Hypothesis Generation in Biology: A Science Teaching Challenge and Potential Solution

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Abstract. Helping students understand and generate appropriate hypotheses and test their subsequent predictions—in science in general and biology in particular—should be at the core of teaching the nature of science. However, there is much confusion among students and teachers about the difference between hypotheses and predictions. Here I present evidence of the problem and describe steps scientists actually follow when employing scientific reasoning strategies. This is followed by a proposed solution for helping students effectively explore this important aspect of the nature of science.

Key Terms: Hypothesis, law, nature of science, prediction, science education, science teaching, theory

Introduction

I taught high school biology and chemistry for eight years before beginning a doctoral program in ecology and environmental science at the University of Illinois. Graduate school revealed, while I had been effective teaching science content to my students, I had mostly failed in teaching them the nature of science (NOS). Indeed, I had even promoted several of the *myths of science* outlined by McComas (1996)—most blatantly that “a hypothesis is an educated guess,” and “science is procedural more than creative.” I had even failed at understanding and teaching the hypothetico-deductive method of science that so many science teachers (this author included) mislead their students into thinking is *the only way to practice science*: formulate a hypothesis, deduce its consequences (make a prediction), and observe those consequences (perform an experiment and collect data).

For example, in my second year of graduate school, a chance conversation in the woods with one of my committee members revealed my own shortfalls. When pressed for the hypothesis I was testing with my research, I delivered the prediction that if we had an average spring warm up, then the timing of leaf growth, caterpillar hatching, and bird migration would be synchronized, but if we had an early or late spring, there would be a mismatch in one or more of the trophic levels. I had given my committee member an “educated guess,” an “If…, then…” statement exactly in the form I had learned in my science classes and identical to how I had taught my high school students to write hypotheses. While I may have based my prediction on some overarching patterns or underlying mechanisms that were already known for the community interactions I was studying, I certainly could not verbalize them.

Since returning to teaching high school biology after graduate school I work to help my students hone the scientific reasoning strategies of abduction (ingenuity, or borrowing an idea from earlier studies), deduction, and induction. But with such a NOS focus in my classroom on these reasoning skills, I have become somewhat hypersensitive to moments when students get it wrong. For example, when students inappropriately marry a method with the tail end of a deductive statement (*If I do X, then Y will happen*.) and call it a hypothesis.

The most common way a hypothesis is used in scientific research is as a tentative, testable, and falsifiable statement that explains some observed phenomenon in nature. We more specifically call this kind of statement an *explanatory hypothesis*. However, as we will see, a hypothesis can also be a statement that describes an observed pattern in nature. In this case we call the statement a *generalizing hypothesis*.

In the sections that follow, I will present evidence that students, teachers, textbooks, and even practicing scientists confuse predictions with generating hypotheses. I will then discuss the ways the terms are defined and used in the logical practice of scientific reasoning. Finally, I will provide some simple ideas for how we can improve the teaching of the nature of science in the classroom.

There is a problem: Data from the field

In 2006, I chaperoned a group of high school students presenting pre-college research at the Intel International Science and Engineering Fair (Intel ISEF) in Indianapolis. Upon inspection of a wide range of student poster presentations, I observed that several students had written predictions on their posters but labeled them as hypotheses. In the interest of quantifying this misconception, I quickly designed a stratified random sampling strategy and visited and read all non-engineering and non-math project posters with project numbers ending in 1, 4, or 7 (n = 127). In this initial survey, 78 (80%) of 98 student posters reviewed had incorrectly identified a prediction as a hypothesis.

Where had these students gone wrong or been misled during their formal science education or in their science fair preparation work? Indeed, it is human nature to formulate explanations for observations that we make about natural phenomena (Brewer, Chinn, and Samarapungavan, 1998; Lawson, 2004). Cognitive scientists sometimes argue that children are themselves "little scientists." For example, children with little or no formal training in the process of science can propose functional hypotheses to explain a natural event (Vosniadou and Brewer, 1992) and causal hypotheses to explain how one event in nature may affect another (Samarapungavan and Wiers, 1997). Have we, the science educators, excised reasoning skill from our students?

