Mr. Dr. Science Teacher

A high school science teacher with a Ph.D. in Ecology and Evolution reflects on teaching, science, and teaching science in the public schools.

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HYPOTHESIS, **SCIENCE PRACTICES**, **TEACHING METHODS**

Teaching the Hypothesis

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In science, there is no one *scientific method*. In fact, we practice scientific methodology in various ways. Sometimes we make observations about nature, ask questions, answer those questions with explanations or generalizations (hypotheses), and test our answers with predictions and experiments. However, while sometimes the way we do science is mostly linear, most of the time this approach to science is oversimplified. 'Understanding Science' at the University of California at Berkeley provides some excellent details on the nonlinear nature of the scientific process here (http://undsci.berkeley.edu/article/howscienceworks_01) and here (http://undsci.berkeley.edu/article/0_0_0/howscienceworks_02).

Scientific methodologies are also not always hypothesis-driven. Some scientific pursuits are based in *discovery science*, in other words, looking for relationships in nature or simply measuring and describing things in nature. But discovery science can generate hypotheses. Other scientific methodology involves testing *models*. For example, we use the semipermeable model to describe the cell membrane. We can test this model by predicting that some kinds of substances can move across the cell membrane and while others cannot. Models can function as testable hypotheses–explanations for how this work or are put together–but that is not the focus of this particular post. Finally, we have engineering, computer science, and mathematics. Engineers, computer scientists, and mathematicians identify problems, formulate goals, and design solutions to the problems.

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, a hypothesis can also be a statement that describes an observed pattern in nature. In this case we call the statement a **generalizing hypothesis**. Explanatory hypotheses are often used to explain the mechanisms behind the patterns that generalizing hypotheses describe. The hypothesis statement can be followed by the specific, measurable prediction you can make if the hypothesis is valid. Thus, we can think of the hypothesis in science as an explanation or generalization on trial.*

Prediction

A prediction in science is a prophecy, a specific and measurable event that is likely to happen in the future as the result of an experiment if the hypothesis is valid.

This post focuses on science that is driven by explanatory hypotheses and aims to help teachers understand what an explanatory hypothesis is in science and how ***the hypothesis is different from the prediction***.

Teaching the Hypothesis Incorrectly

Many teachers and even many textbooks never mention the generalizing hypothesis and teach the hypothesis in a way that makes it no different from a prediction. They teach students to write "If – then" statements for their hypotheses. This approach results in the incorrect form: *If I do X, then Y will happen.* There is no hypothesis here. This is simply a method (*if I do X*) followed by a prediction (*then Y will happen*). Some teachers and textbooks add "*…because…*" at the end of the "If…, then…" statement. The *because* statement is often close to the hypothesis that is being tested, but it still does not carefully delineate the hypothesis from the prediction. Indeed, even professional scientists can make mistakes. This misunderstanding that has been born out of science education is not new. In fact, science education specialist and the current editor of The American Biology teacher, William McComas, identified the hypothesis-as-prediction idea as one of the Ten Myths of Science (http://people.nnu.edu/jocossel/BIOL1010/Myths%20of%20Science.pdf) nearly 20 years ago.

See Table 1 for some authentic good and bad examples.

Table 1. Authentic examples of incorrectly and correctly written hypotheses from (i) students at the Intel International Science and Engineering Fair, (ii) science textbooks, (iii) teachers, and (iv) scientific papers.

	Incorrect	Correct
ISEFStudents	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).

How to Correctly Formulate an Explanatory Hypothesis

Let's say an ecologist notices that in some spring seasons, the migrating birds arrive at their breeding grounds about the same time that their food resources are peaking in availability. The ecologist may ***explain*** this observed pattern with the ***hypothesis*** that the birds and their food resources, usually insects, are responding to the same environmental cues (warm spring temperatures). The ecologist could then ***predict*** that regardless of how early spring comes, the birds and their insect prey will always be somewhat synchronized in time. The ecologist could then test the hypothesis and prediction by carefully recording numbers of birds and their insect prey over several spring seasons. However, there are *alternative hypotheses* in this scenario. For example, the birds and insects may be using different environmental cues. Perhaps the birds use day length to time their movements north in the spring and the insects do in fact use temperature. If this hypothesis is valid, then the ecologist can predict that the birds and insects will become unsynchronized in early springs–the insects hatching early with the birds arriving the same time on the calendar as they always do.

