be more abundant on the north side of trees, at least in the Northern Hemisphere. Why does this particular pattern occur in nature?

You may already know the answer, but in this article we uncover an intriguing exception to the rule, something entirely unexpected! We describe our personal discovery of stemflow and how it can dramatically influence where moss is found on beech trees. What is "stemflow" you ask, and what does it have to do with moss? And what's the deal with beech trees? Good questions, read on. Our narrative has all the twists and turns of any good mystery, providing a review of relevant scientific concepts along the way. Our primary goal, however, is to use the relationship among moss, beech trees, and stemflow as an opportunity to discuss *integrated science*, specifically what it is, why it's important, and how to implement it in your classroom.

Life Science, Physical Science, and Earth Science…Oh My!

Like all plants, moss must reproduce and disperse its offspring. It does so via spores that result from the fertilization of eggs by flagellated sperm. This helps explain why moss is found in wet environments. "Swimming" sperm, produced in the male antheridium, require a film of water to reach an egg in the female archegonium (Figure 1). Following fertilization, a spore-containing capsule, the sporangium, develops and releases spores. The spores germinate and grow into moss plants when conditions are favorable, which includes available moisture. Patterns that occur in nature have causal explanations. In the case of moss, the role of water in its life cycle (sexual reproduction and spore germination) accounts for the plant's distribution and abundance in nature (life science concepts).

> *Each day **celestial noon** occurs when the sun has reached its highest point in the sky and is halfway between sunrise and sunset. In comparison to "clock time," celestial noon varies and depends on a location's longitude, and whether it is day-light savings or standard time.*

You may also be aware that moss commonly grows on trees in an epiphytic relationship. The moss is nonparasitic to the tree, obtaining its nutrients from air and rainfall. The particular side of a trunk that moss grows on can be influenced by sunlight. After light from the sun has traveled through Earth's atmosphere and reached an object on the ground, it is blocked by the object itself, leaving the other side of the object shaded. Shade reduces the evaporation of water due to sunlight, making the shaded side of a tree trunk somewhat wetter (physical science concepts). ▶

To understand where shade occurs one must comprehend the path of the sun through the sky. From the center of the Lower Peninsula (St. Louis, Michigan), the sun is farthest north at celestial noon on the summer solstice, 70.5º above the southern horizon. The sun is farthest south at celestial noon on the winter solstice, 23.5º above the southern horizon. Over the course of a year, the sun's altitude on celestial noon is always located between these points, with sunlight directly striking the south side of objects, including trees (Figure 2). This year-round southern exposure results in a slightly cooler and wetter microenvironment on the north side of trees (earth science concepts). Assimilating knowledge of the life, physical, and earth science concepts described in the last several paragraphs, it makes sense to predict that moss should be more

FIGURE 1. FERTILIZATION AND SPORE DISPERSAL IN MOSS.

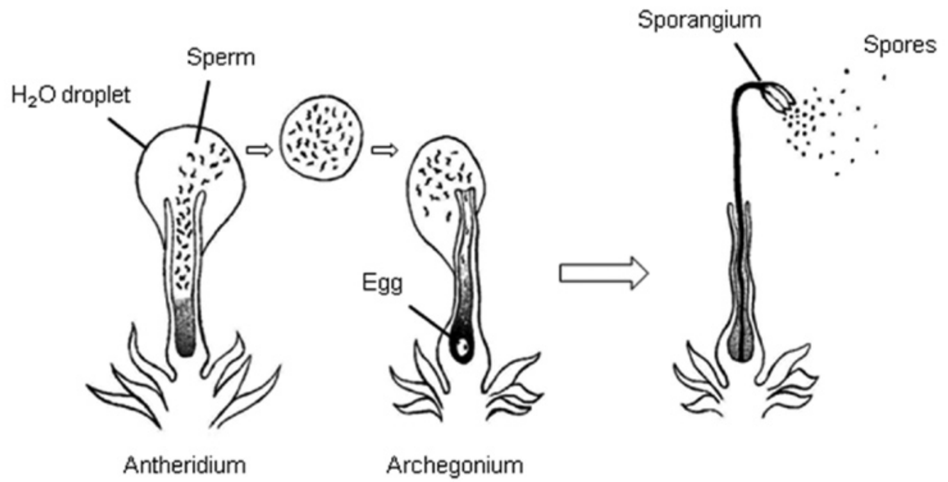
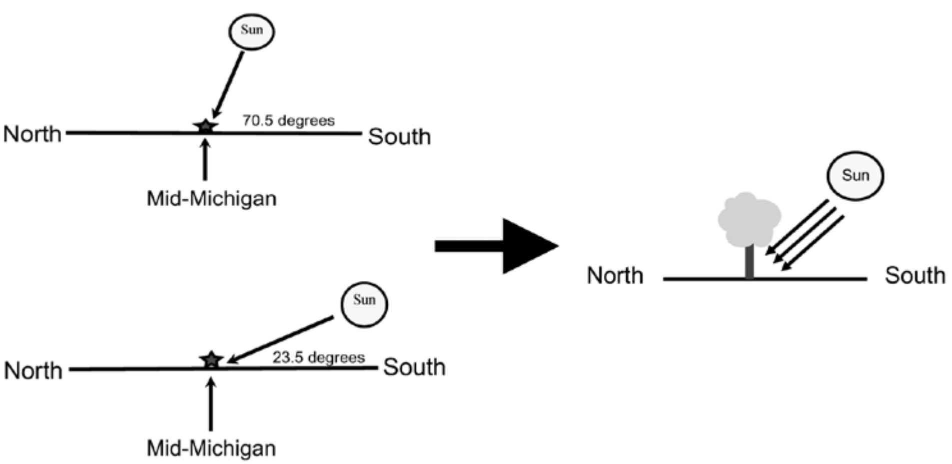