For the Intel ISEF Indianapolis survey and other surveys I report next, I followed the definitions of hypotheses described above, as candidate explanations or generalizations for observations seen in nature. If a proposed explanation or generalization of a pattern is valid, then we can anticipate (predict) a particular outcome from an experiment or that we will see the pattern elsewhere in nature. Therefore, a scientific hypothesis can lead to predictions (Singer 2007; Campbell *et al*. 2008), but it is not itself, just a prediction. This misconception is very common.

Students. My interest in student misunderstanding of the hypothesis was piqued at the 2006 Intel ISEF, so colleagues and I have now surveyed 1,864 student project posters at eight Intel ISEF competitions (2006, 2008-2014; Table 1). Students had identified hypotheses on 1,448 (78%) of their posters, but wrote predictions 81.2% of the time. On only 272 (18.8%) of the posters had students written candidate explanations or generalizations (Table 2). Failure to write hypotheses was consistently greater than success across years and the two groups were statistically distinguishable (Paired *t*-Test: $t = 20.55$, df = 7, $P < 0.001$).

Table 1. Summary of data collected at eight different Intel International Science and Engineering Fair competitions.

ISEF Competitions	Total Projects Surveyed	A Hypothesis identified and correctly constructed		A Hypothesis identified but written as a prediction	
		n	%	*n*	%
Indianapolis 2006	127	20	20.4	78	79.6
Atlanta 2008	199	20	14.1	122	85.9
Reno 2009	248	29	14.1	177	85.9
San Jose 2010	256	32	15.4	176	84.6
Los Angeles 2011	299	41	17.7	190	82.3
Pittsburgh 2012	230	54	26.0	154	74.0
Phoenix 2013	225	41	22.8	139	77.2
Los Angeles 2014	280	35	20.0	140	80.0
Totals	1,864	272	$\bar{x}$ = 18.8%	1,176	$\bar{x}$ = 81.2%

Table 2. Authentic examples of incorrectly and correctly written hypotheses from (i) student posters at the Intel International Science and Engineering Fair, (ii) science textbooks, (iii) teachers, (iv) scientific papers, and (v) science educators.

	Incorrect	Correct
ISEF Students	If a plant receives fertilizer, then they will grow to be bigger than a plant that doesn't receive fertilizer.	It is hypothesized that the structural and functional integrity of the system as a whole is dependent on nerve activity.
	I believe resin content of various pine species will affect its energy output.	The foraging patterns of *S. carpocapsae*, as measured by directional response, are affected by electrical fields.
	It is hypothesized that a forefoot strike pattern will correlate with lower ground reaction forces.	Aspirin inhibits key oncogenic factors and/or activates pivotal tumor suppressor genes.
Textbooks	If food is present in the aquarium, then snails will move with greater speed (toward the food) (Green, 2004).	Marsh grass growth is limited by available nitrogen (Miller and Levine, 2010).
Teachers	If the farmer burns the prairie then the next year will produce taller plants in his field then the previous year.	The fire is replenishing the nutrients in the soil.
Scientists	We aimed to test the hypothesis of whether young healthy women will increase muscle mass and lose fat mass after undergoing 12 wk of intense resistance training (Josse *et al*., 2010).	Based on this observation, we hypothesized that natural selection may have influenced *AMY1* copy number in certain human populations (Perry *et al*., 2007).
Science Educators publishing in *The American Biology Teacher*	Micro-eukaryote diversity in the water samples will be different from micro-eukaryote diversity in sediment samples. If this hypothesis is true, we predict that we will obtain different DGGE banding patterns for water/sediment samples (Lauer et al, 2012).	In this example, the hypotheses could be that (1) rhizobia increase plant performance and (2) nitrogen fertilizer reduces plants' dependency on rhizobia (Suwa and Williamson, 2014).

