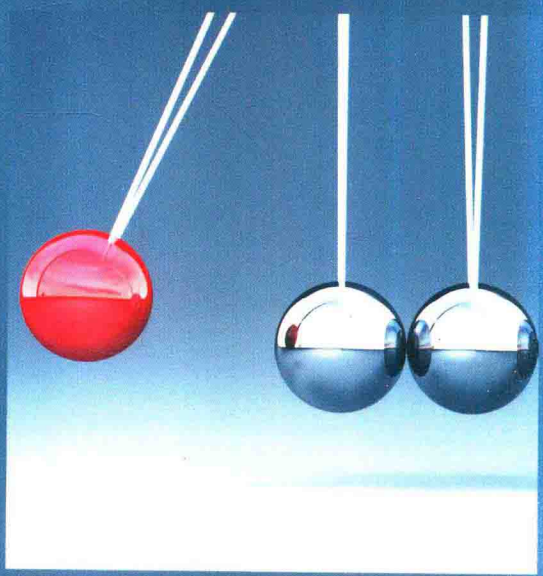
SCIENCE TEACHING

The Contribution of History and Philosophy of Science

20TH ANNIVERSARY REVISED AND EXPANDED EDITION



Michael R. Matthews

ROUTLEDGE

Science Teaching

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20th Anniversary Revised and Expanded Edition

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Science Teaching

'This is a transformative book. It provides an enlightening cartography of the uses of history and philosophy in the science classroom. No one interested in science teaching or science culture should be without a copy of this updated classic.'

Alberto Cordero, Philosophy Program,
The CUNY Graduate Center and Queens College CUNY, USA

'This book's importance transcends science education. Its coverage of topics such as the impact of constructivism on education provides the book with a universal importance. I strongly recommend it to everyone interested in teaching and learning.'

John Sweller, School of Education,
University of New South Wales, Australia

'The Pendulum chapter is a masterpiece! It should be considered obligatory reading for everyone who aims at becoming a science (especially physics) teacher.'

Ricardo Karam, Physikdidaktik,
Universität Hamburg, Germany

'Science Education is a rigorous and necessary resource for science education researchers, policy makers and practitioners.'

Sibel Erduran, School of Education,
University of Limerick, Ireland

Michael R. Matthews is an Honorary Associate Professor in the School of Education at the University of New South Wales, Australia. He is Founding Editor of the international journal *Science & Education*; Founding President of the International History, Philosophy and Science Teaching Group; and President of the Inter-Divisional Teaching Commission of the International Union of History and Philosophy of Science. He has trained, taught and published in science education and in history and philosophy of science.

For my daughters: Clare, Alice and Amelia

Preface (2014)

It is a pleasure to see the twentieth anniversary of my 1994 *Science Teaching* book being celebrated by publication of an updated and enlarged edition. The book has stayed in print for 20 years, which suggests that it has some merit. The intellectual background to the book is described in the following 1994 Preface. Pleasingly, if philosophical arguments are any good, then they retain their merit for a long time. Having 'philosophical merit' is, of course, not the same as 'being correct', but it does mean being clear enough to enable readers to see where the mistakes are (this issue of clarity in communication and argument will be something returned to in Chapter 12). The central conviction of the first edition was stated in its Preface:

> For all its faults, the scientific tradition has promoted rationality, critical thinking and objectivity. It instils a concern for evidence, and for having ideas judged not by personal or social interest, but by how the world is; a sense of 'Cosmic Piety', as Bertrand Russell called it. These values are under attack both inside and outside the academy. Some educationally influential versions of postmodernism and constructivism turn their back on rationality and objectivity, saying that their pursuit is Quixotic. This is indeed a serious challenge to the profession of science teaching.
>
> The vitality of the scientific tradition, and its positive impact on society, depends upon children being successfully introduced to its achievements, methods and thought processes, by teachers who understand and value science. The history and philosophy of science contribute to this understanding and valuation.

World events and educational developments in the subsequent 20 years have only strengthened these convictions. The 'flight from science' has continued unabated and has been extensively documented in US and European government reports. There have been continuing debates over many socio-scientific issues, such as the utilisation of stem cells from manufactured human embryo cells, the control or utilisation of genetically modified crops, the reality and mitigation of androgenic global warming, harnessing or otherwise of nuclear energy, and compulsory child vaccination. With economic and cultural globalisation, serious questions have been asked about the supposed

universality of science and of the justification and utility of teaching orthodox science in cultures that have their own rich lore of understandings of nature and non-scientific worldviews. After the 1960s' Kuhnian trumpet blast, various postmodernist waves have swept through the academy, including schools of education, each disputing the traditional foundations for science teaching. And there are many other such pressing issues, all of which have philosophical dimensions.