FIGURE 2. ALTITUDE OF SUN ON SUMMER AND WINTER SOLSTICES RESULTS IN YEAR-ROUND SOUTHERN EXPOSURE.



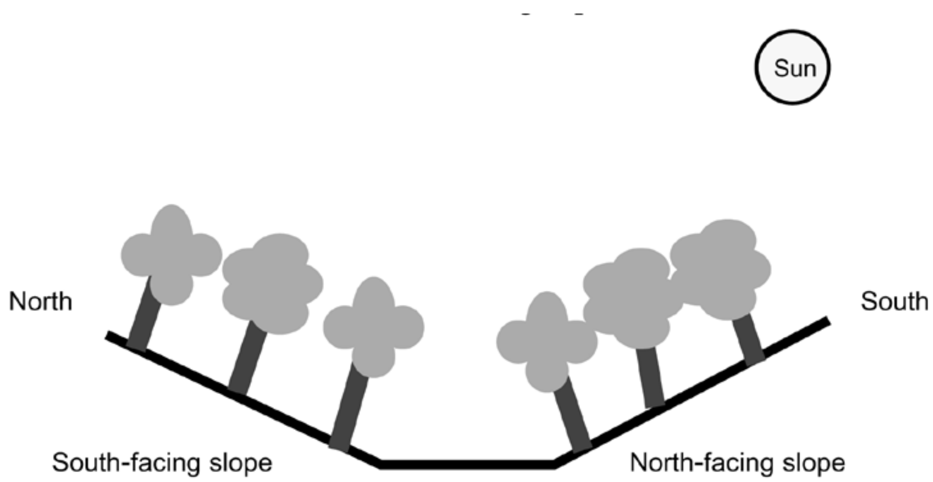
abundant on the north side of trees, at least in Michigan and elsewhere in the Northern Hemisphere.

Making Predictions… (a.k.a. Hypothesis Testing)

Wandering through a wooded ravine system one day, we noticed a large American beech tree (*Fagus grandifolia*) with a healthy population of moss growing on its trunk. We suspected, however, and then confirmed with a compass, that there was noticeably more moss on the south side of the trunk. We were on a south-facing slope with southern exposure and expected moss to be more abundant on the north side of the trunk. More moss on the south side of this particular tree contradicted our prediction, based on our understanding of the life, physical, and earth science concepts discussed above. That's how it works in science: a *hypothesis* is a possible explanation for some observed phenomenon that leads to a specific *prediction*, which allows you to test the hypothesis. If the prediction comes true the hypothesis is supported. If not, the hypothesis should be rejected. Our prediction that moss would be more abundant on the north side of the tree did not come true and forced us to question our hypothesis. Remember, we made our prediction based on the hypothesis that the north side is shaded (wetter), providing a more favorable environment for moss to complete its life cycle (reproduction and germination). Finding more moss on the south side of the tree was puzzling, to say the least!