Textbooks. In addition to the surveys conducted at Intel ISEF, I analyzed all 66 current middle school, high school, and college science textbooks used in my school district by assessing all nature of science chapters, all laboratory prompts, and glossaries. Fifty-four of the 66 science textbooks included instruction for understanding and 12 (18%) did not contain any mention of the hypothesis. Forty-two percent of textbooks that mentioned the hypothesis failed by confusing the hypothesis with a prediction in either (i) the definition of the hypothesis, (ii) an example hypothesis, or (iii) a lab prompt (e.g. “Propose a hypothesis about what will happen…”) (see Table 3 for examples). The largest proportion (13 of 17; 76%) of textbooks with this confused definition or use of the hypothesis came from the middle school sample. Six (17%) of the 35 high school science textbooks failed in at least one of the assessed categories. The 14 textbooks designed for the college market (and used in our upper level, IB and AP classes) fared best with only one (7%), a biology textbook, failing to teach the hypothesis as distinct from a prediction.

Table 3. Instruction statements from three textbooks within the 66 textbook sample for helping students understand the hypothesis. Included is an assessment of the ability of each textbook to effectively teach the hypothesis without confusing it with a prediction.

Textbook	Instruction Statements	Textbook Assessment
Middle School *Life Science* (Padilla 2009)	Definition: A possible explanation to a set of observations or answer to a scientific question. (p. 15) Example: If I add salt to fresh water, then the water will freeze at a lower temperature. (p. 810) Lab prompt: Write a hypothesis for an experiment you could perform to answer your question. (p. 27)	The definition is correct, but the example is incorrect—it is a method followed by a prediction. The lab prompt is written in a way that may encourage students to write a prediction.
High School *Biology* (Miller and Levine 2010)	Definition: A scientific explanation for a set of observations that can be tested in ways that support or reject it. (p. 7) Example: Marsh grass growth is limited by available nitrogen. (p. 6) Lab prompt: Form a hypothesis: given the objective of this lab and the materials you have to work with, what kind of change, if any, do you expect to see in the pH of the kimchi over the course of several weeks? (p. 266)	The definition and example are correct. However, the lab prompt is confusing because it instructs students to "form a hypothesis" but then prompts them to write a prediction.
College *Biology* (Campbell *et al.* 2008)	Definition: A tentative answer to a well-framed question--an explanation on trial. (p. 19) Example: The batteries in the flashlight are dead. (p. 19) Lab prompt: None	Both the definition and example are correct. No lab prompts appear in this textbook.

Teachers. I surveyed all 17 pre-service science teachers in a 2013 graduate-level teacher preparation course focusing on the nature of science at the University of Colorado and 59 biology teachers, selected haphazardly, at the 2011 annual meeting of the National Association of Biology Teachers (NABT). I gave both groups (on the first day of the term for the students in the science education course) a "pop quiz" on paper that asked them to

1) write a definition of the hypothesis in science, and, after reading a set of observations, 2) write a hypothesis about the observations that could be tested with an experiment. In the science education course, five of the 17 teacher-candidates (29%) showed mastery of the hypothesis, while twelve (71%) confused the hypothesis with the prediction. Less than half of all responders (27/59; 45%) at the NABT meeting exhibited a genuine understanding of scientific hypotheses. Thirteen (48%) of the 27 responders with correct understanding were biology teachers with Ph.D. degrees.

As a comparison, Lawson (2002) reported that in a sample of pre-service middle and high school biology teachers 96% "confused hypotheses with predictions and agreed with the statement that a hypothesis is an educated guess of what will be observed under certain conditions." If this situation is not addressed explicitly, teachers are likely to pass this misunderstanding on to their students.