There have been constant wars in the Middle East, Africa and the Indian subcontinent, fuelled by ideology, but fought with high-tech, science-enabled weaponry. Each drone attack, each report of the use of oxygen-deprivation bombs, to say nothing of ordinary bombs and napalm, each poison-gas attack brings into focus the values of science, the responsibility of scientists and the purpose of science teaching. Understanding these events and issues, and then appropriately responding to them, requires a degree of rational, critical and objective analysis; the way forward is not advanced by embracing irrational, uncritical and subjective thinking. These intellectual and personal capacities – scientific habits of mind or scientific temper – can be developed in science classrooms, if the curriculum and pedagogy are informed by the history and philosophy of science (HPS).

Since the book's first edition, there have been considerable developments in science-education curricula that explicitly recognise the importance of teaching the philosophical, cultural and historical dimensions of science. In the United States, the first-ever National Science Education Standards were published by the National Research Council in 1996 (National Research Council 1996). These standards recognise the centrality of philosophical and historical knowledge in the teaching of science. In the UK, a group of prominent science educators, reflecting on Britain's National Curriculum and the most appropriate form of science education for the new millennium, wrote a report with ten recommendations, the sixth of which said that: 'The science curriculum should provide young people with an understanding of some key ideas about science, that is, ideas about the ways in which reliable knowledge of the natural world has been, and is being, obtained' (Millar & Osborne 1998, p.20). Different European and Asian countries have comparable statements about desired broader and deeper outcomes of school science.

Clearly, the goals of the US National Standards, the UK group and other national groups can only be realised if science teachers have some familiarity and enthusiasm for the history and philosophy of their subject. A position paper of the US Association for the Education of Teachers in Science, the professional association of those who prepare science teachers, has recognised this in its own recommendation that: 'Standard 1d: The beginning science teacher educator should possess levels of understanding of the philosophy, sociology, and history of science exceeding that specified in the [US] reform documents' (Lederman *et al.* 1997, p.236).

The arguments advanced by the above curriculum writers are basically the same as those advanced in the first edition of this book.

Along with curriculum developments, there has been, in the past 20 years, a significant amount of interdisciplinary research in the field of HPS and science teaching (HPS&ST). This research makes contributions to three categories of question faced by science teachers:

1 *theoretical* questions that impinge on science education, such as: constructivist claims about the knowledge claims of science, feminist critiques of science, the status of indigenous or local sciences and how they should or should not be taught in science programmes, science and religion, the status of models in science, scientific values and their relation to cultural values, and so on;
2 *curriculum* questions about the structure, content and scheduling of school science programmes;
3 *pedagogical* questions about how the utilisation of historical and philosophical material affects student motivation, interest and learning *of* science and *about* science.

The major development in HPS&ST research since the 1994 publication has been the establishment and continued growth of the journal *Science & Education: Contributions from History, Philosophy and Sociology of Science and Education*. The journal is now in its twenty-third year of publication, with ten issues being published per year (www.springerlink.com). About 800 research papers have been published; in 2011, there were 108,650 article downloads from the journal's website, and it is noteworthy that the most downloads are from Asia.

A core part of the HPS&ST infrastructure has been the International History, Philosophy and Science Teaching Group (IHPST) (www.ihpst.net). The group has been associated with the journal; it held its inaugural meeting in Tallahassee in 1989 and has continued to hold successful biennial conferences,[1] with select proceedings published in the journal;[2] and it has commenced a programme of biennial regional meetings in Latin America and Asia.[3] These are attended by teachers, educators, historians, philosophers and cognitive scientists.

The vitality and international reach of current HPS&ST scholarship and engagement is manifest in the three-volume, seventy-six-chapter *International Handbook of Research in History, Philosophy and Science Teaching* (Matthews 2014). It has sections on Pedagogical Studies, Theoretical Studies, National Studies and Biographical Studies and is contributed to by 125 authors from thirty countries and contains 11,000 references. Many of the issues and debates 'touched on' in this book are developed at length in chapters of the *Handbook*.

