ABSTRACT

I modified the classic Mystery Tube activity to teach not only the nature of science but also the nature of what is not science. In order for evidence and logic to be effective tools for teaching evolution, instructors may first benefit from giving students a tangible reason to set aside any prior nonscientific ideas they bring to the classroom. This activity helps instructors intentionally delineate scientific from nonscientific hypotheses, providing a clear and logical reason for teaching evolutionary theory, but not metaphysical ideas, in the science classroom.

Key Words: Nature of Science; evolution; inquiry; hypothesis; pseudoscience; Mystery Tube.

Teaching the nature of science (NOS) has become an essential part of the K–16 science curriculum. Science standards have made it increasingly clear that along with traditional science content, instructors must teach what science is and how scientific knowledge is acquired (National Research Council, 1996; NGSS Lead States, 2013). Science educators have reasoned that when students understand what science is, they are better equipped to learn and accept scientific concepts. However, this strategy may not be enough to address some of the unique difficulties teachers face when teaching concepts like evolution. Intentionally teaching what science is not may also be necessary in order to convey a full understanding of NOS and address some of the biggest roadblocks in evolution education.

For centuries, scientists and philosophers have considered what defines science as a discipline, how scientific knowledge is acquired, and what constitutes a scientific worldview, as distinct from other ways of interpreting the world. But only in recent decades have we asked teachers to educate all students in these NOS principles (American Association for the Advancement of Science [AAAS], 1990; McComas, 2004) so that students become equipped to evaluate the world through a scientific lens. Having students understand the scientific endeavor is especially important when teachers are addressing concepts, such as evolution, that are continually challenged by the nonscience community. In fact, the high school Next Generation Science Standards identify strand HS-LS4-1: Biological Evolution: Unity and Diversity as a specific content target for NOS integration. Pressure from political and religious groups has successfully sustained a public debate about whether nonscientific ideas like Creationism and Intelligent Design should be taught in the science curriculum (Shapiro, 2013). Lawyers have been asked to decide the fate of scientific education in light of the pseudoscientific claims that continue to threaten the discipline (Epperson v. Arkansas, 1968; Overton, 1982; Kitzmiller v. Dover Area School District, 2005). While science education groups have continued to stand up to this continuing pressure (National Science Teachers Association, 2000, 2013; National Academy of Sciences, 2008; National Research Council, 2012), a lack of clear scientific understanding by the public is at the heart of these controversies. Therefore, effectively teaching NOS in every classroom is essential to preserving the K–16 science content curriculum.

Many curricular activities attempt to separate scientific evolutionary theories from metaphysical explanations of Intelligent Design or Creationism by trying to debunk these nonscientific ideas with scientific evidence and logic. Using compelling evidence is a powerful tool, but it doesn’t get at the heart of the conflict students have. Students with a religious belief or strong metaphysical background often do not find the presence of scientific evidence convincing enough to replace their prior ideas. In fact, the use of evidence to show that their belief system is “wrong” often makes students all the more resistant to evolution instruction. This is one key difference between the disciplines of science and religion. While scientific ideas can change in light of new information from the natural world, metaphysical belief systems do not. This makes it nearly
impossible to use scientific logic to oppose metaphysical belief. In addition, students resent it when instructors completely ignore the existence of their nonscientific beliefs and leave the impression that there is only one “right” way to interpret the human experience.

The classic Mystery Tube activity (Lederman, 1997; McComas, 1998) readily engages students in the process of scientific inquiry (National Academy of Sciences, 1998) but does not intentionally address both scientific and nonscientific hypotheses. Because this activity experiments almost exclusively with scientific hypotheses based on natural laws, it can leave students with the impression that all hypotheses are scientific and can be tested and evaluated equally. Modification of this classic NOS activity builds on the previous work by Lederman et al. (1997) by intentionally including nonscientific hypotheses. This approach allows a more complete understanding of NOS and works to eliminate any attempts that students may make to put scientific hypotheses head-to-head with faith-based hypotheses and other metaphysical beliefs, particularly when learning about evolution. The modified activity also does not dismiss the existence of these metaphysical ideas, but instead helps students categorize them as nonscientific hypotheses to be addressed by other, nonscience disciplines.

