Making the Princeton Companion to Applied Mathematics

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Making the Princeton Companion to Applied Mathematics

Is there a need for a printed 'companion to applied mathematics'? Surely one can Google any mathematical topic, term, or equation, and find explanations, definitions, and so on? And does anyone use books nowadays?

When Princeton University Press (PUP) asked me to edit the *Princeton Companion to Applied Mathematics* (Figure 1) in 2009, they told me that many people have trouble navigating the vast amount of information available online and that the need for carefully curated thematic reference works, written by high calibre authors, is as great as ever. And they assured me that print is definitely not dead.

PUP had published the *Princeton Companion to Mathematics* (PCM), edited by Timothy Gowers (with June Barrow-Green and Imre Leader as associate editors) in 2008. Despite the general title, that 1034-page book is essentially about pure mathematics. The book's success has led not only to *The Princeton Companion to Applied Mathematics* but also to a project, announced earlier this year, to produce *The Princeton Companion to Physics* (edited by Nobel prizewinner Frank Wilczek from MIT).

One reservation about accepting the invitation from PUP was that although I have reasonably broad interests my knowledge of applied mathematics as a whole felt quite narrow. Fortunately, I had the opportunity to appoint an editorial board who could provide broader coverage of the subject.

The first task was to write a proposal, for approval by the Princeton University Press editorial board. For help in designing the outline of the book I recruited my Manchester colleague Paul Glendinning (IMA Vice President, Learned Society, 2011–2014, and author of the 'View from the Pennines' column that ran for a decade in *Mathematics Today*), who became the first associate editor. We felt that the book should convey the breadth, depth, and diversity of applied mathematics, while not trying to cover everything. We produced the following list of parts, which remains unchanged in the final book:

I *Introduction to Applied Mathematics*. What applied mathematics is and examples of its use in everyday life.

II *Concepts*. Short articles that explain specific concepts and their significance.

III *Equations, Laws, and Functions of Applied Mathematics*.

IV *Areas of Applied Mathematics*. Longer articles giving an overview of the whole subject and how it is organised, arranged by research area.

V *Modelling*. A selection of mathematical models, with explanations of how the models are derived and how they are solved.

VI *Example Problems*. Short articles covering a variety of interesting applied mathematics problems.

VII *Application Areas*. Articles on connections between applied mathematics and other disciplines,

VIII *Final Perspectives*. Essays on broader aspects.

Unlike in PCM, we did not include a part containing biographies of famous mathematicians. However, the articles in Part III provide a link into the history of applied mathematics through equations, laws, and functions, most of which are eponymous, and many articles include historical background.

