Our philosophical science correspondent Massimo Pigliucci says

Hypotheses? Forget About It!

Newton famously said "*hypotheses non fingo*," meaning, "I frame no hypotheses" – a rather startling position for a scientist to advocate. Isn't science precisely the activity of constructing and testing hypotheses about the natural world? Certainly this has been the view of influential philosophers of science such as Karl Popper. Popper said that scientific hypotheses can never be proven correct, but they can be *falsified*, that is *proven wrong*. For Popper, science progresses through the successive elimination of wrong hypotheses. Many scientists proudly ignore philosophy, but Popperian falsification is one of the only two philosophical concepts you are likely to find in an introductory science textbook. (The other is Thomas Kuhn's idea of *paradigms*. This is rather strange, since Kuhn was a fierce critic of Popper.)

I came across a delightful paper by David Glass and Ned Hall – the first a biomedical researcher, the second a philosopher – published in a rather unlikely place, the journal *Cell* (August 8, 2008). As its title states, the main point of the paper is to provide readers with 'A Brief History of the Hypothesis'. This makes it a must-read for young (and perhaps not so young) scientists. But what caught my attention in the paper is Glass and Hall's suggestion that, contrary to Popper's conception of science, scientists would be better off replacing hypotheses with two other guides to their research: questions and models.

Let me explain. Half of the problem with hypotheses was mentioned above: there is no way to conclusively prove a hypothesis correct, because there is always the possibility that a new set of observations will disprove it. The bad news is that, unbeknownst to most scientists, philosophers have also made a very compelling argument that hypotheses cannot be decisively *disproved* either. Falsification doesn't work, because one can always tweak the hypothesis enough to accommodate the initially discordant data, or question some of the ancillary hypotheses, or even question the accuracy of the data itself. (This is not as far fetched as it may seem given the complexity of the machinery used nowadays to produce scientific data, from particle colliders to genomic sequencers.)

What now? Glass and Hall advise us to go back to the basics. Science is really about asking questions, they suggest: "it would seem that a question is the appropriate tool because the question, as opposed to a hypothesis, properly identifies the scientist as being in a state of ignorance when data are absent." Right! I became a scientist because science has the power to answer questions about nature. Questions can be formulated in either open-ended or very specific ways, and both ways can provide guidance for fruitful empirical research. Besides, as Glass and Hall also note, in many fields of modern science one would not even know how to begin to formulate sensible hypotheses. For instance, in the field of genomics, it's easy to ask questions: how many genes are there in the human genome? How much does the human genome differ from that of other primates, and in what ways? But what sort of hypotheses could one possibly formulate to replace such questions?

Genomic research is highly explorative, so it is natural to base it on well-thought-out questions. Even when research is more advanced and less explorative, Glass and Hall contend that hypotheses still will not do, as they can't be proven and they can't be disproven. Instead, here we need *models* of the phenomena under study.

Unlike a hypothesis, a model is constructed after some of the data is in, and then the model is used to predict new data. A model can be statistical or directly causal in nature, mathematical or verbal, but its predictions are probabilistic and always subject to refinement.

It is the very dynamism of models which makes them powerful intellectual tools in the scientific quest for knowledge. Glass and Hall write: "eliminate the 'hypothesis' term and substitute the 'question' for settings where experiments are performed before sufficient data exist, and the 'model' for situations where the scientist is working with sufficient data to produce a construct that can be tested for inductive [predictive] power."

In fields which rely heavily on statistical analysis, such as biology and the social sciences, some scientists have already moved away from hypothesis testing to model comparisons. It used to be that statistical tests were rigidly set up to pit a simple (some would say simplistic) 'null hypothesis' (nothing's happening) against an alternative, catch-all hypothesis (there's something going on here...). Slowly but surely, people have figured out that this is not particularly productive, and recent years have seen a steady increase in the use of statistical software that can pit several alternative models against each other, with analytical methods that can tell which ones are more likely, given the available data.

The funny thing about all this is that a few years ago the US National Science Foundation made a 'philosophical' move in their guidelines for grant proposals. They explicitly asked scientists to do away with questions (the traditional way to frame grants) and to replace them instead with the more 'solid' concept of hypothesis. So now a prospective grant applicant can be seriously penalized if she does not put her proposal in a way clearly contradictory to Newton's dictum (I venture to say that citing Newton as a reference will not help). But this is what happens when scientists pay so little attention to philosophy that they are a few decades out of date with the philosophy of science literature. Maybe we should mandate Philosophy of Science 101 for all graduate students in the sciences.

Massimo Pigliucci is Chair of the Philosophy Department at City University of New York, Lehman College, and is the author of several books, including Making Sense of Evolution: The Conceptual Foundations Of Evolutionary Biology *(Chicago Press, 2006). His philosophical musings can be found at* www.platofootnote.org