Explanatory Hypothesis 1: *Birds and insects respond to the same environmental cues, mostly temperature.*

Related Prediction: *Birds and insects will remain synchronized regardless of the timing of spring.*

Explanatory Hypothesis 2: *Birds use day length while insects respond to spring temperatures.*

Related Prediction: *In early or late springs, the birds will arrive at the same time as always, while the insects will appear either early or late, depending on the timing of spring.*

The Research Hypothesis

Some scientists, in their experimental planning stages, write a large, sophisticated statement called the *research hypothesis*. Research hypotheses force scientists to be very clear to themselves and their colleagues about exactly what the explanation is that they are testing, the general method they are using to test it, and the prediction they can make if their explanation is reasonable. The research hypothesis follows the form: *If X is a valid hypothesis (explanation), and I perform Y methods (experiment), then I can predict Z as a specific measurable outcome*.

In the birds and their insect prey in spring example, the ecologist may state her research hypothesis the following way:

If birds use day length to time their movements north in the spring while their insect prey respond to warming spring temperatures, and I record the daily number of birds and insects in a forest for several spring seasons in a row, then in early springs the birds will arrive after the insects have already peaked in abundance while in late springs the birds will arrive before there are enough insects for them to eat.

While the above example is a sophisticated way to state a hypothesis, it may not be the best way to communicate a hypothesis and prediction in a scientific report or in a science fair setting.

Getting Students to Think About Hypotheses: Imagine this scenario…

A teacher was guiding her students through science inquiry. She had her students analyze several small tomato plants she had grown and record their observations. The students observed that roughly half of the plants were taller, were darker green, and had more leaves than the other plants. The students also noticed that on stickers on the pots with the better-looking plants was the word "nitrogen." Following is a hypothetical conversation the teacher might have with one of her students to help him plan an experiment and work on his understanding on the role of the hypothesis in scientific methodology. Notice how the teacher reinforces to the student that the hypothesis is an explanation.

Teacher: "What did you observe about the tomato plants?"

Student: "I noticed that the plants labeled nitrogen were taller, were darker green, and had more leaves than the other plants."

Teacher: "What hypothesis can you think of that might explain what you observed?"

Student: "I think that if I add nitrogen to some tomato plants, then they will grow taller than other plants."

Teacher: "Okay, what you have given me is a prediction of what you think will happen in an experiment. ***Why*** *are you able to make that prediction?"*

Student: "Because it looks like the nitrogen helps the plants grow better."

Teacher: "That's more like it! What you've just given me is an explanation, an actual hypothesis. But I think you can make it even better. For example, we call those materials that organisms take in from the environment and are helpful in growth and development nutrients. Knowing that, how can you improve that hypothesis?"

Student: "How about nitrogen is a nutrient and helps plants like tomatoes grow better."

Teacher: "Sounds great! Now you've got a testable explanatory hypothesis. How could you design an experiment to test this hypothesis?"

Student: "I could grow tomato plants in ten separate pots of soil with no fertilizer and other tomato plants in ten separate pots of soil with nitrogen fertilizer."

Teacher: "So, the only variable you would change is presence or absence of fertilizer and you would keep all other variables the same?"

Student: "Yes."

Teacher: "What then is your prediction if your nitrogen nutrient hypothesis is a valid explanation? In other words, what outcome of your experiment can you measure that will provide support for your hypothesis?"

Student: "I think the tomato plants grown with nitrogen fertilizer will grow faster and maybe even taller than the tomato plants without fertilizer."

The teacher then had students write their hypotheses and predictions in their lab notebooks as separate statements:

Explanatory Hypothesis*: Plants need nitrogen as a nutrient for growth.*

Prediction*: Tomato plants with grown nitrogen fertilizer will grow faster and taller and have more leaves than tomato plants grown without nitrogen fertilizer.*

In summary, here are three things to think about when you are guiding your students in science inquiry:

- Have students think carefully about their projects and help them decide if a hypothesis is appropriate. They may in fact be doing discovery science, be testing a model, or pursuing an engineering goal. In these cases, asking students to write hypotheses results in students writing predictions, or just being really confused.
- If the project is testing a hypothesis, help students avoid "If – then" statements because it becomes too likely they will write a method followed by a prediction and forget the hypothesis altogether. If a student does write a prediction and call it a hypothesis, ask them **why** they are able to make that particular prediction and emphasize that ***hypotheses are explanations or generalizations about nature***.
- Instruct students to carefully separate their hypotheses from their predictions in their planning so that they are able to articulate, "This is the overarching explanation or generalization I am testing and this is the prediction I can make if my hypothesis is valid."

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