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Distorting the Process of Scientific Inquiry

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There is beauty in the scientific method, but that beauty can become distorted if parts of the process are misrepresented, misplaced, or missing altogether. Unfortunately, such distortion is becoming more common. Specifically, students and practicing scientists alike are dwelling excessively on statistical hypothesis testing at the expense of research hypothesis testing. Many are even using the word *prediction* in association with statistical hypothesis testing, where it does not belong. Consequently, these distortions are converting a process designed to help explain natural phenomena through the use of strong inference (*sensu* Platt 1964) into a process that is little more than an empty exercise in fact finding.

The reasons for an emergence of such distortions in the scientific method are unclear, but there are at least two issues that are likely to have played a role. First, there has been a concerted effort to downplay the linear, stepwise nature of the scientific method (National Research Council 2011). Indeed, a clear outline of the steps involved in the process of scientific inquiry is surprisingly difficult to find these days. This change in emphasis may have left people comfortable practicing only the initial fact-finding step and then passing that off as science. Second, similarities in the terminology associated with statistical and research hypothesis testing has not only caused confusion but has misled people into thinking that statistical hypothesis testing is the same thing as research hypothesis testing. As long as the words *hypothesis* and *prediction* are used, people think they are doing science! It would be timely to remind ourselves how the method of scientific inquiry actually works (Karsai and Kampis 2010), because sometime in 2012, the new Next Generation Science Standards are expected to emerge from the Framework for K–12 Science Education (National Research Council 2012).

The general nature of the scientific method is well described. Even its Wikipedia entry nicely summarizes that scientists "propose hypotheses as explanations of phenomena and design experimental studies to test these hypotheses via predictions which can be derived from them" (*http://en.wikipedia.org/wiki/Scientific_method*). The process of scientific inquiry is a logical procedure that involves the following four steps: (1) Find something interesting to talk about by using statistical hypothesis testing to expose an observation or pattern that is unlikely to have arisen from chance alone; (2) suggest alternative explanations (research hypotheses) for why the nonrandom pattern exists; (3) use *if–then* logic to generate a series of predictions that follow logically and necessarily from each hypothesis; and (4) distinguish among the alternatives by testing the predictions that were generated in step 3.

So how has such a simple process become distorted? It is an unfortunate coincidence that any explanation for a phenomenon is called a *hypothesis*, which is precisely the same word one uses to label alternative outcomes (the null and alternative hypotheses) in a statistical test. To avoid the risk of confusing the process involved in scientific inquiry, potential explanations for nonrandom patterns should be termed *research hypotheses* so that they are labeled as something distinct from *statistical hypotheses*. Unlike statistical hypotheses, which usually consist of two alternatives (random or not), there is no limit to the number of research hypotheses that a person might generate to explain a pattern. More important, research hypotheses are explanations; statistical hypotheses are not. Research hypotheses can be considered guesses, but those guesses are still explanations of a pattern; they are not, as is frequently taught, guesses about the outcome of an experiment. Another source of confusion involves the use of the word *prediction*. Predictions are not guesses about which hypothesis is the most likely explanation, nor are they guesses about the outcome of an experiment; they are logical consequences that follow necessarily from a stated research hypothesis, and they can be observational, comparative, or experimental in nature. Simply put, if a prediction is not part of an *if–then* series, it does not belong.

Just to illustrate that distortion of the scientific method occurs at an early age among students, consider the nature of most science-fair projects. They represent independent work, but relatively few projects can be classified as *science*, because most do not involve the last three steps outlined above. Most science-fair participants provide a purpose or stated question (e.g., Can I build a bridge? Can a hovercraft lift extra weight? How many licks will it take to get to the center of a Tootsie Roll Pop? Can I grow plants without soil?), but these questions alone are not at all suited to scientific inquiry, because they do not represent attempts to *explain* anything. Actual "hypotheses" that I observed in association with these questions (e.g., respectively, I bet I can; a hovercraft should be able to lift 400 pounds off the ground; it should take 277 licks; I should be able to) and the associated "predictions" (most often restatements of the hypotheses) are nonsense and are a clear indication that something is wrong with the participants' understanding of the scientific method.

Fortunately, many other science-fair participants provide a stated purpose or question that fits well into step 1 (e.g., Does music type affect one's blood pressure? Will lodgepole pine benefit from fire? Do girls have better memory than boys? Which disinfectant kills the most bacteria? Does age affect color perception?), but the participants then introduce "hypotheses" where they do not belong (e.g., respectively, classical music will lower and rock will increase blood pressure; fire helps lodgepole pine; girls will do better than boys; I bet Clorox will kill the most; yes, it will). Because of this, the "hypothesis" becomes no more than a guess at the answer to the *yes–no* question that the student posed as the purpose of the project, which is really no more than a step-1 attempt to expose a nonrandom pattern. These "hypotheses" are not step-3 explanations for something that has already been established as a fact or pattern in step 1. For too long, students have been told that a hypothesis is nothing more than what they think will happen. This represents a confusion of explanations (*research hypotheses*) with *predictions* that logically follow from any given explanation. Predictions are not gut feelings about the outcome of a test; they are logical consequences that must be true if the hypothesis is true.

Practicing scientists are not immune to distorting the scientific method, and these instances seem to be increasingly common. The words *hypothesis* and *prediction* appear in most scientific studies, but they are often entirely decoupled from the broader context of what should be an elegant, overarching method. Neither research hypotheses nor predictions are associated with step 1 (the observation step). One does not guess—"hypothesize" or "predict" in the lingo of those who abuse the terms—what the answer to a statistical test might be.

Students today have been led to believe that statistical hypothesis testing constitutes the entire process of science, because they have (inappropriately) inserted the words *hypothesis* and *prediction* into the exploration phase (step 1) of the scientific method. If fact finding (statistical hypothesis testing) alone is considered "science," the mere act of seeking an answer to a question would constitute science-based learning. Fact finding based on statistical hypothesis testing is a part of science but is only a part of the four-step process outlined above.

There may not be "one distinctive approach common to all science—a single 'scientific method'" (National Research Council 2011, p. 3-2), but we cannot ignore the stepwise nature of the process by testing "predictions" that do not emerge from a research hypothesis or by testing "hypotheses" that were not erected to explain something and still call that "science." The sources of confusion about the process of scientific inquiry are not difficult to understand, but eliminating the confusion first requires recognition that there is a problem. Therefore, I hope that exposing some of the distortions associated with this elegant method will help limit those that have become embarrassingly widespread. The consequences of our failure to clarify and simplify the process of science for students are profound. Not only are we driving children away from science through our failure to describe scientific inquiry as a simple yet creative process, but we are also graduating students who have never experienced or fully understood science as a way of seeking knowledge.

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