Scientists. I analyzed all (n = 300) peer reviewed, published scientific papers that are part of a teaching collection I have accumulated over several years of teaching various biology courses. The papers are mostly from fields of biology where hypothesis testing is common, but also represent other fields of science, as well as science education papers. Sixty-two percent (186/300) of the scientific papers analyzed use some form of the hypothesis term (hypothesis, hypotheses, hypothesize, or hypothesized) and 12.3% (23/186) mislabel predictions as hypotheses. Again, see Table 2 for examples of incorrectly and correctly written hypotheses from students, textbooks, teachers, scientists, and science educators.

How should *hypothesis* and *prediction* be defined?

Many textbooks oversimplify the definition of the hypothesis to *an educated guess*. But as McComas (1996) asks, “An educated guess about what?” Some textbooks do better; Campbell *et al*. (2008) in their popular upper level textbook, *Biology*, define the hypothesis as “A tentative answer to a well-framed question—an explanation on trial (p. 19) (Table 3). However, getting to that tentative answer or explanation is not as easy as it seems and many scholars have written about it.

Generalizing and explanatory hypotheses. McComas (1996, 2004, 2015) explains that observations of natural phenomena can produce two strands of hypothetical reasoning: generalizations and explanations. We often use generalizing hypotheses to summarize patterns we observe in nature and we can refer to these types of hypotheses as *immature laws*. If the generalizations hold true over and over again, they become established laws of nature. We then use explanatory hypotheses to provide reasons for the generalizations. Explanatory hypotheses can also be referred to as *immature theories*, because if the explanations survive various angles of rigorous testing they become established theories. Thus, theories can explain laws but never become laws.

As an example, consider Harvard University evolutionary biologist Jonathan Losos, who, with his colleagues, studies the *Anolis* lizards of the Caribbean Islands. One specific pattern that the researchers have consistently observed is that some anoles (e.g. *Anolis valencienni*) living on narrow twigs in their forest habitats have short legs (Losos and Schneider 2009). This observed pattern produces the generalization (generalizing *hypothesis* or *immature law*) that particular body shapes and sizes in anoles are linked to particular habitats and we can *predict* that anoles discovered living on twigs in forests on other islands will also have short legs. Losos and his colleagues proposed that adaptation to their twig habitats by way of natural selection was a likely explanation (explanatory *hypothesis* or *immature theory*) for the pattern of short-legged anoles living on twigs. In one experiment to test the twig adaptation hypothesis, small breeding populations of long-legged trunk anoles (*A. sangrei*) were placed on small anole-free islands with only small-twigged bushes as habitat (Losos *et al*. 2001). The *prediction* that follows the twig adaptation *hypothesis* is that, after several generations, the surviving anole population would have shorter legs as the environment and natural selection sift out the individuals with longer legs that are unable to use the twiggy habitat efficiently. Indeed, later generations of the anoles had significantly shorter legs than their ancestors. Figure 1 illustrates how these ideas are applied to the *Anolis* lizard example. Teachers might use a figure like this one in direct instruction to explain the situation or, to check for understanding, might ask students to create one after reading a scientific paper.