Reluctant to completely reject our hypothesis based on one trouble-making beech tree, we knew we needed a larger sample size. As always in science, the results needed to be repeatable. Could we find additional trees with moss more abundant on the south side of their trunks? We also began to wonder if the fact that this tree was growing on a relatively steep slope, leaning slightly downslope, could be impacting moss growth. So we decided to conduct an investigation of moss abundance on tree trunks on north- and south-facing slopes, focusing on our primary suspect, the American beech (Figure 3). We also thought it prudent to pay attention to whether or not trees tended to lean downslope, and if so, how much. We decided to estimate the degree of lean of each tree away from vertical, if any, using a weight attached to a protractor with string (plumb bob method). ▶

Figure 3. Beech trees on north- and south-facing slopes. slopes.



We suddenly realized that we were testing two competing hypotheses, each leading to different predictions. If a more shaded environment on the north side of trees is most influential in determining moss abundance (shade hypothesis), we expected to find more moss on the north side of trees on both north- and south-facing slopes. If trees tend to lean downslope, and that somehow favors moss growth on the downslope side of trees (downslope hypothesis), we predicted that we would find more moss on the north side of trees on north-facing slopes and on the south side of trees on south-facing slopes. Remember, hypotheses lead to specific predictions, and these predictions allow you to test the hypotheses. Hot dog, we were hypothesis-testing!

You may already see this coming, but we found significantly more moss on the downslope side of trees on both slopes. Again, because this is worth restating, moss was consistently more abundant on the south side of trunks on south-facing slopes. We also found that trees on both slopes did tend to lean downslope, an average of about six degrees from vertical. These findings supported our downslope hypothesis and forced us to reject our shade hypothesis, or at least acknowledge that it needed modification (more on this later). This is definitely not what we had expected, moss preferring the south side of so many trees! We had a genuine mystery on our hands. Fortunately, we found our mystery-solving clue not long thereafter. It happened one cold, rainy day. That's when we saw it—stemflow!

Stemflow Runs Down Lichen Lane

It was raining fairly hard, and we were huddled underneath a large beech recording moss abundance and the degree of tree lean away from vertical. As with most trees on the slopes we investigated, this particular beech was leaning noticeably downslope. To our amazement, we saw a gushing "stream" of water funneling down the downslope side of the trunk, leading straight to a healthy patch of moss at the base of the trunk. We later came to learn that this phenomenon is called *stemflow*. Stemflow occurs when it's raining; water accumulates in the upper leaves and branches of trees and is channeled downward toward the trunk. It is especially pronounced in trees with smooth bark like beech. On flat terrain trees tend to grow relatively vertically. This results in stemflow down one or more sides of the trunk, depending on various ridges and grooves in the bark, as well as the particular orientation of major branches feeding water to the trunk. What we discovered that day is that when a beech tree is leaning, stemflow runs along the downslope side of its trunk (Figure 4). We quickly hypothesized that the reason moss is more abundant on the south side of beech on south-facing slopes is that the trees tend to lean downslope, directing stemflow to that side of their trunks. More water, more moss. Solving our mystery of why moss would be more abundant on the south side of so many trees seemed close at hand.

Of course, there was that whole "repeatable" thing we have to concern ourselves with in science. Would we see stemflow occurring primarily on the downslope side of other beech trunks on sloped terrain? One difficulty in answering this question was that it required us to be out with our trees in rainy weather, not always easy to accomplish. That's when we made our second case-cracking discovery. As we watched water funneling down the trunk of that large beech tree, we noticed an abundance of lichen growing right along the path of stemflow. Lichen is a symbiotic relationship between a fungus and algae and/or bacteria. Like moss, lichen is a nonparasitic epiphyte, getting all its nourishment from air and rainfall. Naturally, lichen would benefit from stemflow in a similar fashion to moss. More water, more lichen. Then it dawned on us; we could use lichen growth on a trunk to estimate the path of stemflow on days without rain (Figure 5). Using this indirect measure of stemflow along trunks, we were able to answer our remaining question about its location on slopes. Stemflow did occur primarily on the downslope side of beech trees on sloped terrain. This result correlates with moss abundance. Both stemflow and moss occurred more frequently on the north side of trees on north-facing slopes, and on the south side of trees on south-facing slopes. Mystery solved, case closed! Well, almost. ▶

FIGURE 4. STEMFLOW ON A VERTICALLY GROWING TREE & ON ONE LEANING DOWNSLOPE.

