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Why You Need to Read a Little Philosophy First

The Philosophy of Science Governs the Practice of Science

AT MEDICAL SCHOOL, STUDENTS ARE trained in the basics of the medical craft: how to perform a physical examination, interpret symptoms, approach a patient, and perform a differential diagnosis. At law school, the initial course load is designed to steep the novitiate in the forensic approach: how to write a brief, follow legal procedures and prepare contracts; how lawyers are expected to conduct themselves in various situations; and how to think like a lawyer.

Now, here is an amazing fact: At this writing, PhD and MD candidates receive very little formal instruction in the theory and practice guiding the design of experiments, despite the fact that the effective design, conduct, and interpretation of experiments is critical to their future success as basic and clinical scientists. In the curricula of universities, courses for PhD students in cell biology, biochemistry, genetics, physiology, and related disciplines are devoted almost entirely to substance: the facts gleaned from prior experimentation. Process—the way in which scientists must approach and conduct their experiments, the essential training as to how science should be performed—is often neglected.

Indeed, most graduate programs place very little emphasis on the formal processes required to perform experiments, nor do they discuss how these processes derive from various—and sometimes dissenting—theories of epistemology.[1] Throughout the history of biology, frank disagreements have arisen concerning ways of interpreting experimental data. Biologists must understand these dis-

[1] Epistemology is the study of knowledge—its limits and validity. Scientific epistemology is the subject of this book, addressed so as to be useful to the working scientist at the most practical level: How can we produce and interpret a data set that can be reproduced by others? How can we come to a conclusion that can be validated by its predictive power?

agreements so they can recognize different experimental designs that could be constructed to collect data and, from there, the distinct statistical methodologies that might be used in interpreting their data.[2] The scientist must be alerted as to how even the most common approaches to experimental design, data collection, and subsequent data analysis can unintentionally result in inappropriate interpretations and, most problematically, in representations of data that cannot subsequently be reproduced when the experiment is repeated by others.

The exception to this lack of procedural education is training in statistics. However, even this is sporadic, varying across scientific discipline and school. Moreover, in most statistics courses, there is little emphasis on inductive statistical methods, such as Bayesian statistics, that help the researcher to appreciate the probabilities of future outcomes. Furthermore, as is discussed later, a reductionist emphasis on the binary question of statistical significance ("binary" because an experiment is either statistically significant or it is not) sometimes clouds the equally important emphasis on the biological relevance of the effect seen. The premise for this book is that both the apprentice and more experienced scientists need a broader understanding of all of the steps that are required before, in concert with, and after consideration of statistical methods.

I wish I could report that there was a single, accepted, agreed-upon set of precepts that establish the basis for setting forward a scientific project. Unfortunately, there is instead a fundamental disagreement that has existed since at least the early 1700s as to what sort of conclusions are permissible from any prior knowledge. In this case, we mean, more pointedly, what we might conclude as a result of the data produced in a particular experiment, from a set of experiments, or even from an entire project. It is important for the scientist to understand this disagreement, because it explains the divergent schools of statistics, the use of terms such as "hypothesis falsification" versus "model verification," and the validity (or lack of validity) of predictive statements based on prior experience or, in the case of an experiment, prior data.

Before explaining this disagreement, we should discuss some basic premises. First, let us consider what scientific research is and what it can accomplish, because these concepts will help to establish parameters for what we seek to do in the laboratory.

[2] Statistics are outside the scope of this book, because that subject requires a text in itself. What is missing from most statistics books are the other issues that arise in formulating experiments, which create the demand for particular statistical approaches; it is those other issues that form the basis for this book.