Doing sophisticated science simply: Help students understand the nature of science

We all recognize the power of inquiry-based instruction when implemented in our classrooms. It engages students and motivates them to actively participate in their learning. But do our students develop a deep understanding of the nature of science? For example, students commonly strive to prove their ideas during scientific investigations. However, this mindset contradicts the tentative nature of science; even well-supported conclusions must be accepted with a degree of uncertainty. Albert Einstein highlighted this important aspect of science with, "No amount of experimentation can ever prove me right; a single experiment can prove me wrong" (according to an unsourced statement popularly attributed to Einstein). Comprehending its *tentative* nature is the first step toward developing a meaningful understanding of science. Students can do sophisticated science in your classroom, and this article describes how simple it is to facilitate.

What is science?

At its core, science involves asking and answering questions about our world. Yet, students often approach science by memorizing the steps of the scientific method without establishing an appreciation for the ability of science to predict and explain natural phenomena. Consider transforming your students' factual knowledge into a conceptual understanding of basic scientific inquiry. This shift in emphasis will generate more insight about the nature of science. Focusing on the process encourages students to emulate scientists—doing science to learn science—as called for in the National Science Education Standards (NRC 1996). Students propose several possible explanations (hypotheses) for their observations, attempt to eliminate them one by one, and tentatively accept the one (or ones) that remain. They collect and analyze evidence and explain their conclusions, just as scientists do when they publish and present their findings. Viewing their investigations as a *process* of basic scientific inquiry allows students to continue to develop a more sophisticated understanding of science.

Science with your students

Whether doing an environmental investigation outside, or a controlled experiment in the classroom, remember to have students focus on making observations. The observations may be obvious at first, but encourage students to pay close attention to details. For example, while investigating the evaporation of water from a cup inside a plastic bag, students may only notice the missing water at first. However, upon closer inspection, they may also see little droplets of water that have condensed on the inside of the bag. Careful observation is the entry point into doing good science.

During this inquiry process, it is inevitable that questions will arise. Most students ask causal questions, otherwise known as the *why* or *what causes* questions. For example, "Why does moss grow on the north side of trees?" Because of the many factors potentially influencing them, *causal* questions tend to be complex and difficult to answer. However, they can be transformed into more readily answered *descriptive* questions. Descriptive questions are those that can often be answered by making a large number of observations and reaching a conclusion, based on the results. In this sense, making a large number of observations is much like conducting an experiment. For instance, "Does moss grow more often on the north side of trees?" To answer this question, students can count the number of trees with moss growing on the north versus the south side. Using evidence they collect themselves, students can reach a conclusion with a high degree of confidence.

Students can also use a series of related descriptive questions like this to investigate their original, more difficult to answer, causal question. For instance, questions such as, "Is there more light on the north side of trees?" and "Is it wetter on the north side of trees?" can begin to frame an understanding of why moss grows more abundantly on the north side of trees in the Northern Hemisphere (more shade and moisture). We do not suggest discouraging students from asking causal questions. Rather, our role as teachers should be working with students to ask good descriptive questions to help answer their more complex causal questions.

Sample investigation

Early one summer in a local Michigan forest, a few students noticed an abundance of oak leaves on the forest floor, but saw mainly maple trees overhead. From this observation, they asked the causal question, "Why are there so many oak leaves on the ground, but so many maple trees in the canopy above?" Students proposed the following hypotheses, or possible explanations:

H_1: Oak trees are actually more abundant than maple trees in the forest.
H_2: Oak trees produce more leaves than maple trees.
H_3: Oak leaves decompose slower than maple leaves on the forest floor.

Based on these hypotheses, they formed the following descriptive questions:

- Are oak trees more abundant in this area than maple trees?
- On average, do oak or maple trees produce more leaves?
- Do oak leaves decompose more slowly than maple leaves?

By proposing multiple explanations and transforming a potentially complex causal question into several more manageable descriptive questions, students were able to construct several tests to try and eliminate the competing hypotheses one by one until just one remained.

Students counted oak and maple trees in the forest and determined that the two species were equally abundant. They counted the number of leaves on a one-meter section of several oak and maple tree branches of comparable size. They determined that the two species have a similar number of leaves on average. To compare the decomposition rates of oak and maple leaves, they created decomposition bowls in the forest. They placed freshly picked oak/maple leaves inside large open bowls with soil, rocks, and fallen branches, and made weekly observations of the leaves' decomposition. They found that maple leaves do indeed decompose more quickly than oak leaves. Based on the results of these tests, they rejected all but one of their hypotheses.

H_1: ~~Oak trees are more abundant than maple trees in the forest.~~
H_2: ~~Oak trees have more leaves than maple trees.~~
H_3: Oak leaves decompose slower than maple leaves.

Of course, students should be reminded to consider what exactly they have proved, if anything, recalling the tentative nature of science. What other possible explanations exist? Are there other contributing factors? Yes, our students found that oak and maple trees have a similar number of leaves per branch. But what if oaks have significantly more branches per tree than maples? That could also account for the large number of oak leaves in our forest, in addition to slower decomposition rates. We could have students explore this and other follow-up questions generated by their study. What a wonderful way for them to discover that scientific investigations often raise more questions than they answer!

Conclusion

We want students to experience the excitement of actually doing science: make observations, ask questions, and explain the collected evidence with posters, presentations, and written reports. The type of extended investigation we've described is necessary for students to develop a rich understanding of the nature of science. It more accurately reflects the way real science is practiced, relative to a cookbook-type laboratory experience. At the very least, we hope we've convinced you that it's simple to do sophisticated science with your students.

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Reference

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