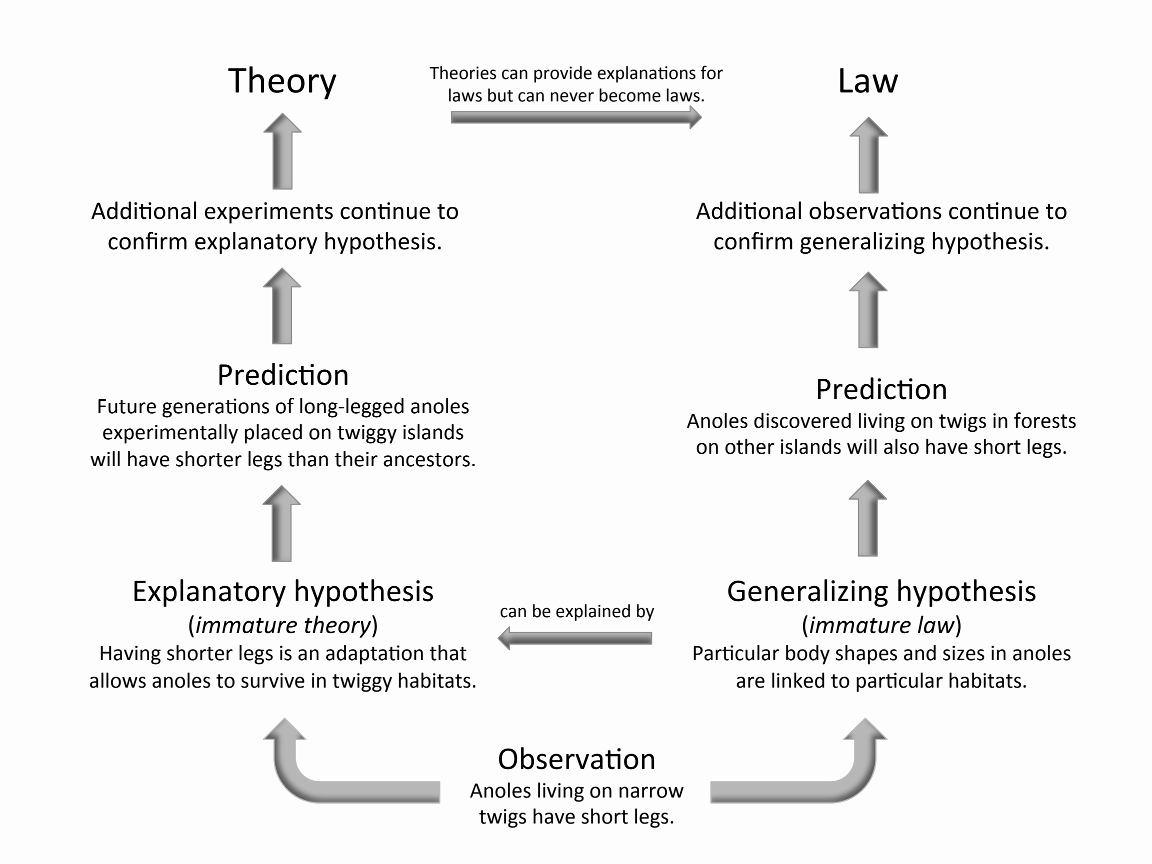

Figure 1. Two pathways to theories and laws by way of explanatory hypotheses and generalizing hypotheses. Note that both types of hypotheses can generate predictions and that explanatory hypotheses and their resulting theories can provide explanations for generalizing hypotheses and their resulting laws, respectively.

Abduction, deduction, and induction. In the above example, Losos and his colleagues moved through several levels of logic that have been summarized by Lawson (2010). These levels form the basic inferences of scientific reasoning, argumentation, and discovery—they are abduction, deduction, and induction. In noticing the short legs on twig anoles and that they moved easily in their twig habitat, the researchers proposed that the short legs were an adaptation driven by the uniqueness of the twig habitat. Proposing that the twig habitat may have driven the twig anoles to evolve short legs required some imagination and ingenuity on the part of Losos and his colleagues—a logical strategy in science called *abduction* and also known as the "creative leap" (Langley 1999). However, sometimes the abductive strategy involves literally abducting (figuratively stealing) an idea from the results of an earlier study. Indeed, adaptation had already been shown as an explanation for traits in other species. For example, different beak shapes and sizes of the Galapagos finches (e.g. the medium ground finch, *Geospiza fortis*) function as adaptations to different food resources. Perhaps Losos and his colleagues saw the connection between the short legs of the anoles and their twig habitats as an analogy to the small beaks of the medium and small ground finches and the soft seeds the birds eat. In short, *abductive reasoning produces explanatory hypotheses*, and sometimes through leaps of creativity.

If adaptation by natural selection is a reasonable hypothesis for the short legs on the twig anoles, then a logical consequence is that long-legged anoles placed in habitats with only twigs as perches would evolve shorter legs. This second logical strategy is called *deduction*—the researchers deduced an outcome of an experiment, a prediction, given the adaptation by natural selection hypothesis. Thus, *deductive reasoning tests ideas with predictions*.