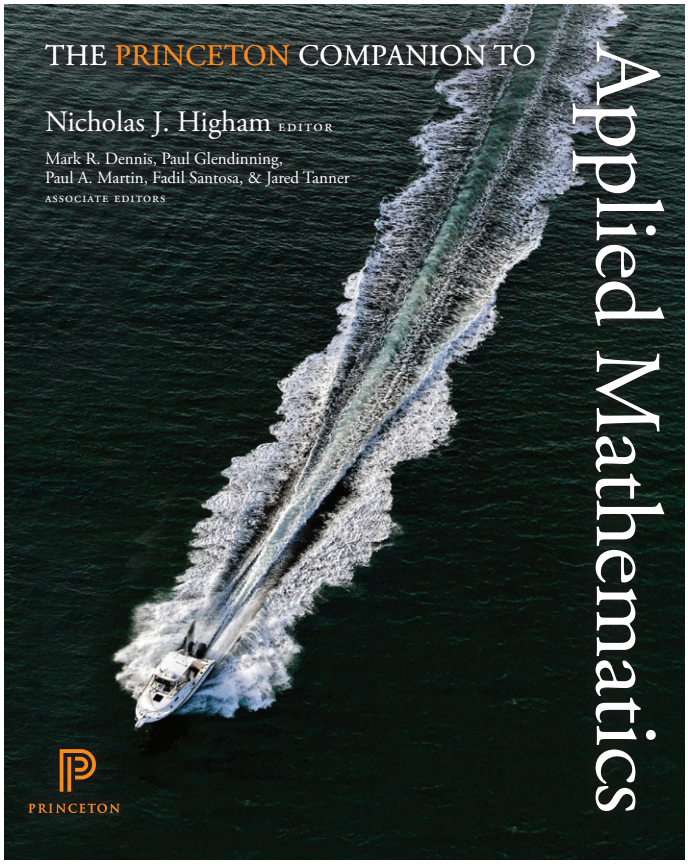

Figure 1: The cover.

One reviewer of the proposal concluded that the book could 'fill a much needed gap'. Thankfully, the rest of the review indicated that this was not the intended meaning, and the proposal was approved.

Over the next few months the rest of the editorial board was appointed: Mark Dennis (University of Bristol), Paul Martin (Colorado School of Mines), Fadil Santosa (University of Minnesota), and Jared Tanner (University of Oxford). The whole board then met to make an initial selection of articles and authors.

It has been gratifying how many of our first-choice authors accepted the invitation to write for *The Companion*. For some articles it was, however, hard to find a willing author, and we had to abandon a small number of planned articles for this reason.

Table 1 gives some statistics about the book.

Table 1: The Companion *in eleven numbers.*

Pages	xvii + 994 + 16 colour plates
Articles	186
Authors (countries)	165 (23)
Figures	196 + 23 colour
Cross references	751
Index pages (entries)	33 (2842)

In the opening article 'What Is Applied Mathematics?' I deliberately avoid giving a definition of 'applied mathematics', preferring instead to quote views on the meaning of the term expressed by luminaries such as Courant, Lax, and Rayleigh. To

answer the question in the title I outline the general steps in solving an applied mathematics problem and give examples of problems relating to searching web pages, digital imaging, and computer arithmetic. A long Part I article by historians of mathematics June Barrow-Green and Reinhard Siegmund-Schultze gives an overview of the history of applied mathematics and, in particular, explains how the term 'applied mathematics' came into being.

I hope the existence of the separate *Companion* volumes will not serve to encourage classification of mathematics as 'pure' or 'applied'. The boundaries are becoming ever more blurred and in many contexts the distinction is no longer explicitly made. Indeed the recent report *The Mathematical Sciences in 2025* [1] noted that 'distinctions between "core" and "applied" mathematics increasingly appear artificial; in particular, it is difficult today to find an area of mathematics that does not have relevance to applications', and similar remarks were made in the report of the 2010 *International Review of Mathematical Sciences*.

Articles in *The Companion* are meant to be widely accessible, including to undergraduates in mathematics, and are very different from the research papers aimed at specialists that most authors are used to writing. There is no bibliography and almost no citations are given in the text; instead most longer articles provide a short list of further reading. Generally, every effort is made to avoid the reader having to turn to other pages while reading