This book has three core purposes: one, to show educators that HPS is an interesting and engaging subject, and that it can usefully illuminate many of the theoretical, curricular and pedagogical issues that they encounter; two, to show historians and philosophers that their own expertise and scholarship

can be utilised in science-education debates, curriculum development and classroom teaching; and three, to cultivate a sense among science teachers of belonging and contributing to the scientific and philosophical tradition that has had such enormous international social and cultural influence. Everyone should be mindful that, without science teachers, there would be no science. I have tried as much as possible to provide extended quotations from the main scholars discussed – Aristotle, Galileo, Huygens, Newton, Priestley, Mach and others – so that something of their own voice can be heard; too often, the names are known, but their voices are not heard; quotations are a meagre way of giving them some expression.

Michael R. Matthews
School of Education, University of New South Wales,
Sydney 2052, Australia
February 2014

Notes

1 These were: Minneapolis 1995, Calgary 1997, Pavia 1999, Denver 2001, Winnipeg 2003, Leeds 2005, Calgary 2007, Notre Dame 2009, Thessaloniki 2011 and Pittsburgh 2013.
2 For select proceedings, see: Pavia (Vol.10, Nos. 1–2, 2001), Winnipeg (Vol.14, Nos. 3–5, 2005), Leeds (vol.16, nos. 2–4, 2007), Calgary (Vol.18, Nos. 3–4, 2009), Notre Dame (vol.20, nos. 7–8, 2011) and Thessaloniki (Vol.22, No. 6, 2013).
3 Brazil (2010), Argentina (2012), Korea (2012) and Taiwan (2014).

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Matthews, M.R. (ed.): 2014, *International Handbook of Research in History, Philosophy and Science Teaching*, 3 volumes, Springer, Dordrecht, The Netherlands.
Millar, R. and Osborne, J.: 1998, *Beyond 2000: Science Education for the Future*, School of Education, King's College, London.
NRC (National Research Council): 1996, *National Science Education Standards*, National Academies Press, Washington, DC.

Preface (1994)

This book seeks to contribute to science teaching and science-teacher education by bringing the history and philosophy of science and science teaching into closer contact. My belief is that science teaching can be improved if it is infused with the historical and philosophical dimensions of science. Such contextual, or liberal, teaching of science in schools benefits both those students going on to further study of science, and those, the majority, for whom school science is their last contact with formal science instruction.

The conviction that the learning of science needs to be accompanied by learning about science is basic to liberal approaches to the teaching of science. This position has been eloquently argued by, among others, Ernst Mach, James Conant, Gerald Holton, Joseph Schwab and Martin Wagenschein. This book is a housekeeping effort in the liberal tradition: it attempts to survey the history of debate on the matter; to list the chief publications; to itemise contemporary relevant research, particularly in children's learning of science; to point to present-day practical and theoretical problems in science education to which the history and philosophy of science can contribute; to give an account of curriculum developments embodying the liberal spirit of science instruction; and to indicate ways in which the history and philosophy of science can be usefully included in teacher preparation programmes.

This book is the work of an under-labourer in the garden, to use John Locke's expression. Some furrows have been made, and some seeds planted. Hopefully, other people will water the garden, straighten the furrows, plant other seeds and remove some of the weeds. If the book stimulates science teachers at both schools and universities to be more interested in the history and philosophy of science, and encourages historians, philosophers and sociologists of science to become interested and involved with science education, then it will have achieved one purpose. If it contributes to the inclusion of HPS studies in science-teacher education programmes, it will have achieved another purpose. If it promotes an interest in educational theory among science educators, it will have achieved still another.

The theme of this book is that science teachers need three competencies: first, knowledge and appreciation of science; second, some understanding of HPS in order to do justice to the subject they are teaching and to teach it well, and in order to make intelligent appraisals of the many theoretical

and educational debates that rage around the science curriculum; third, some educational theory or vision that can inform their classroom activities and relations with students, and provide a rationale and purpose for their pedagogical efforts. Science teachers contribute to the overall education of students, and thus they need some moderately well-formed view of what education is, and the goals it should be pursuing. Teachers need to keep their eyes on the educational prize, the more so when social pressures increasingly devalue the intellectual and critical traditions of education.