**Using the Mystery Tube**

The Mystery Tube experiment can be used as a stand-alone activity to introduce NOS and the process of scientific inquiry in any science classroom. It is physically and mentally engaging and sets the stage for the types of inquiry experiences students can expect when learning science throughout the year. I typically use it at the beginning of the year but keep my Mystery Tube handy at all times, using it as an instructional reminder each time students are asked to make observations and generate hypotheses. It is especially useful to review this activity and NOS prior to teaching key content in Evolution. Alternatively, the Mystery Tube activity can be used as an immediate introduction to an evolution unit that directly applies these Mystery Tube NOS concepts in an inquiry-based curriculum. The Mystery Tube itself is simple enough for any grade level to manipulate, and the activity can easily be modified for younger grades by using more general terminology and less detail (Lederman, 2014). Younger children should have no problem with the basic process of scientific inquiry, but they may require more instruction in how to distinguish between natural and supernatural properties.

**What Science Is**

The classic Mystery Tube experiment has been used for years as an inquiry activity to demonstrate NOS (National Academy of Sciences, 1998). To construct the tube, the teacher makes four holes in a cardboard toilet paper tube or PVC pipe and runs two strings or ropes through the holes and knots the ends. Inside the tube, the ropes are looped or tied so that they pull on one another when the ends are tugged. Figure 1 shows the simplest Mystery Tube configuration teachers typically make, but any configuration in which the ropes are connected in the middle behaves similarly. The ends of the tube are then sealed using nontransparent tape or end caps so that students cannot see inside the tube. Students are then asked to experiment with the tube by pulling the knotted ends and observing the behavior of the ropes. On the basis of these observations, they are asked to make hypotheses about what must be happening inside the tube for the ropes to behave as they do.

Of course, there are many possible hypotheses for how the ropes are configured inside, and instructors ask students to test their hypotheses by generating their own toilet-paper-tube models to compare with the original Mystery Tube. Students share their findings with others, reformulate new hypotheses from what they learn, and generate a pattern of commonality between functional designs. Students’ hypothetical drawings and tube models, along with short descriptions of their successes, failures, and conclusions about supported hypotheses, are assessed for accuracy and inquiry process skills. This experience specifically targets many of the key NOS parameters (AAAS, 1990; McComas, 2004):

- Scientific concepts are based on empirical evidence and logic.
- Scientific hypotheses are falsifiable, or at least verifiable.
- Scientific concepts are tentative but durable.
- Science does not follow a strict scientific method.
- Science is a social enterprise.
- Science is a creative process.

Most published Mystery Tube activities primarily address how the testable, scientific hypotheses that students come up with might be falsified through experimentation, but do not intentionally address the issue of nonscientific hypotheses. Students usually come up with some variation of the scientific hypotheses shown in Figure 2. All of these hypotheses are based on natural laws and
can be tested through modeling and experimentation, key concepts in NOS. When students are observing the Mystery Tube, they have no personal, nonscientific beliefs about it. So, usually, the hypotheses students generate are almost exclusively based on the predictable laws of nature. They do this automatically, because they hold no other metaphysical or supernatural views of this particular content. But instructors may take this universal construction of scientific hypotheses as an assumption that students must therefore understand what a scientific hypothesis is and why it is different from other hypotheses, when in fact students aren’t being engaged specifically to consider nonscience alternatives at all. Even when an instructor takes the time to discuss scientific versus nonscientific hypotheses at this point in the curriculum, they do so without nonscientific examples on which to anchor the discussion.

Because students usually generate scientific hypotheses, the traditional Mystery Tube activity fails to intentionally address the following important core principles of NOS (AAAS, 1990; McComas, 2004):

- Scientific hypotheses are guided by the laws of nature.
- Science cannot answer all questions (including those of morality, ethics, and faith).

This omission in the NOS curriculum becomes most disruptive when instructors attempt to teach scientific concepts like evolution, about which many students (and instructors) have nonscientific ideas that they incorrectly want to treat as scientific concepts. If instructors don’t intentionally teach what science is not, they are inevitably surprised when students put up a metaphysical roadblock to learning evolution. Intentional instruction in what science is not helps to gently and clearly explain what we can learn through scientific exploration and what ideas must be explored by other disciplines, such as philosophy and religion.

**What Science Is Not**

Occasionally during the Mystery Tube activity, a student will produce a hypothesis similar to those shown in Figure 3. The enchanted stick person, magic bubble, and leprechaun each represent a supernatural explanation for the behavior of the ropes. Students who make these types of drawings typically do so in order to get a laugh in the classroom, but I have found them to be the most instructive hypotheses of all. In fact, if no students come up with nonscience hypotheses, I draw one or two of them myself and ask students what they think. For younger students, I may draw the Tooth Fairy or Tinkerbell inside for a more relevant example. These drawings usually generate chuckles and an assortment of “You’re a crazy science teacher” remarks. But the discussion that follows is most valuable.