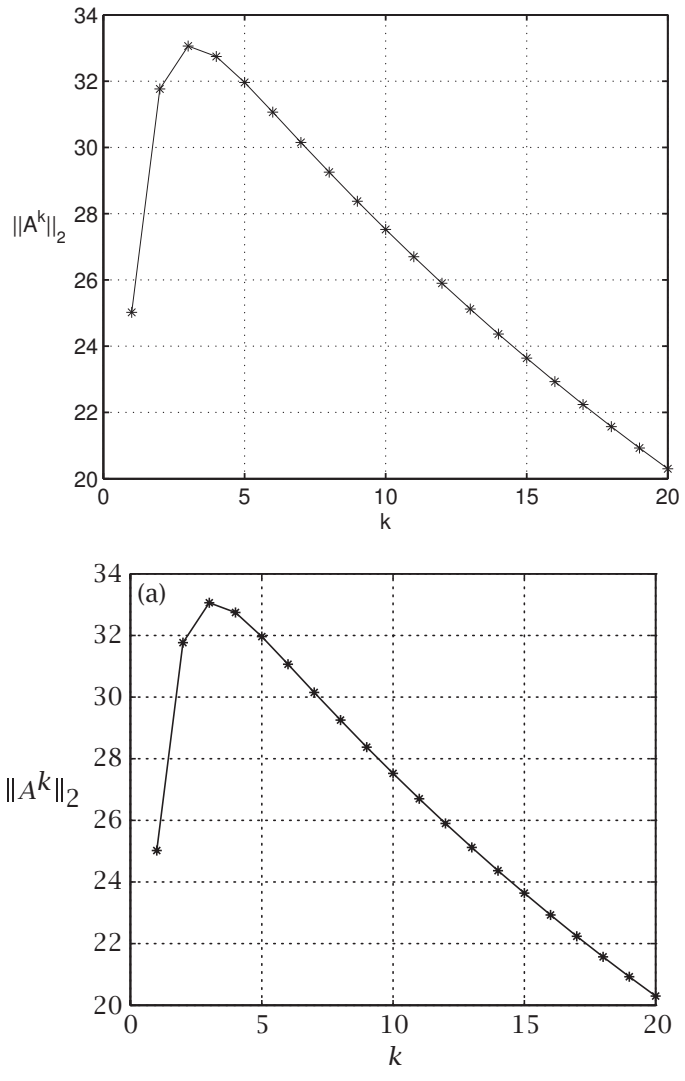

Figure 2: Original figure (top) and edited version (bottom).

an article. Adhering to these aims was quite a challenge. However, consistency of presentation and level, along with the many cross references between articles and the comprehensive index, are important ways in which a book such as this can play a role that an online resource such as Wikipedia (say) cannot.

Articles underwent a rigorous editing process, which often involved multiple revisions and major changes. Further improvements were made at the copy-editing and typesetting stage by Sam Clark (T&T Productions, London), who handled these tasks as well as project management and all aspects of the book design. To describe his work as 'copy-editing' would be an understatement, because Sam was responsible for many improvements in clarity and accuracy. He often suggested ways to rewrite sentences that helped us avoid the sometimes telegraphic style of academic writing. The level of cooperation between Sam and me is indicated by the roughly 3000 emails that have passed between us.

We wanted *The Companion* to have plenty of figures. Figures can often explain an idea better than words and they help to break up the monotony of hundreds of pages of text. As a glance at any journal will show, producing high-quality figures with a consistent style is difficult, even with today's computer drawing packages.

All figures in *The Companion* were edited by Sam Clark in Adobe Illustrator, or occasionally redrawn by the PUP art department, in order to harmonise fonts, line thicknesses, etc. For an example of the difference this makes, see Figure 2. The plot on the top is the best I could produce in MATLAB R2013b. The edited version underneath has more prominent grid lines, a thicker plot line, has had the font changed to be the same as the body text, and generally looks better proportioned.

A website was used to provide authors with information about the project, including guidelines on format and style, as well as for the editors to keep track of submissions. Readers are welcome to take a look at it by going to `pcam.tandtproductions.com` and logging in with username `Guest` and password `PCAM_PW`.

One benefit of editing PCAM is that it gave me good reason to scour the shelves of my office and the university library looking for information, fact-checking, and so on. One book that I had not previously spent much time with, but which is mentioned in numerous *Companion* articles, is the *NIST Handbook of Mathematical Functions* [3], edited by Olver, Lozier, Boisvert, and Clark. While the NIST handbook is a very different type of reference book to *The Companion*, I appreciate the challenges that Frank Olver must have faced in leading the project and I have tremendous admiration for what he produced. For me, the NIST handbook sets a benchmark for the quality of writing, editing, typesetting, and indexing, and I hope we have come close to matching it.

