Preface

Science is a process of asking questions, in most cases precise, quantitative questions that allow distinctions to be drawn between alternative explanations of events. Asking the right questions in the right way is a fundamental skill in scientific enquiry, yet in itself it receives surprisingly little explicit attention in scientific training. Students being trained in scientific subjects, for instance in sixth forms, colleges and universities, learn the factual science and some of the tools of enquiry such as laboratory techniques, mathematics, statistics and computing, but they are taught little about the process of question-asking itself.

The first edition of this book had its origins in a first-year undergraduate practical course that we, and others since, ran at the University of Nottingham for many years. The approach adopted there now also forms the basis for a more advanced second-year course. It is also the approach for FdSc- and BSc-level research methods courses at Cornwall College Newquay. The aim of all these courses is to introduce students in the biological sciences to the skills of observation and enquiry, but focusing on the process of enquiry – how to formulate hypotheses and predictions from raw information, how to design critical observations and experiments, and how to choose appropriate analyses – rather than on laboratory, field and analytical techniques per se. This focus is maintained in the fifth edition. However, as in previous editions, we have responded to a number of positive suggestions from people who have used the book, either as teachers or as students, which we think enhance further its usefulness in teaching practical biology generally.

Again, the largest change has been with respect to the presentation of statistical tests. In the fourth edition we replaced the previous boxes based on the procedures and output of the Statistical Package for the Social Sciences (SPSS®) with the freeware package '**R**®', obtainable from www.r-project.org. This collaborative project of biologists and statisticians worldwide is now pretty much the industry standard in biology. It also has the enormous benefit of an extensive user base who can provide advice rapidly when you hit a snag.

Thus in the fifth edition we have decided to base the analyses on R® alone, to encourage undergraduates to use it. Unlike most modern programs, R® is not a 'point-and-click' process, but you have to write the commands in yourself. This means you need to know what you are doing, otherwise you will not get any meaningful results. Several colleagues have suggested that this will be a barrier to modern undergraduates who have become used to simpler ways of obtaining output

from such programs. However, our experience teaching it to undergraduates shows that they learn it almost as quickly as any other package, and so the 'barrier' is not as large as many think. And using R® will be much more useful to students in the longer term.

The book website (www.pearsoned.co.uk/barnard) contains instructions for using SPSS®, Minitab®, Genstat® and the Excel®-based AQB package from the fourth edition, as well as data files. The formulae and hand calculations remain because, as previously, we consider it important that the underlying arithmetic of the tests is understood.

The range of tests remains as in the fourth edition, i.e. it includes, among other things, repeated-measures designs, analysis of covariance, multiple regression and principal components analysis. This is a wider spectrum of designs than is likely to be encountered in a first course in experimental design, but caters for many kinds of data collected in field-course and final-year projects. The Test Finder, Quick Test Finder and Help sections should enable students to find what test they need to carry out, while simultaneously underlining the principles involved.

With increasing emphasis on the wider communication and public understanding of science, we have retained the sections on presenting information. We include giving talks or presenting posters at scientific meetings, and writing for broader non-specialist readers such as newspapers and magazines. To the sections on using online literature databases such as the World of Knowledge, we have added some practical tips on how to extract the information you require from the literature such searches throw up. We have retained sections on the ethical implications of working with biological material, now an essential consideration in any study as legal regulation of biological experiments in both teaching and research becomes ever more stringent.

The book looks at the process of enquiry during its various stages, starting with unstructured observations and working through to the production of a complete written report. In each section, different skills are emphasised and a series of main examples runs through the book to illustrate their application at each stage.

The book begins with a look at scientific question-asking in general. How do we arrive at the right questions to ask? What do we have to know before we can ask sensible questions? How should questions be formulated to be answered most usefully? Chapter 1 addresses these points by looking at the development of testable hypotheses and predictions and the sources from which they might arise.

Chapter 2 looks at how hypotheses and predictions can be derived from unstructured observational notes. Exploratory analysis is an important first step in deriving hypotheses from raw data, and the chapter introduces plots and summary statistics as useful ways of identifying interesting patterns on which to base hypotheses. The chapter concludes by pointing out that although hypotheses and their predictions are naturally specific to the investigation in hand, testable predictions in general fall into two distinct groups: those dealing with some kind of *difference* between groups of data, and those dealing with a *trend* in the quantitative relationship between groups of data.

The distinction between difference and trend predictions is developed further in Chapter 3, which discusses the use of confirmatory analyses. The concept of statistical significance is introduced as an arbitrary but generally agreed yardstick as to whether observed differences or trends are interesting, and a number of broadly applicable significance tests are explained. Throughout, however, the emphasis is on the use of such tests as tools of enquiry rather than on the statistical theory underlying them. Having introduced significance tests and some potential pitfalls in their use, the book uses the main worked examples to show how some of their predictions can be tested and hypotheses refined in the light of testing.

In Chapter 4, the book considers the presentation of information. Once hypotheses have been tested, how should the outcome be conveyed for greatest effect? The chapter discusses the use of tables, figures and other modes of presentation, and shows how a written report should be structured. The chapter then moves on to consider the presentation of material in spoken and poster paper formats, and how to recast written reports of results for a general, rather than specialist, readership.

At the end of the book are a number of appendices. These provide expanded self-test questions and answers sections based on the material in the previous chapters and some statistical tables for use in significance testing.

We said that the book had its inception in our introductory practical course. This course was developed in response to an increasingly voiced need on the part of students to be taught how to formulate hypotheses and predictions clearly and thus design properly discriminating experiments and observations. As we descend into ever more neurotically prescribed teaching and assessment procedures, the need for students to be given clear guidance on such aspects of their work becomes correspondingly greater. As always, both our practical teaching and the book have continued to benefit enormously from our ongoing and enjoyable interaction with our undergraduates. Their insights and enquiries continue to hone the way we teach, and have been the guiding force behind all the discussions in the book.

Finally, we should like to thank all the people who have commented on the book since its first appearance, and encouraged us to think about the further amendments we have made in this present edition. We particularly thank Kelly Haynes and Angus Jackson and the 2013 and 2014 cohorts of BSc Applied Zoology students at Newquay for input to the 'Getting key information from papers quickly' section. In particular, we thank Tom Reader for the generous amount of time he has spent discussing the book with us, commenting on drafts of many of the amendments and giving freely of his experience in and enthusiasm for the business of communicating science. Rufus Curnow at Pearson Education encouraged us to produce a fifth edition, and guided us as to how it should be modified. James Gilbert and Lucy Browning made useful changes to the R® descriptions.

Francis Gilbert
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Figures

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