When Losos and his colleagues looked at the results of their experiment, they found that the long-legged anoles had evolved shorter legs. They thus logically concluded that the result was in support of their twig habitat hypothesis and was also in support of established natural selection theory. This final logical step is called *induction*: if the observed result matches the predicted outcome, then the hypothesis is supported. As in

Figure 1, Figure 2 illustrates how abduction, deduction, and induction are applied to the *Anolis* lizard example.

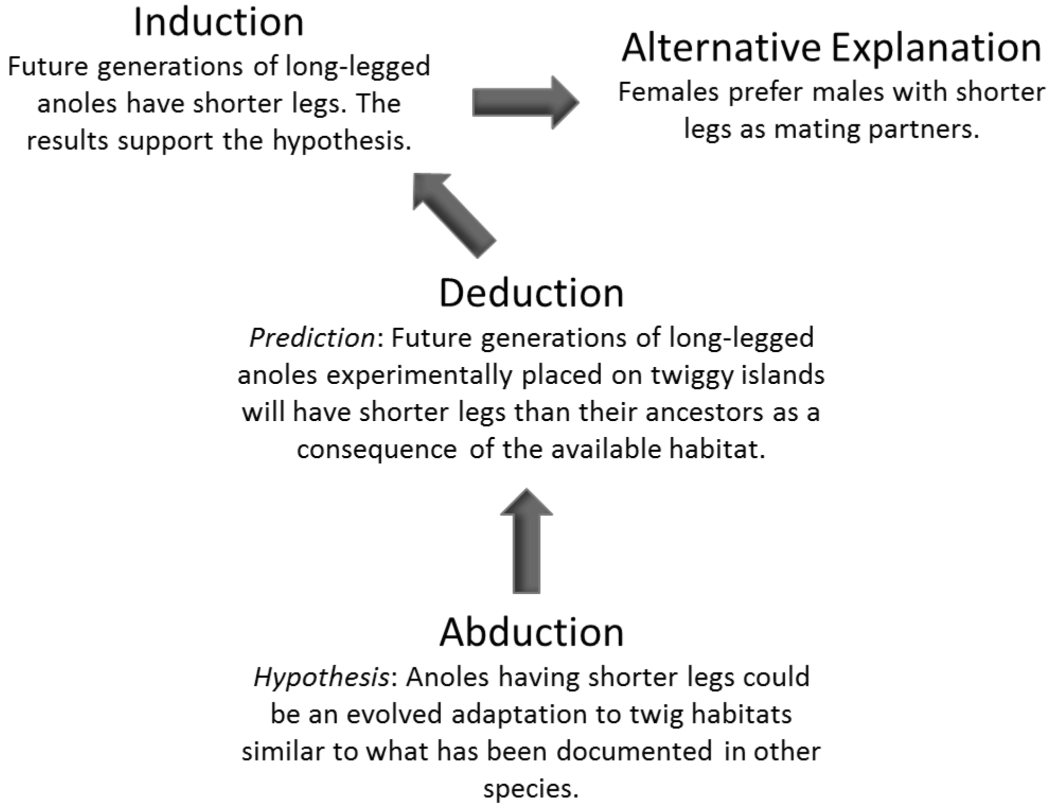

Figure 2. Three logical inferences of scientific reasoning: abduction, deduction, and induction. Note that the alternative explanation (hypothesis) can also produce the observed result of the experiment.