It is widely recognised that there is a crisis in Western science education. Levels of science literacy are disturbingly low. This is anomalous, because science is one of the greatest achievements of human culture. It has a wonderfully interesting and complex past, it has revealed an enormous amount about ourselves and the world in which we live, it has directly and indirectly transformed the social and natural worlds, and the human and environmental problems requiring scientific understanding are pressing – yet students and teachers are deserting science.

This flight from the science classroom, by both teachers and students, has been depressingly well documented. In the US in the mid 1980s, it was estimated that, each year, 600 science graduates entered the teaching profession, while 8,000 left it (Mayer 1987). In 1986, 7,100 US high schools had no course in physics, and 4,200 had no course in chemistry (Mayer 1987). In 1990, only four states required the three years of basic science recommended by the sobering 1983 report *A Nation at Risk*; the rest allowed high-school graduation with only two years of science (Beardsley 1992, p.80). Irrespective of years required, 70 per cent of all school students drop science at the first available opportunity – which is one reason why, in 1986, fewer than one in five high-school graduates had studied any physics. In 1991, the Carnegie Commission on Science, Technology and Government warned that the failings of science education were so great that they posed a 'chronic and serious threat to our nation's future' (Beardsley 1992, p.79). In the UK, recent reports of the National Commission on Education and the Royal Society have both documented similar trends. One commentator has said that, 'wherever you look, students are turning away from science . . . Those that do go to university are often of a frighteningly low calibre' (Bown 1993, p.12). In Australia, in 1989, science-education programmes had the lowest entrance requirement of all university degrees.

There are complex economic, social, cultural and systemic reasons for this rejection of science. These are beyond the scope of teachers to rectify. But there are also educational reasons for the rejection of science that are within the power of teachers and administrators to change. In 1989, for example, a disturbing number of the very top Australian school science achievers gave 'too boring' as the reason for not pursuing university science. It is these curriculum and pedagogical failings that the history and philosophy of science (HPS) can help rectify.

One part of this contribution by HPS is to connect topics in particular scientific disciplines, to connect the disciplines of science with each other, to

connect the sciences generally with mathematics, philosophy, literature, psychology, history, technology, commerce and theology; and finally, to display the interconnections of science and culture – the arts, ethics, religion, politics – more broadly. Science has developed in conjunction with other disciplines; there has been mutual interdependence. It has also developed, and is practised, within a broader cultural and social milieu. These interconnections and interdependencies can be appropriately explored in science programmes, from elementary school through to graduate study. The result is far more satisfying for students than the unconnected topics that constitute most programmes of school and university science. Courses in the sciences are too often, as one student remarked, 'forced marches through unknown country without time to look sideways'.

The defence of science in schools is important, if not necessary, to the intellectual health of society. Pseudoscientific and irrational worldviews already have a strong hold on Western culture; anti-science is on the rise. It is not just the ramparts of society that have been invaded – witness the checkout-counter tabloids with their 'Elvis lives' stories, Gallup polls showing that 40 per cent of the adult US population believe that human life began on Earth just a couple of thousand years ago, and astrology columns in every newspaper. But the educational citadel has been compromised – a small, and hopefully not representative, 1988 survey of US biology teachers revealed that 30 per cent rejected the theory of evolution, and 22 per cent believed in ghosts (Martin 1994). For all its faults, the scientific tradition has promoted rationality, critical thinking and objectivity. It instills a concern for evidence, and for having ideas judged, not by personal or social interest, but by how the world is; a sense of 'Cosmic Piety', as Bertrand Russell called it. These values are under attack both inside and outside the academy. Some educationally influential versions of postmodernism and constructivism turn their back on rationality and objectivity, saying that their pursuit is Quixotic. This is, indeed, a serious challenge to the profession of science teaching.

The vitality of the scientific tradition, and its positive impact on society, depends upon children being successfully introduced to its achievements, methods and thought processes, by teachers who understand and value science. The HPS contribute to this understanding and valuation.