The book is typeset in LaTeX, but it uses a font called Lucida Bright rather than the standard Computer Modern. This font was designed in the 1980s by Charles Bigelow and Kris Holmes with low and medium resolution digital output devices in mind [5]. It has a large x-height (the height of the letter 'x' and of the body of 'h', 'n', etc.), which makes it look bigger than its point size would suggest. It is the font used in *Notices of the American Mathematical Society*, *The LaTeX Companion* [2], and at one time in *Scientific American*. Importantly for a book that includes both mathematics and (a small amount of) computer code, Lucida Bright has a full set of mathematical symbols (a rare occurrence among fonts) and an associated typewriter font. For comparison, Figure 3 shows some sample text composed in both Lucida Bright and Computer Modern.

Once the articles were in final form, three main tasks remained. The first was to insert cross references between articles. These are very important for pointing the reader to definitions and related discussions in other articles. The second was to finalise the typeset book, optimising page breaks. This problem will not be familiar to most TEX users, since it is less of an issue for articles and papers and is usually carried out by the publisher. The difficulty of the task was summed up well by Tony Siegman of Stanford, who typeset in TEX his 1986 book *Lasers* (a standard reference in the field) [4]: 'Obtaining aesthetically pleasing page breaks, which also produce the most effective relationship between subheadings, illustrations, tables, and text references to these elements, seems to be the most difficult and tedious part of the whole book production process in TEX.' Optimising page breaks is, in general, an NP-complete problem, and it was indeed a very time-consuming task for Sam Clark.

The Airy function $w(z)$ satisfies the second-order differential equation $w'' - zw = 0$. It is one of the built-in special functions in MATLAB:

```
>> w = airy([0 pi/2 pi])
w =
   3.5503e-01    6.5120e-02    5.0894e-03
```

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Figure 3: Sample text set in Lucida Bright (top) and Computer Modern (bottom), both at 10pt.

The final stage was for a professional indexer to produce an index, working from a PDF file. The index contains many entries for famous mathematicians and scientists: 78 in total, ranging from to Niels Henrik Abel to Thomas Young. This means that even though there are no biographical articles, authors have included plenty of biographical snippets – otherwise the indexer would not have deemed them worth indexing. Figure 4 shows a word cloud for the names in the index, with font size proportional to the number of occurrences. John von Neumann is the most frequently mentioned mathematician, reflecting his vital contributions to many different areas, including computational science, economics, rounding error analysis, foams, the Monte Carlo method, random number generation, shock waves, and spectral theory.

Figure 4: Word cloud for names in the index of The Companion.

What lessons have I learned from this project? Three come to mind. First, that authors were generally very amenable to suggestions and did not mind me editing their LATEX, which proved to be much better than writing comments on a printout, as I did with the first few articles. In this respect the `latexdiff` command proved to be very useful for showing authors what changes had been made to a LATEX file.

Second, in writing my own articles I wish I had made even more notes, in comments in the source code, about the choices I made and references for equations, results, quotes, etc.: sources are easily forgotten when an article is revised months after it was first written.

Third, our authors are a dedicated and well-travelled lot. Rob Corless responded to one of my emails from a gannet colony in New Zealand, while Ken Golden emailed from a US Coast Guard icebreaker in the Arctic Ocean.

I have not said much about the content of the book. I hope that the main applied mathematics topics that readers will expect to find are all represented. Indeed the cover (Figure 1) reflects the strong presence of fluids and waves in the book. But the editors also ensured that *The Companion* includes some modern and less well-known topics. Among these are

- modelling of the hi-tech swim suits that are now banned in competitive swimming,
- airport baggage screening with X-ray tomography,
- cloaking (as in Harry Potter, and Romulan spaceships in Star Trek),
- evolving social networks and their importance in national security,
- the mechanical modeling element called an inerter, which was secretly introduced into Formula 1 racing by McLaren in 2005 and is now a standard element of suspension systems in Formula 1 and IndyCar racing.

The Princeton Companion to Applied Mathematics is published by Princeton University Press in October 2015. Further information on the book project can be found at the blog `nickhigham.wordpress.com` and on the Twitter feed @ThePCAM (`twitter.com/thepcam`).

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