The process described above and illustrated in Figure 2 is often referred to in textbooks as the hypothetico-deductive strategy of “the scientific method.” It is important to point out here that hypothetico-deductive reasoning, coupled with induction is not without problems. First, if not tentative, a logical fallacy of induction is affirming the hypothesis without considering other explanations—there may be other hypotheses that explain the observed result. The case may simply be that females prefer to mate with short-legged males. Indeed, false hypotheses can produce true predictions. A second problem with induction is that in designing and carrying out our experiments and affirming our hypotheses we may unknowingly be making several assumptions, also called *auxiliary hypotheses*, that if violated throw doubt on our conclusions. For example, Losos and his colleagues assume that leg length in anoles is a strongly heritable trait, similar to beak size in finches. If the trait is not heritable, they will not see their predicted result.

Solving the problem of "hypothesis" in the science classroom

The results of the various surveys reported here are evidence that many of our students are not learning how to formulate and propose hypotheses to drive their scientific studies. Even our best science students, those who qualify for the Intel ISEF, are generating predictions but calling them hypotheses. These mistakes likely arise from several correctable teaching approaches. First, and perhaps the most commonly observed error in teaching hypothesis writing is having students write "if..., then..." statements, where the *if* phrase is actually an experimental method, and the *then* phrase is a specific prediction. For example, a textbook, a teacher, or a student may propose the prediction, "*If fertilizer is added to the soil, then the plants will grow taller*," but call it a hypothesis. Textbooks, teachers, students, and scientists who propose predictions in place of explanations are skipping abduction and analogical reasoning and proceeding directly to making predictions (Lawson 2004).

The if-then mistake is correctable. For example, when my students verbalize or write predictions and call or label them as hypotheses, I point out the mistake, but then ask them *how* or *why* they are able to make those predictions. Students invariably begin their answers with, “Because…,” and often end up stating something close to the hypotheses they are testing. Using this strategy, we can guide our students toward a generalizing hypothesis or help them work through analogical reasoning and abduct an explanatory hypothesis. An additional strategy to help students delineate the hypothesis from the prediction is to have students write predictions and *label them as predictions* when they are planning their investigations. Perhaps the most critical component of this pedagogical strategy is that students become focused on keeping their explanations (generalizing or explanatory hypotheses) as completely separate statements from their predictions.

A second, egregious, and all too common practice is when teachers require students to write hypotheses for “canned” lab activities, the likely objective of which are simply to make determinations, such as the value of a physical constant (Yip 2007). In these cases, teachers can help students to write generalizing hypotheses that explain patterns, but *only after* students have made some observations and recorded some data. In all cases, teachers may consider providing students with a flow chart similar to Figure 1 above that helps students move through the two strands of generating explanatory and generalizing hypotheses and their related predictions.

Finally, teachers are advised to take a close look at the textbooks they are using and carefully assess how their textbooks define and use the hypothesis. They may indeed be using a textbook that confuses students on some level about what hypotheses are.

Correcting the confusion between the hypothesis and prediction in particular and the nature of science in general will not happen over night, or even within the next few weeks, but it does begin with readers like *you*.

Conclusion

Science is an essential course in a student's formal education but many have demonstrated that misunderstanding of the nature of science by students and teachers can be a major challenge. Perhaps the most important goal of science education in a democracy is to produce a future consensus of public policy makers and an informed electorate who have a scientific understanding of the natural world. Indeed, a lack of understanding of the nature of science has made it far too easy today for science denial and pseudoscience to influence personal and public decision-making (Flammer 2006). Science educators thus must teach students how to use the logical strategies of scientific reasoning and how to employ the procedures for obtaining meaningful and credible knowledge through scientific results that will contribute to scientific knowledge and to the formation of effective, evidence-based public policy (Forrest 2011; Dias *et al*. 2004). The public must understand how science works, and I am convinced that we can produce a more scientifically literate public and have a measurable impact on the understanding by the public of how science works if we commit to a greater focus in science education on the nature of science, starting with the hypothesis.

References:

Brewer, W.F., Chinn, C.A., & Samarapungavan, A. (1998). Explanation in scientists and children. *Minds and Machines*, *8*(1), 119-136.