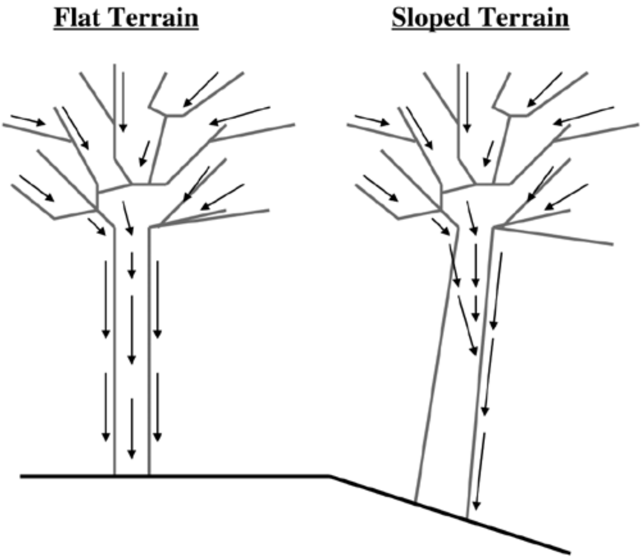
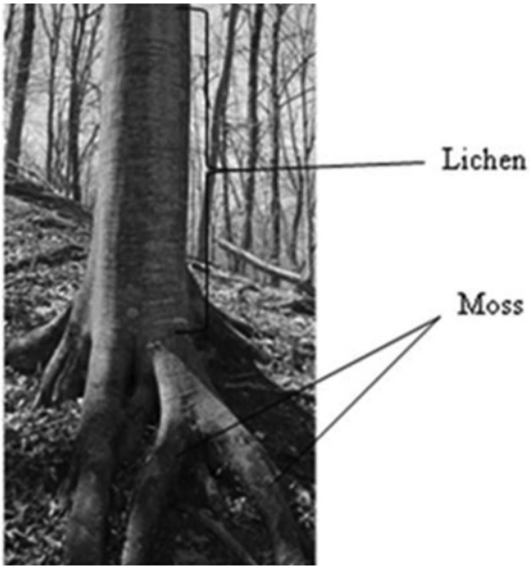


FIGURE 5. LICHEN GROWTH INDICATING STEMFLOW DOWN TRUNK.



Identifying and Explaining Patterns in Nature

Scientists look for patterns in nature and then try to provide explanations for those patterns. In this article we have identified an intriguing pattern of preferential moss growth on the south side of beech trees on a south-facing slope. Our original hypothesis was that moss needs water to complete its life cycle and that the north side of trees is more shaded, providing a moister, more favorable environment. This led to the prediction that moss should be more abundant on the north side of trees. Because we found more moss on the south side of our beech trees, our hypothesis requires modification. In this case, we need not reject our hypothesis entirely. Rather, we must revise it, taking stemflow into account. In science, the iterative process of hypothesis testing and modification advances our understanding and improves our explanations of the patterns we observe in nature.

In general, moss may be more abundant on the north side of trees, although exceptions obviously occur. Moss has no compass; it simply thrives where moisture is available. Any circumstance that provides adequate water to a specific portion of the trunk, such as tree lean or a particular branch orientation, will foster moss growth there. Because beech have smooth bark, stemflow is especially pronounced and appears to trump cardinal direction, north or south, in determining where moss is most abundant. Other trees commonly found in Michigan forests, such as sugar maple (*Acer saccharum*), possess bark that is deeply furrowed, or grooved. This seems to reduce the shift of stemflow from one side of a trunk to the other. Stemflow on leaning maple trees may not end up on the downslope side of trunks as readily as it does on beech. We have not investigated this, but would be interested to hear what you and your students find should you do so. In any case, our investigation does highlight how hypotheses often warrant modification, rather than complete abandonment.