This book grows out of, and is a contribution to, the International History, Philosophy, and Science Teaching Group. This is a heterogeneous group of teachers, scientists, educators, historians, mathematicians, philosophers of education and philosophers of science who, over the past 5 years, have staged two conferences[1] and have arranged the publication of many special issues of academic journals devoted to HPS and science teaching.[2] Some basic papers in the field have been gathered together and published in Matthews (1991), *History, Philosophy, and Science Teaching: Select Readings* (OISE Press, Toronto, and Teachers College Press, New York, 1991). These might be useful for further reading. The International History, Philosophy, and Science Teaching Group is also associated with a new journal devoted to the subject

of this book – *Science & Education: Contributions from the History, Philosophy, and Sociology of Science and Mathematics.*[3]

Notes

1 The proceedings of the 1989 Tallahassee conference are available in Herget (1989, 1990); those of the 1992 Kingston conference are in Hills (1992).

2 The journal special issues include the following: *Educational Philosophy and Theory* 20(2), (1988); *Synthese* 80(1), (1989); *Interchange* 20(2), (1989); *Studies in Philosophy and Education* 10(1), (1990); *Science Education* 75(1), (1991); *Journal of Research in Science Teaching* 29(4), (1992); *International Journal of Science Education* 12(3), (1990); and *Interchange* 23(2,3), (1993).

3 The journal is published by Kluwer Academic Publishers, PO Box 17, 3300 AA Dordrecht, The Netherlands. It is available at reduced rates through the international HPS&ST group (inquiries to the author).

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Acknowledgements

Acknowledgements (2014)

The bulk of personal debts for this twentieth anniversary edition of my 1994 book are the same as those for the original. First, as with all book writing, families pay a price. Since 1994, my wife, Julie, and Clare and Alice have been joined by a third daughter, Amelia, and two grandchildren, Joshua and Elenore. All have seen my time taken up with this project and have, pleasingly, taken it on faith that I have been doing something worthwhile. It is for readers to judge whether my time would have been better spent with my family.

Writing this second edition has been a wonderful opportunity to revisit and re-evaluate thoughts and arguments that were originally written in response to a 1989 invitation from Israel Scheffler to write a book on science teaching for his Routledge Philosophy of Education Research Library. Neither of us could have thought that the book would stay in print for so long, or that, 25 years later, a second edition would be warranted.

In 1994, I mentioned my debt to teachers who first introduced me to the subject matter of the book: at the University of Sydney, Wallis Suchting (Philosophy) and Bill Andersen (Education); at Boston University, Robert S. Cohen, Abner Shimony and Marx Wartofsky (Philosophy). Clearly, the debt to learned and capable early teachers always remains. In the 20 years since the first edition, I have learned things from a number of scholars whom I have had the good fortune to meet and engage with. Among these, Mario Bunge warrants particular mention. Now enjoying his ninety-fourth year, he continues to write books and articles that move easily, but with great erudition, across history of philosophy, science and philosophy of science, always with an admirable clarity of expression and a willingness to engage with serious educational issues.

In 1994, I mentioned my good fortune to edit the journal *Science & Education*, which then was in its second year of publication. Twenty years later, I am still editing the journal, and it has put me in contact with hundreds of scholars, from scores of countries around the world. These have been a great source of ideas and a privileged way of being kept abreast of current research, even if this knowledge has not always been internalised in ways that it deserved to be.

In 1994, I also mentioned my debt to the IHPST. This debt has simply grown by a further 20 years of valuable and intellectually productive friendships. Of special note have been the meetings held in Greece, Finland, Argentina, Brazil, Mexico, Denmark, Spain, India and Korea – these have all been wonderful occasions for discussing and hearing about history, philosophy and science teaching in contexts outside the dominant Anglo-American sphere. Within the latter sphere, for the past 20 years, the biennial IHPST meetings have been themselves happy and enormously productive gatherings, characterised by the admirable mix of serious scholarship and good fellowship.

I have benefited significantly from my editorship of the seventy-six-chapter, three-volume *Handbook of Research in History, Philosophy and Science Teaching* (Springer 2014), which has been contributed to by 125 authors from thirty countries. My debt is plainly visible in the Reference list for each of this book's chapters. The present book could be regarded as a 'primer' for the larger handbook; all of the arguments here, and more, are developed and documented at considerable length in the latter work.

Many friends have read and commented on different chapters of this book: Ricardo Karam, Yann Benétreau-Dupin, Colin Gauld, Robert Nola, Roland Schulz, Edgar Jenkins and Gürol Irzik. I am indebted to them, as are readers, for their suggestions and corrections. Julie House and Hans Schneider pleasingly corrected and copy-edited different chapters. A particular debt is owed to Paul McColl, who closely read, made valuable suggestions for, and carefully copy-edited the entire manuscript: a heroic task. Special thanks are due to the diligence and professional competence of Louise Smith, a Routledge-contracted UK copy-editor, who even after all the foregoing reading and corrections, nevertheless raised 110 'author queries' for me to rectify. Readers have been saved a good deal of frustration by these 110 lapses not finding their way into print. I commend her services to any author.