Campbell, N.A., J.B. Reece, J.B, Urry, L.A. Cain, M.L., Wasserman, S.A., Minorsky, P.V., & Jackson, R.B. (2008). *Biology, 8th Ed.* San Francisco, CA: Pearson Benjamin Cummings.

Dias, R.A., Mattos, C.R., & Balestieri, J.A.P. (2004). Energy education: breaking up the rational energy use barriers. *Energy Policy, 32*, 1339-1347.

Flammer, L. (2006). The importance of teaching the nature of science. *American Biology Teacher 68*, 197-198.

Forrest, B. (2011). The non-epistemology of intelligent design: its implications for public policy. *Synthese, 178*, 331-379.

Green, T.F. (2004). *Marine Science: Marine Biology and Oceanography*. New York, NY: Amsco School Publications.

Josse, A.R., Tang, J.E., Tarnopolsky, M.A., & Phillips, S.M. (2010). Body composition and strength changes in women with milk and resistance exercise. *Medicine and Science in Sports and Exercise, 42*, 1122-1130.

Langley, A. (1999). Strategies for theorizing from process data. *Academy of Management Review, 24*, 691-710.

Lauer, A., McConner, L., & Singh, N. (2012). Micro-eukaryote diversity in freshwater ponds that harbor the amphibian pathogen *Batrachochytrium dendrobatidis* (*BD*). *The American Biology Teacher, 74*, 565-569.

Lawson, A.E. (2002). Sound and faulty arguments generated by preservice biology teachers when testing hypotheses involving unobservable entities. *Journal of Research in Science Teaching, 39*, 237-252.

Lawson, A. E. (2004). The nature and development of scientific reasoning: A synthetic view. *International Journal of Science and Mathematics Education*, *2*, 307-338.

Lawson, A. E. (2010). Basic inferences of scientific reasoning, argumentation, and discovery. *Science Education 94,* 336-364.

Losos, J. B., Schoener, T. W., Warheit, K. I., & Creer, D. (2001). Experimental studies of adaptive differentiation in Bahamian *Anolis* lizards. In *Microevolution Rate, Pattern, Process* (pp. 399-415). Springer, Netherlands.

Losos, J. B., & Schneider, C. J. (2009). Anolis lizards. *Current Biology, 19*, R316-R318.

McComas, W. F. (1996). Ten myths of science: reexamining what we think we know about the nature of science. *School Science and Mathematics, 96*, 10-16.

McComas, W. F. (2004). Keys to teaching the nature of science. *The Science Teacher, 71*, 24-27.

McComas, W. F. (2015). Revisiting the myths of science: Enhancing science teaching by focusing on its nature. *The Connecticut Journal of Science Education, 52*, 20-30.

McPherson, G. R. (2001). Teaching & learning the scientific method. *The American Biology Teacher*, *63*, 242-245.

Miller, K.R., & Levine, J. (2010). *Biology*. Upper Saddle River: Pearson Education.

Padilla, M. J. (2009). *Life Science*. Upper Saddle River: Pearson Education.

Perry, G.H., Dominy, N.J., Claw, K.G., Lee, A.S., Fiegler, H., Redon, R., Werner, J., Villanea, F.A., Mountain, J.L., Misra, R., Carter, N.P., Lee, C., & Stone, A.C.

(2007). Diet and the evolution of human amylase gene copy number variation. *Nature Genetics, 39*, 1256-1260.

Samarapungavan, A., & Wiers, R. W. (1997). Children's thoughts on the origin of species: A study of explanatory coherence. *Cognitive Science*, *21*, 147-177.

Singer, F. (2007). Dualism, science, and statistics. *BioScience*, *57*, 778-782.

Suwa, T., & Williamson, B. (2014). Studying plant-rhizobium mutualism in the biology classroom: connecting the big ideas in biology through inquiry. *The American Biology Teacher, 76*, 589-594.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive psychology*, *24*, 535-585.

Yip, D.Y. (2007). Biology students' understanding of the concept of hypothesis. *Teaching Science, 53*, 23-27.

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