I ask students the following questions, have them discuss their thoughts in small groups, and guide them in generating their own parameters for what constitutes a scientific versus nonscientific hypothesis:

- Why are you laughing at the leprechaun tube hypothesis? Why don’t you think some of these hypotheses are scientific solutions for what’s happening in the tube? Students overwhelmingly feel that neither magic, nor a tiny stick person, nor a supernatural leprechaun is responsible for the behavior of the ropes. Their reasons for this are varied but are usually based on prior experience with, and confidence in, the laws of nature.
- How can you know for sure which hypotheses can be evaluated scientifically and which cannot? Students generally know that science commonly involves testing. When asked, they quickly articulate that they can reproduce a model of the hypotheses in Figure 2. However, none of them can come up with a way to test the hypotheses in Figure 3, because to do so would require them to reproduce real magic or supernatural activity.
- What happens to these nontestable hypotheses? Do they have any validity? Because students have no personal beliefs in magical stick people or leprechauns, they typically want to discard these hypotheses altogether. Most students agree that these nonscientific hypotheses cannot be addressed as scientific concepts. However, I then ask them, “If they can’t be tested scientifically, are there other disciplines that may be interested in exploring supernatural hypotheses?” For many students, it’s the first time they’ve considered how to separate their thoughts about the world into different categories.
The discussion eventually leads us to a correct, although generalized, list for the parameters of a scientific hypothesis: (1) Based on predictable laws of the natural world. (2) Testable. (3) Falsifiable. I also ask students to define the parameters of a nonscientific hypothesis, just to solidify the point. Students come to a consensus on these “other” hypotheses: (1) Based on the supernatural or metaphysical. (2) Not testable. (3) Not falsifiable. (4) Hypotheses, but not scientific hypotheses.

I keep these lists posted all year and revisit them each time my students are asked to generate hypotheses or evaluate scientific data. Engaging in this activity prior to teaching evolution theory allows us to clearly establish the boundaries of science. Students are assessed, following the Mystery Tube activity, on their ability to determine whether each hypothesis from an instructor-generated list is scientific or nonscientific. They must articulate a clear reason for each choice they make, using NOS parameters. In addition, I often ask students to choose one of the scientific hypotheses and briefly describe how they might test it scientifically. The ultimate learning goal is for students to understand that there are many ways of interpreting the world, but only those that follow the laws of nature are scientific.

Evolution instruction that follows this Mystery Tube activity can build on the established NOS foundation. Instructors can provide observations to students and help them generate explanatory hypotheses. For example, Darwin's observations about turtle shells on the various Galapagos Islands, or an evolutionary tree showing the absence of tetrapods until the Devonian period, or an anatomical comparison of forearm bones in various animals, can spark a varied list of hypotheses. By now, students are ready to sort these into scientific and nonscientific ideas and explain their choices. Any nonscientific hypotheses are then set aside, while the scientific hypotheses are carried through subsequent activities that provide additional data for students to evaluate. Eventually, the list of hypotheses narrows to those that support the key concepts of evolutionary theory, based on available evidence. These types of layered experiences guide students through the entire process of science, generating and evaluating hypotheses critically using NOS parameters.

In my experience, the modified Mystery Tube activity removes the tension that can surround evolution instruction. When evaluating a list of hypotheses related to evolution theory, students are able to separate scientific from nonscientific ideas without feeling the need to defend their metaphysical beliefs. In addition, the use of this activity enables teachers to have authentic, evocative conversations about evolution content without having to defend the exclusion of Creation stories and Intelligent Design from the science curriculum.

**Conclusion**

This modified Mystery Tube activity introduces an effective way to teach all facets of NOS, including both what science is and what it is not. For teachers and students who have metaphysical or religious beliefs, the intentional addition of nonscientific hypotheses to the activity gives clear reasons why the science curriculum includes evolutionary theory but not other, supernatural, ideas. The activity provides a neutral environment in which to teach students the boundaries of science by separating scientific from nonscientific hypotheses. These clearly articulated parameters can then be applied to content areas like evolution, where the controversy over what should and shouldn’t be taught in science classrooms continues to cause public debate. The categorization of scientific and nonscientific hypotheses in this activity also relieves the “either science or faith” issue and allows for the acceptance of multiple worldviews, while at the same time clearly demarcating what can be taught within the scientific discipline.

**References**


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