Throughout this article, we have framed our explanation for the distribution of moss by considering relevant concepts in the life, physical, and earth sciences. We continue to do so by exploring additional interactions and circumstances that lead to the formation and path of stemflow along the downslope side of trunks. During a rain, the force of gravity acts on water droplets that accumulate on leaves and branches in a tree. Rather than dripping to the ground, much of the water sheets down increasingly larger branches, merging like the tributaries of a river. On a leaning beech, stemflow eventually makes its way to the underside of the trunk, the downslope side, again because of gravity. Water (H_2O) also happens to be a polar molecule, and hydrogen bonding between individual molecules results in cohesion and surface tension as it streams down the tree. And although the bark is wettable, absorbing some water through adhesion to hydrophilic substances such as cellulose, the bark is mostly impermeable to water as a result of hydrophobic interactions with the fatty substance suberin. Together, gravity and interactions due to the polar nature of H_2O produce a steady stream of water feeding the downslope side of trunks (physical science concepts). In addition, tree lean on the slopes we investigated is due to creep, the slow, gradual downslope movement of soil (earth science concept). A tree tilts downslope at its base as the ground below it is subjected to creep, and responds phototropically by bending and growing straight upwards toward the sun (life science concept). Creep is a type of mass wasting, the movement of surface land masses due to…interestingly enough…gravity. Other mass wasting processes, such as landslides, also tilt trees, potentially impacting stemflow as in our beech trees.

Some of these concepts may be unfamiliar to you, but including them illustrates how truly understanding a particular pattern in nature, such as moss growth on trees, can involve several levels of complexity. We realize that, depending on grade level, some of the concepts presented may be inappropriate or too detailed for your students. We are also cautious to generalize the results of our investigation, from beech on some local north- and south-facing slopes, to other tree species and forested regions. Our findings do, however, call into question the popular wisdom of using moss on the north side of trees as a navigational tool. Clearly, there is much involved in explaining the distribution and abundance of moss on any given tree, and this explanation repeatedly and indiscriminately crosses boundaries of the traditional science disciplines (life, physical, & earth sciences).

iNTeGRaTEd SciENCe

Now we use our investigation of moss, beech trees, and stemflow as a springboard for discussion of integrated science, specifically what it is, why it's important, and how to implement it in your classroom. Like the inconsistent capitalization in our section heading above, interpretations of integrated science among educators vary. A general lack of consensus on the definition and conceptualization of integration permeates science education. So what is integrated science? There is integration of mathematics in science instruction and integration of science across the curriculum with the social sciences and humanities (e.g., a writing assignment on the history of the microscope). Integration also occurs within a particular branch of science, such as biology, through the simultaneous learning of distinct but related concepts (e.g., genetics, evolution, and ecology). These types of integration, however, do not constitute "integrated science" in its intended sense, which requires the combination of concepts from multiple science disciplines to understand some topic or issue.

Blum (1991) claimed that integration among the branches of science occurs in two ways: 1) When the unity of knowledge and procedures among them are emphasized, as intended by the *National Science Education Standards* (NRC 1996) unifying concepts and processes (e.g., "systems, order, and organization" or "evidence, models, and explanation"); and 2) When the sciences are taught in an integrated way for pedagogical reasons; concepts from an additional discipline are needed to understand a problem being studied within a particular branch of science. Venville et. al (2002) proposed that integration in this second sense falls along a continuum from multidisciplinary to interdisciplinary, to transdisciplinary, with each additional label signifying a reduction in compartmentalization between disciplines.

The Biological Sciences Curriculum Study (BSCS 2000) suggested thinking of integration as the combination of parts to make a whole. They described integrated science as requiring students to make meaningful and coherent connections among discipline-specific concepts that connect logically and obviously:

> *For coherence to prevail, the physics, chemistry, and biology must be woven into a discernable whole that draws on but transcends the coherence that characterizes each of the individual disciplines.*

Connections among the sciences must be evident, purposeful, and critical for comprehension of some larger concept. Learning science in this manner blurs boundaries between the traditional disciplines and, in our opinion, is the intended meaning of integrated science.

Consider the middle school content statements below from the *Grade Level Content Expectations* (MDE 2009) that are related to understanding the growth of moss on trees (content statements in italics and relevance to moss abundance in parentheses).

