Introduction

This book is intended to help students shift from being passive consumers of scientific content to active participants in the process of science. This transition, from the student in the classroom to the effective practitioner, can be frustrating at first. A genuine scientific question can be asked and answered in a variety of ways. There is no one correct way to tackle a problem and no one correct approach to answer a question. Starting to actually do real science can be intimidating. What constitutes a good question? How do you know what data you need to answer it? How do you convince others that what you are doing is worthwhile?

Outside the classroom, scientists do not know the answers to questions they ask in advance. Each new scientific project has its own particular sets of challenges. Therefore, no step-by-step instructional guide can provide the one correct way to tackle all problems, frame all questions, or analyze all data sets. It is possible, however, to develop a systematic approach to asking and answering scientific questions through practice:

- General questions must become focused.
- The data used must represent the scale of the processes or changes of interest.
- Data analysis should help showcase emergent patterns, cycles, events, or changes.
- The conclusions drawn must be supported by evidence.

Doing science is more than doing a calculation. Practising authentic science in a classroom requires students to ask focused scientific questions, logically develop an approach, and use real data to answer

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the question. Focusing a question, aligning data with the question, analyzing and presenting the results to highlight key findings, and drawing supported conclusions all require a combination of logic and creativity. When students engage in authentic science activities, they have to grapple with the uncertainly of open-ended projects. This book aims to support students through this process using a real data set as a practical example of how to iteratively ask and answer scientific questions.

Environmental science has its own unique particularities. Questions in environmental science commonly investigate an intersection between natural processes and human activities. These questions can investigate changes in space or time, on local to global scales, over minutes to millenia (or longer). In many cases, environmental data sets are composites of more than one signal with more than one scale of variability. To a beginning scientist, this can be daunting. Working with environmental data sets requires imagination, organization, and patience. As the logistics of working with large and complex data sets are normalized, more opportunities arise to ask and answer more interesting questions.

This book is loosely organized into three parts:

Part I Thinking Environmental Science

Chapters 1–4 are focused on developing scientific thinking skills and providing context for environmental science questions. In Chapters 1 and 2, the process of doing science is differentiated from the practice of communicating science. This distinction is important. Written scientific communication is linear with distinct headings (introduction, methods, results, discussion, conclusions) that help communicate information clearly in written form. But the process of doing science is more fluid and iterative than is depicted by a scientific publication. The misconception that the process of science is linear can be a pitfall for the beginner scientist. The inevitable iterative process of asking a question, investigating the question, gaining more knowledge, revising the question, and so on can feel unproductive.

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With the development of scientific thinking, students gain the ability to read published papers and interpret scientific graphs critically. Reading a paper to find the science is different from reading a paper to find the answer. Once the process of science is illuminated within the publication, it is easier to critically evaluate what has been done to date and find knowledge gaps. At this stage, the process of asking a question, investigating the question, gaining more knowledge, revising the question, and so on can feel productive.

Chapters 2 and 3 remind us that environmental science is place based. Investigating the natural world requires us to consider the natural processes at work and the impacts that these processes have on the systems or phenomena we are interested in. Environmental data is collected by many institutions for many reasons. The extent of environmental data that is now publicly available is a resource that should not be overlooked when planning a project.

Part II Doing Environmental Science

Doing environmental science starts with recognizing that data is information. With that in mind, the focus of this book is on how to isolate particular information from a particular data set to help answer a particular question. To demonstrate this idea, one data set is used across Chapters 5–12. Employing a question-driven approach, the iconic record of atmospheric CO_2 concentrations (originally collected at Mauna Loa Observatory by Charles David Keeling and known colloquially as the Keeling Curve) is characterized statistically, decomposed, correlated, and modelled. Both general concepts and specific examples of basic data analysis are presented in each chapter. Answering one question provides new information and therefore opportunities for new questions. In this way, basic timeseries data analysis and the process of science are presented.

Students are encouraged to obtain the Mauna Loa CO_2 data set and work with it alongside reading this book. A conceptual understanding of averaging, variance, standard deviation, correlation, and regression is emphasized in the text. Practical knowledge can only be gained by doing. All calculations are explained and demonstrated in simple spreadsheets to encourage students to execute the calculations and not solely rely on software functions.

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Part III Communicating Environmental Science

Writing a research proposal is an important practical step in the process of science. A successful research proposal can realize access to a research program or funding for a research project. A research proposal is also an excellent way to consolidate ideas. Chapter 13 outlines how to scope a research project, frame a research question, and ensure that the project relevance and implications are differentiated and clearly articulated. Chapter 14 tackles the abstract, the scientific summary. The epilogue synthesizes all of the information in the book by suggesting a rubric that can be used both a tool to guide proposal writing and as a tool for assessment.

In advance of each chapter, readers are prompted to think about a few ideas related to the upcoming material. These opportunities allow readers to determine their own level of comfort and competency with the material. Considering a topic in advance of the chapter allows readers to identify their own areas of confusion. Identifying personal gaps or uncertainty prepares readers to make better use of the chapter materials. I encourage readers to take the time to engage in the chapter preparation activities before reading the chapter.

Throughout the book, two themes are reiterated:

Logic: The alignment of research question, methods, results, and conclusions are discussed as part of the development of scientific thinking. This same alignment is necessary when doing data analysis, presenting results, and writing a research proposal.

Scale dependence: As environmental processes can act on multiple temporal and spatial scales at the same time, the importance of matching the scale of the phenomenon of interest with a process acting on that same scale is highlighted. It is important to actively assess scale dependence when interpreting published results, when collecting or finding data, when analyzing data, and when proposing new work.

This book will guide students to *think* scientifically, *do* basic data processing, and *communicate* a scientific idea as a proposal. Although the practical examples and data sets used in this book derive from the environmental sciences, the thinking, basic data processing, and communication skills that will be gained are applicable beyond environmental sciences.

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