Finally, this book would not have happened except for the kind invitation of Naomi Silverman, the Routledge Taylor & Francis Education Editor, to write a second and enlarged edition of the 1994 book. Working with her has been a very happy and easy experience; I commend her to all authors.

Sources

In a number of places, this enlarged edition has drawn on material I have published over the past 20 years, specifically:

- Chapter 6 is partly dependent on: Matthews, M.R.: 2001, 'Methodology and Politics in Science: The Case of Huygens' 1673 Proposal of the Seconds Pendulum as an International Standard of Length and Some Educational Suggestions', *Science & Education* 10(1–2).
- Chapter 7 is partly dependent on: Matthews, M.R.: 2009, 'Science and Worldviews in the Classroom: Joseph Priestley and Photosynthesis', *Science & Education* 18(6–7).

- Chapter 10 is partly dependent on: Matthews, M.R.: 2009, 'Teaching the Philosophical and Worldview Components of Science', *Science & Education* 18(6–7).
- Chapter 11 is partly dependent on: Matthews, M.R.: 2012, 'Changing the Focus: From Nature of Science (NOS) to Features of Science (FOS)'. In M.S. Khine (ed.) *Advances in Nature of Science Research*, Springer, Dordrecht, The Netherlands.
- Chapter 12 is partly dependent on: Matthews, M.R.: 2014, 'Discipline-based Philosophy of Education and Classroom Teaching', *Theory and Research in Education* 12(1), 19–108.

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Acknowledgements (1994)

For the past 5 years, the writing of this book has severely encroached upon my family time. My wife, Julie House, and daughters, Clare and Alice, deserve thanks for their forbearance. Julie House is owed a significant additional debt for copy-editing and proofing numerous drafts of the book. She did her best to correct the worst of the expression, the most serious of the grammatical mistakes and frequent misspellings. In addition, she argued over most of the central points and was persistent in trying to keep the text focused. All readers are indebted to her for making their job so much easier than it otherwise would have been.

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I am indebted to the many members of the International History, Philosophy, and Science Teaching Group, who have been generous over the past 5 years with ideas, hospitality and enthusiasm. Two major conferences, organised by Ken Tobin and David Gruender (Tallahassee 1989) and Skip Hills and Brian McAndrews (Kingston 1992), stimulated much that has gone into this book. Editorship of the journal *Science & Education*, which is devoted to the theme of the book, has enabled me to read, and benefit from, the work of a wide range of authors from all over the globe. The advice and encouragement of Martin Eger and Fabio Bevilacqua have been of special importance. Others, too numerous to mention, are, I hope, aware of my gratitude.

I have a debt to my teachers who introduced me to the history and philosophy of science. I am particularly grateful to Professor Wallis A. Suchting, formerly of Sydney University, whose standards of scholarship and breadth of knowledge are a model for those who have had the good fortune to be his students. Professor Abner Shimony, at Boston University, introduced me to the writings of Galileo, and Professors Robert S. Cohen and Marx W. Wartofsky, also of Boston University, helpfully placed science and the

philosophy of science in the broader social and historical context. I am also indebted to Dr Bill Andersen, formerly of Sydney University, my first teacher in philosophy of education, who encouraged, among others, a young, naive science student to identify and grapple with philosophical questions in education.

My employers, the University of New South Wales and the University of Auckland, have made this book possible. The former's library is a cornucopia of materials in science education and the history and philosophy of science. The University of Auckland was a generous and supportive employer during my 2-year period as the Foundation Professor of Science Education. This enabled me to complete the book.

Friends have been good enough to read the penultimate version of the manuscript and suggest corrections and offer valuable advice. To Drs Michael Howard, Peter Slezak, Colin Gauld, Wallis Suchting, Richard Thorley, Fabio Bevilacqua, Harvey Siegel and James Wandersee, I am very grateful. Their scholarship and attention to detail have saved readers from the worst of my errors. Jan Duncan has been of great assistance in proofreading, checking of references, and the preparation of figures.

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