Life Science:

- *L.EV.M.1 – Species Adaptation and Survival* (moss adapted to particular environments)
- *L.EC.M.3 – Biotic and Abiotic Factors* (water availability impacts moss abundance) ▶

- *L.OL.M.6 – Photosynthesis* (moss uses sunlight to make sugar from H_2O and CO_2)
- *L.HE.M.2 – Reproduction* (moss life cycle: sexual reproduction and spore germination)

Physical Science:

- *P.FM.M.2 – Force Interactions* (effect of gravity on stemflow)
- *P.EN.M.4 – Energy Transfer* (solar radiation carries energy from the sun to Earth)
- *P.CM.M.1 – Changes in State* (water changes from liquid to gas during evaporation)
- *P.EN.M.3 – Waves and Energy* (sunlight increases evaporation of H_2O on trunks)

Earth Science:

- *E.ES.M.6 – Seasons* (southern exposure makes north side of trees wetter)
- *E.SE.M.1 – Soil* (creep and other mass wasting processes cause trees to lean)
- *E.ES.M.1 – Solar Energy* (sun drives water cycle through evaporation of H_2O)
- *E.ES.M.8 – Water Cycle* (stemflow down trees contributes to water cycle)

Why is integration important? An integrated approach in science instruction is consistent with the goal of increasing scientific literacy among students (AAAS 1989 and NRC 1996). Bybee (1997) clarified scientific literacy as including an understanding of science content, scientific inquiry and the nature of science, and the interrelationships of science, technology, and society. In addition to helping students learn concepts, adopting an integrated approach facilitates a more sophisticated perception of science and makes learning personally relevant through the context of social or environmental issues. For example, evaluating global climate change requires an integration of energy, atmosphere, and impacts on plant and animal life (physical, earth, & life science concepts), an understanding of the methods and uncertainty in science, and social implications of scientific findings.

How can you implement integrated science in your classroom? In our opinion, a thematic approach like global climate change is not required. Although social or environmental issues lend themselves to integration, many natural phenomena that your students could study are inherently integrated. Take, for instance, the smaller and more specific question about moss growth on beech trees. Our investigation led us on a journey that repeatedly traversed discipline boundaries, requiring an exploration of concepts throughout the life, physical, and earth sciences. An integrated examination of these discipline-specific concepts was necessary to understand moss abundance. None of the concepts alone sufficiently explains the pattern of moss growth we observed.

A working knowledge of Michigan science standards (MDE 2006 & 2009), however, is a must. We suggest viewing the standards as less prescriptive, and more as guidelines. You need to be familiar enough with them to recognize which are addressed in any given lesson or unit. You could choose to first review standards throughout the life, physical, and earth sciences in order to select an integrating topic to investigate. For example, you might choose to highlight conservation of mass (physical science), photosynthesis (life science), and atmospheric composition (earth science) in exploring how primitive photosynthetic bacteria changed Earth's early environment through millennia of oxygen production. Alternatively, you could identify standards from among the disciplines that are relevant to some topic which you or your students have already elected to study. As an example, imagine that your students become interested in learning about biofuels. You could peruse the standards to determine which life, physical, and earth science concepts can be addressed in learning about this topic. Either way, it's crucial to help students explicitly recognize the integration of discipline-specific concepts needed to understand our world. In addition, a knowledge of standards outside your current grade level will allow you to review content previously learned by students and even introduce concepts they will learn in future grades.

Adopting an integrated approach does not necessarily require major changes to your current curriculum. It may, however, call for thinking about your curriculum differently. We suggest viewing your curriculum along a continuum from complete integration, with some overarching theme like global climate change, to a few small-scale, integrated lessons such as moss distribution and abundance. Think baby steps! You do need to carefully consider the integration of content in your lessons, making connections between the sciences evident, purposeful, and critical to understanding some larger concept. But don't feel obligated to incorporate concepts from each discipline in every lesson; connections should be meaningful and coherent. Finally, we advocate learning through inquiry as an inherently integrated approach, because students explore concepts from multiple disciplines to answer the questions of their investigations.

In this article, we shared our discovery of the fascinating relationship among moss, beech trees, and stemflow. The excitement we felt in uncovering the effect of stemflow on moss growth resonates as a central feature of scientific inquiry, one we want our students to experience firsthand. We also wanted to highlight the use of hypothesis testing and modification in science for explaining patterns observed in nature. Our main objective, however, was to use our investigation of moss to illustrate the meaning of integration as it relates to the concept of integrated science. We intend no authoritative stance on the subject; rather, we wanted to present our interpretation of integration as we continue to explore and struggle with how best to accomplish it in our classrooms. We hope to have stimulated interest, potentially initiating a dialogue among Michigan educators about the meaning and importance of integration in science education. At the very least, you should think twice before using moss growth on trees to find your way out of the woods!

Acknowledgments

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